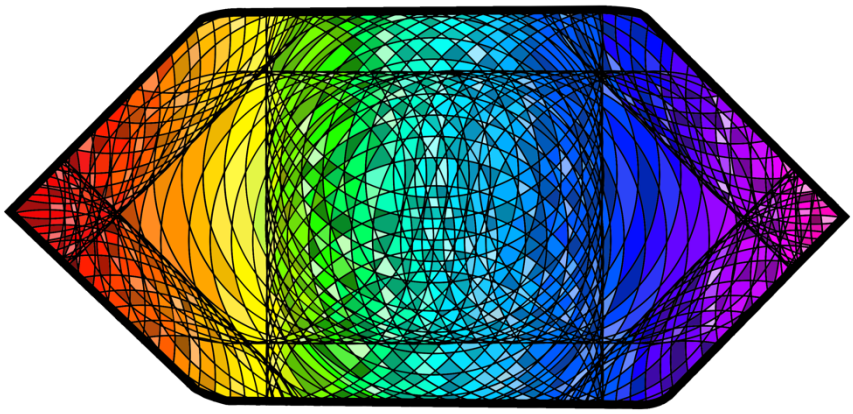

BEYOND
KANDINSKY
NOEMI DREKSLER

Beyond Kandinsky: Exploring colour-shape correspondences through the lenses of emotions, individual differences, and aesthetics

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Trinity 2019



Thesis submitted for the degree of Doctor of Philosophy in Experimental Psychology at the University of Oxford.

Word count (approximate): 94,000.



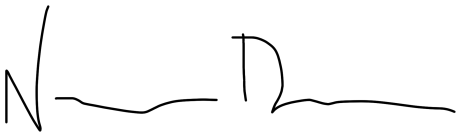
To the erudite diva,
the most caring and thoughtful plot spoiler,
and the vivacious, loquacious heavenly veil.

Acknowledgements

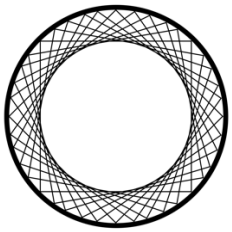
To my supervisors – Charles Spence and Robin Murphy – thank you for the continued comments, guidance, and moral support. Thank you to my family for being a fountain of sanity and positivity and my ever-firm foundation. To my friends who struggled in the doctoral trenches with me – thank you for making this journey a little bit more bearable, and a lot more filled with laughs. Thank you to the reviewers and editor at *Psychological Bulletin* for their comments on the review that makes up Chapter 1. I felt honoured to have received such detailed responses on the work – they helped immensely in developing it further. I would like to thank my Transfer and Confirmation of Status assessors, Hannah Smithson, Mark Stokes, and Gaia Scerif, for allowing me to test my early ideas and aiding me in my progress along the way. This thesis would not have been possible without the generous financial support of the Medical Research Council and St John's College. Finally, thank you to the researchers and thinkers that came before, that built towering pyramids of knowledge, into which I can slot this miniscule brick.

Declaration

I hereby declare that the content of this thesis is entirely my own work and has not previously been submitted for the completion of any degree, at any university.



Noemi Dreksler



In our reasonings concerning matter of fact, there are all imaginable degrees of assurance, from the highest certainty to the lowest species of moral evidence. A wise man, therefore, proportions his belief to the evidence.

– David Hume, An Enquiry Concerning Human Understanding Section X, Part 1.4

Since the number of forms and colors is infinite, the number of possible combinations is likewise infinite as well as their effects.
This material is inexhaustible.

– Wassily Kandinsky, On The Spiritual in Art, Chapter VI

The manner in which trains of imagery and consideration follow each other through our thinking, the restless flight of one idea before the next, the transition our minds make between things wide as the poles asunder, transitions which at first sight startle us by their abruptness, but which, when scrutinized closely, often reveal intermediating links of perfect naturalness and propriety – all this magical, imponderable streaming has from time immemorial excited the admiration of all whose attention happened to be caught by its omnipresent mystery.

– William James, Psychology, Chapter XVI Association

Your mind will take the shape of what you frequently hold in thought,
for the human spirit is coloured by such impressions.

– Marcus Aurelius, Meditations 5.16

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Abstract

Beyond Kandinsky: Exploring colour-shape correspondences through the lenses of emotions, individual differences, and aesthetics. Noemi Dreksler, St John's College, DPhil in Experimental Psychology, University of Oxford, Trinity 2019.

This thesis brings together historical and empirical research on colour-shape correspondences. Historical accounts usually start with Wassily Kandinsky's universal visual language of art and design, which explored colours and forms in depth as fundamental building blocks. Whilst colour-shape correspondences provide an example of an intramodal sensory correspondence, modern empirical work in this area has typically been grounded in the field of crossmodal correspondences research. All empirical work conducted on colour-shape correspondences is examined through a systematic review of 28 articles ($k = 50$, $N = 4599$), finding, on average, colour and shape to be associated to a small to moderate degree in terms of effect size. However, many inconsistencies in research to date are also found. Over the course of nine experiments, the high amount of variance in colour-shape matches and their task and stimuli-dependent nature is demonstrated. Particular areas that are explored are whether certain shape characteristics can be found that predict chosen colour characteristics, the role of individual differences, and the relationship of colour-shape correspondences with aesthetics. Key conceptual, statistical, and practical issues are highlighted throughout the thesis. Finally, a theoretical groundwork for colour-shape correspondences is posited based on a dynamic representational geometry associative model for intramodal and crossmodal correspondences.

Extended Abstract

Over the course of this thesis, a systematic review and nine experiments are presented that examine the nature of, and mechanisms underlying, colour-shape correspondences. Chapter 1 contains an introduction to the topic of colour-shape correspondences, considers their relationship with synaesthesia, and considers potential causal mechanisms of association that could underlie colour-shape associations. Finally, a systematic literature review of the topic of colour-shape correspondences is conducted. This includes initial effect size calculations made on the basis of data reported by other researchers. The review highlights both consistencies and inconsistencies in the existing research on colour-shape correspondences and offers a critical analysis of the field to date.

Chapter 2 examines anew the associations that exist between the Kandinsky shapes (triangle, circle, and square) and colours (red, blue, and yellow). Additionally – leaning on the examination of Kandinsky's own writings presented in Chapter 1, as well as the application of the semantic differential technique in previous work on colour-shape and crossmodal correspondences – perceptual, emotional, and semantic factors that may mediate colour-shape matches are examined. Furthermore, Chapter 2 examines the role played by creativity in colour-shape correspondences. The three experiments reveal that whilst squares are strongly positively associated with the colour blue, triangles are strongly negatively associated with blue, and this finding is connected to the most

frequent combinations of colour-shape associations found for these three shapes and colours.

In Chapter 3, the set of stimuli is extended to include larger numbers of both shapes and colours. The experiments grapple with whether consistent colour-shape correspondences can be found across experiments, sets of stimuli, and individual differences such as culture and gender. Other individual difference measures (e.g., visual mental imagery, alexithymia, openness to new experience, and autism) are investigated in terms of how they affect shape appraisals and how intuitive individuals find making colour-shape matches. By including continuous measures of colour as well as shape, it is possible to use statistical methods to analyse and assess whether there is convincing evidence for universal and replicable colour-shape correspondences. Four experiments highlight that colour-shape correspondences are stimuli-dependent, highly-variant across participants, and difficult to capture at the choice level. This remains the case even when methods are used to mitigate the pitfalls of online experiments, which make up the majority of the experiments reported in this thesis. However, the importance of the affective appraisals of liking and arousal in mediating colour-shape correspondences finds strong support.

Chapter 4 examines colour-shape correspondences from the perspective of aesthetics and art by exploring the effects that colour-shape associations have on aesthetic evaluation. Building on the results in Chapter 2, the way in which aesthetic evaluations

affect colour-shape associations is examined. To do this, novel stimuli (Kandinsky-inspired paintings) were used, as well as new experimental paradigms that go beyond the typical way colour-shape correspondences are investigated. Standard experiments in the field present a shape and ask individuals to choose a colour from an array. Instead, here, colours were presented, and individuals chose between two shapes that were matched on all perceptual characteristics except for angularity. The results of Experiment 4A and 4B highlight an association between red and angularity, pink and curvature, as well as the role that aesthetic evaluations play in mediating colour-shape correspondences.

Finally, Chapter 5 critically reflects on and summarises the results of the experiments presented in this thesis, considers standing issues and limitations, attempts to make steps forward in terms of building a theoretical foundation for the field by creating a blueprint for a dynamic representational geometry associative model for intramodal and crossmodal correspondences, and ends with some final thoughts on the existence and mechanisms of colour-shape correspondences.

1 Introduction: The Historical Context and a Systematic Review of Colour-Shape Correspondences

1.1 Introduction

The field of colour-shape correspondences, or colour-shape associations research, is rooted in two traditions. On the one hand, it is a field that has sprung directly from artists' and designers' theorizing in the early 20th Century about the interconnections between visual attributes. Most famously, Wassily Kandinsky, postulated and searched for a universal language that would unite and systematize the simplest visual attributes (lines) with a host of other sensory dimensions and emotional experiences. Inspired by psychological developments during the opening years of the 20th Century, in 1923 Kandinsky presented his wall painting workshop with a survey that asked workshop participants to colour in a triangle, square, and circle with the colours red, blue, and yellow (see Appendix 6.1). These shapes and colours became influential themes in the Bauhaus movement's designs and artworks. Further, Kandinsky's theorising about colour and form more generally became important influences in the works of artists and thinkers of future generations (e.g., Birren, 1955; Dreyfuss, 1972; Gerstner, 1986; Leijonhielm, 1967). Even today, asking an experienced designer about Kandinsky's correspondence theory and the associations between the triangle, circle, and square and red, blue, and yellow will most likely strike a chord of recognition. Even in a

sample of laymen, Jacobsen (2002) found that 62% reported that a fundamental relation between colour and shape was possible. This highlights how Kandinsky may have been tuning in to a fundamentally intuitive phenomenon at the level of folk psychology.

On the other hand, colour-shape correspondences fit into the growing, if not altogether new (Köhler, 1914, 1929, 1947), field of crossmodal correspondences (Parise, Spence, & Deroy, 2016). Except, of course, that they are, strictly-speaking, at least when shape is presented visually, an instance of an intramodal or unimodal correspondence. Crossmodal correspondences have been defined as mappings between attributes or dimensions of sensory modalities (Parise, 2016; Parise & Spence, 2012; Spence, 2011). Additionally, such pairings often give rise to congruency effects in performance. Crucially, they are usually experienced to match one another phenomenologically (Parise & Spence, 2013) – a concept lacking clarity but elucidated most clearly by the fact that most participants feel comfortable intuitively matching characteristics across senses or features in crossmodal correspondence research with measurable consistencies found across populations.

A wealth of crossmodal correspondences have been documented between features of most sensory modalities. A few oft-studied examples include: pitch and elevation, pitch and brightness, taste/smell/flavour and music or shape, and colour and music (see Spence, 2011, for a review, and also, e.g., Brunel, Carvalho, & Godstone 2015; Crisinel,

Cosser, King, Jones, Petrie, & Spence, 2012; Deroy, Crisinel, & Spence, 2013; Evans & Treisman, 2010; Palmer, Langlois, & Schloss, 2016, Parkinson, Kohler, Sievers, & Wheatley, 2012; Spence, 2019a; Turoman, Velasco, Chen, Huang, & Spence, 2018). Crossmodal correspondences are relevant to colour-shape correspondences research since there is no immediate reason as to why one should distinguish between crossmodal and intramodal associations in this case, even if, ultimately, salient differences may be found between the two classes of phenomena.

Of course, colour and shape share pathways and cognitive architecture in our brain, both being features that are processed by the 'what' ventral visual pathway (Kravitz, Saleem, Baker, Ungerleider & Mishkin, 2013). Arguably, colour and shape thus share functional architecture from an early stage far more than two separate senses might, such as audition and taste. Indeed, the study of how colour and shape are processed, separately, in conjunction, and interactively in an intertwined manner is a rich field of research in both cognitive and biological neuroscience. Colour and shape are processed in distinct, separate, and dissociable ways to each other (e.g., Cant & Goodale, 2006; Cant, Large, McCall, & Goodale, 2008; Horel, 1994; Livingstone & Hubel, 1988). But they are also processed interactively (in other words, they are not separate processing streams that do not affect one another, e.g., Cant, 2009; Werner, Pinna, & Spillman, 2007). Additionally, colour and shape are likely bound together early-on in the visual system as colour-form conjunctions (Seymour, Clifford, Logothetis, & Bartels, 2009)

and are continuously integrated from early visual areas onwards, especially when the task requires it (see Hanna & Remington, 1996).

Furthermore, considering colour and shape neurons as independent computational units disregards the horizontal and feedback connections that likely allow dynamic adaptations of a neuron's selectivity and thus the taking into account of contextual information and past experience (see Moutoussis, 2015; Rentzeperis, Nikolaev, Kiper, & Van Leeuwen, 2014, for reviews). Arguably, then, it may be colour-shape correspondences, in particular, with the wealth of research that looks at both how colour and shape are separately and interactively processed, that could help future researchers begin to determine what crucial differences may exist between how intramodal and crossmodal correspondences arise, function, and bias human perception and performance.

This thesis too focuses on how colour and shape intertwine. But, contrary to studies that focus on the cognitive neuroscience of how colour and shape are processed and associated noted above, it homes in narrowly on the associations that exist explicitly and implicitly between specific shapes or shape features and certain colours, colour categories, and colour dimensions. Put simply, if individuals are presented with a shape, are they more likely to feel – at a gut level – that a certain colour matches it? The experimental work of this thesis focuses on the question of whether these intuitions generalize across populations, experiments, and types of colour and shape stimuli.

Furthermore, it reviews whether these correspondences transfer to more potentially automatic, implicit tests of association and what cognitive and neural mechanisms may underlie such colour-shape associations.

1.1.1 The need for a review of the field of colour-shape correspondences.

There are four main reasons as to why the field needs a critical systematic review at this stage of its nearly 100-year history and is relevant to our understanding of the mind at a broader level. First, no exhaustive review has ever been conducted leaving the field without a coherent overview of the consistencies and inconsistencies of results across research groups, resulting in stifled progress on developing a theoretical basis for the phenomenon, and no constructive way forward. Second, within multisensory perception research, and, in particular, crossmodal correspondences research, looking at how intramodal features may be interconnected could also contribute to theoretical frameworks. Further, it will likely help expand into fruitful avenues of research in regard to questions such as the binding problem and multisensory integration (Ernst, 2007; Spence, 2011; Spence & Frings, in press) and how crossmodal correspondences should be conceptualized on a theoretical level as a coherent phenomenon, or set of associated phenomena, in our cognitive architecture. A question, indeed, that has been insufficiently addressed in the literature to date.

Third, there is an undoubted reliance on colour and shape as experimental stimuli, especially coloured shape stimuli, in psychological research – innumerable studies

investigating everything from attention and learning to working memory and feature integration use colour and shape as a way to probe the inner workings of our mind and those of animals (e.g., Bonnel & Prinzmetal, 1998; Byrom & Murphy, 2016; Chmiel, 1989; Horne & Pearce, 2009; Lee, Leonard, Luck, & Geng, 2018; Mordkoff & Danek, 2011; Mordkoff & Yantis, 1993). Historically too, psychologists have made generous use of how individuals interact with colour and forms as diagnostic tools and as a basis for theorizing about human development (see, for example, Katz, 1975). It would therefore be remiss to disregard a field that may indicate that colour-shape stimuli should be attentively chosen and most definitely highlights that such stimuli have to be, at the very least, carefully counterbalanced. This consideration is becoming all the more pertinent as colour-shape correspondence researchers have started finding significant and meaningfully sized results of the effect that colour-shape associations can have on reaction times (RTs) in visual search and go/no-go tasks (Chen, N., Matsuyoshi, & Watanabe, submitted; Chen, N. & Watanabe, submitted). Additionally, if colour-shape associations can operate at a conscious symbolic level as well as at a more implicit associative level, there may also be opportunities to capitalize on colour-shape associations, for example, in areas such as development, learning, marketing, and ergonomics (cf. Münchow, Mengelkamp, & Bannert, 2017; Spector & Maurer, 2008, 2011; Spence, 2012).

Finally, there remains significant public interest in Kandinsky's work, theories, and influence on art. Take the Museum of Modern Art's 2009 Bauhaus retrospective that

set up a standalone mini-website centred around the history of the Bauhaus that included a remake of the original Kandinsky questionnaire (the data of which is, unfortunately, no longer available[1]). Moreover, the evocative abilities and hedonic effects of both colour and shape are recurrently shown in studies that probe their emotional association and their study has a long history in psychology and aesthetics that has followed through to the current day (e.g., Adams & Osgood, 1973; Collier, 1996; Hevner, 1935; Kimura, Wada, & Noguchi, 2005; Lyman, 1979; Oyama, 1998, 2003; Palmer, Schloss, & Sammartino, 2013; Poffenberger & Barrows, 1924; Shimamura, 2013; Silvia & Barona, 2009; Smets, 1971; Valdez & Mehrabian, 1994), Undoubtedly, at one time or another, the affective expressive strengths of colour and shape have become apparent to even the most unartistic of us as we transverse the natural, man-made, and digital worlds. Both colour and shape are potent sources of information for our brains from a statistical and evolutionary perspective. A deeper understanding of them can be enriching and engaging for the public and is likely to influence and inspire artists in the future, as it has undoubtedly done in the past. Indeed, it is at the intersections of sensory science, technology, and art, where some of the most interesting phenomenological effects take place when the remit of psychology is extended outside of the laboratory (e.g., Haverkamp, 2014; Maglione *et al.*, 2017;

[1] The curatorial assistant for the website, Professor Dara Kiese (personal communication, February 4 2019), was contacted and relayed that the likelihood of the data having been preserved was very low. Nevertheless, the website can still be accessed here: https://www.moma.org/interactives/exhibitions/2009/bauhaus/Main.html.

Pinna, 2011; Seah *et al.*, 2014; Spence, 2017; Vi, Ablart, Gatti, Velasco, & Obrist, 2017).

1.1.2 The historical context of colour-shape correspondences.

Wassily Kandinsky was one of the pioneers of modern abstract art and a key member of the Bauhaus collective – a movement that wanted to break away from the pictorial traditions of the past and free itself from the so-called *Tyranny of the Object* (see Barasch, 1998, p. 293). For Kandinsky, this was far more than merely a revolt, it was a deeply spiritual undertaking – dreaded was the prospect that abstract painting would be seen as serving only an aesthetic purpose (Kandinsky, 1926/1994, p. 171). The Russian painter's aims ran much deeper: Through his extensive theoretical work, he wanted to discover, reveal, and systematize a universal visual language. Indeed, this simplification of colour and form to primary shapes and colours was a key process for the Bauhaus artists who were attempting to create an ideal means of communicating visually in the fields of both art and design (Jacobsen, 2002, 2004b).

Alongside Bauhaus contemporaries, such as Johannes Itten and Paul Klee, Kandinsky "sought this origin [of a universal visual language] in basic geometries, pure colours, and abstraction" (Lupton & Miller, 1993, p. 21). For this language, lines, shapes, colours, and even music, were not only essential, but fundamentally intertwined. As pointed out by Lupton and Miller, for Kandinsky, a translation existed between graphical features (*viz.* lines) and non-graphical phenomena such as music, colour,

perception, and even spiritual intuition (Kandinsky, 1926/1994). The correspondences that are the focus of this thesis – namely, the associations between colour and shape – were central to Kandinsky's teachings. To him, the fundamental and universal correspondences between shape and colour that existed were (at the very least) threefold: A triangle was linked with yellow, a square with red, and a circle with blue.

In the 1914 work, *The Art of Spiritual Harmony*, Kandinsky reflects extensively on the nature of colour and form. He notes the insistent aggressive personality of yellow, the depth and introspective nature of blue, and the sharpness, strength, and vigour of red (Kandinsky, 1914). Kandinsky also hints at their connection to specific forms: "keen colours are well suited by sharp forms (e.g., a yellow triangle), and soft, deep colours by round forms (e.g., a blue circle)" (Kandinsky, 1914, p. 57). The connection of red to a square is not specifically noted. According to Gage (1993), these intimations were only explicitly set out as Kandinsky's three correspondences in an illustration in the Russian version of the work, from which point on it exerted a strong influence on both Russian and German art circles.

In 1923, inspired by the rise of experimental psychology and borrowing from its methods, Kandinsky famously handed out a questionnaire to the participants of a wall-painting workshop that asked his Bauhaus contemporaries to intuitively fill out the square, triangle, and circle with red, yellow, and blue (see Appendix 6.1; or Kandinsky, 1923/1994, p. 850). By this time, many of his contemporaries at the Bauhaus school

and beyond would most likely already have been aware of the postulated correspondences (Droste, 1990). This, alongside the fact that the results from the workshop and the one thousand questionnaires that were apparently sent out to the community were never published (Gage, 1993), obviously makes any traditional data analysis impossible. Kandinsky's correspondences enjoyed a seeming consensus from the Bauhaus community, great acclaim, and also had a profound effect on the Bauhaus' image. The correspondences also exerted a continued presence in Kandinsky's teachings (see, for example, Batz's (1929) *The Spatial Effect of Colours and Shapes*, an exercise from Wassily Kandinsky's class, or the famous Stuttgart archive catalogue by Herzogenrath and Bayer (1968) that celebrated the 50 year anniversary of the Bauhaus[2]) and influenced his contemporaries such as Johannes Itten (Gage, 1993) and future colour theorists and designers (e.g., Birren, 1955; Dreyfuss, 1972).

Despite Kandinsky's influence and the experimental methods used, dissenting opinions to Kandinsky's colour-shape matches existed even within the Bauhaus, as Gage's (1993) historical research makes clear. According to Van Biema (1930), Hölzel proposed a yellow triangle like Kandinsky, but a red circle and blue square. The painter Liubov Popova endorsed the same correspondences as Hölzel (Lodder, 1983). As Schlemmer (1972, p. 188) put it: "All the experts agree on the yellow triangle, but not on the others. Instinctively, I always make the circle red and the square blue." When,

[2] Unfortunately, these paintings cannot be shown in this dissertation due to copyright restrictions.

in 1990, Lupton and Miller reproduced responses to a modified version of Kandinsky's questionnaire from seven designers and theorists, the given justifications made clear that their responses were substantially tinged with knowledge of the legacy of Kandinsky's correspondences (Lupton & Miller, 1993). Even then, the only two responses filled out in line with Kandinsky's instructions (one colour should be given to each shape, an instruction left out of the modified questionnaire), also endorsed the dissenting correspondence triplet of the yellow triangle, the blue square, and the red circle (see Appendix 6.2).

Interestingly, as the systematic review of the literature reveals, this particular dissenting intuition – the yellow triangle, blue square, and red circle – does enjoy somewhat more empirical support than Kandinsky's correspondences when all of the empirical studies to date are considered.

1.1.3 Crossmodal correspondences and synaesthesia.

The aforementioned language of vision and its basic correspondences were considered by Kandinsky to be "speaking directly to the mechanics of the eye and brain" (Lupton & Miller, 1993, p. 22). This certainly sounds more palatable to the modern perceptual psychologist than Kandinsky's more common phrasings, such as that a shape or musical note always have a "corresponding vibration of the human soul" (Kandinsky, 1914, p. 57). Of course, it remains true that Kandinsky's theorizing about a universal visual language and its fundamental correspondences, in both style and method, are

outdated and come across today as unempirical. Nevertheless, his work does lend itself to comparison with various multisensory phenomena studied in the field of perception today.

For one, Kandinsky's fundamental correspondences and confident assertions on translations between simple graphical and other perceptual characteristics in his universal visual language do not sound unlike a synaesthete's phenomenological experience, not to mention their emotional investment in it. Consider, for example, the varying chromatic nature of letters that can be imbued not only with colour, but also personality and emotion for someone with synaesthesia. Or the symphonic displays of colour during a concert for a music-colour synaesthete. These experiences are not only undeniably real to the individual concerned but also feel unchangeable and determined (Martino & Marks, 2001). Indeed, it is debated almost as often as it is stated as fact, as to whether Kandinsky himself may have experienced various forms of synaesthesia (Harrison, 2001; Ione & Tyler, 2003; see Just, 2017, for a full discussion of why Kandinsky is likely to have been a synaesthete).

Further still, as mentioned above, the parallels to the growing field of crossmodal correspondences research are also notable (see Parise, 2016; Spence, 2011). The similarity of Kandinsky's process and his feelings about colours and shapes which exude from his writings (see Kandinsky, 1994, for a publication of his complete writings), is less surprising in light of the fact that people can feel these phenomenological and

emotionally intuitive links between two sensory features that go beyond expected semantic connections (e.g., between the sound of bark and the picture of a dog). These links can be revealed in crossmodal matching paradigms and follow-up questionnaires (Parise & Spence, 2013), and may indeed be prevalent across sensory dimensions (Parise, 2016). Indeed, such affective, semantic, and aesthetic links will be examined in the coming chapters. In the experiments conducted for this thesis, it becomes clear in debriefings that whilst some participants are not very attached to their choices, others do feel strongly about the matches that they have made and how 'right' they feel (cf. Saluja & Stevenson, 2018; Spence, Corujo, & Youssef, 2019). It may also be exactly this 'feeling of rightness' that the term 'phenomenologically match' is trying to latch on to. It is this response – of finding a phenomenological match – that the basic set-up used in the experiments reported in this thesis is trying to elicit in participants. Additionally, this thesis will also attempt to capture and explore the fact that some individuals find certain matches, or matches overall, more intuitive by exploring potential predictors such as individual difference measures and shape characteristics that could be driving these outcomes. Of course, it should be considered that, alternatively, the reported matches may also reflect some measure of the choices that they expect other individuals would make (Koriat, 1975, 2008). However, if this is the case, the large amount of variation that is seen in individuals' responses – as Chapter 3 will show – implies that, at the very least, there is no consensus as to what matches others would make that could be driving consistent colour-shape matches.

Similarly, consider again the fact that crossmodal mappings between dimensions and features can, and most often do, result in congruency effects on performance in various perceptual tasks such as speeded detection, classification and discrimination, or implicit association tests (see Jamal, Lacey, Nygaard, & Sathian, 2017; Marks, 2004; Parise & Spence, 2012; Spence, 2011; Spence & Deroy, 2013a, for reviews). From a cognitive neuroscience perspective, such congruency effects have, of course, to be grounded in the cognitive and biological architecture of the brain and point to a degree or partial form of automaticity (at least in certain cases; Spence & Deroy, 2013a, though see, Getz & Kubovy, 2016, 2018). This allows for a charitable agreement with Kandinsky that these correspondences are rooted in our neural mechanisms and increase processing fluency (see Reber, 2012, and later discussion in Section 3.1.3) by, most probably, triggering closely related associative nodes when congruent features are presented.

1.1.3.1 Grapheme-colour synaesthesia and non-synaesthetic associations.

A closely related field to colour-shape correspondences is the field of grapheme-colour synaesthesia and the way in which such associations may also be found in non-synaesthetic individuals. Since graphemes are, arguably, a very specific subset of shape stimuli, with a special status in terms of how we process them, the findings in this area are worth exploring before turning specifically to a systematic review of colour-shape correspondences. Grapheme-colour synaesthesia is one of the most common and most studied types of synaesthesia (Simner *et al.*, 2006). It denotes the phenomenon whereby

a letter 'inducer' consistently (for the individual) elicits a specific 'concurrent' colour experience. Although such associations can be idiosyncratic between individuals, there is also evidence from large sample studies that there are consistencies across populations of individuals with grapheme-colour synaesthesia, which may, in part, be driven by conditioned mental imagery (Simner *et al.*, 2005; Witthoft, Winawer, & Eagleman, 2015), much as colour-shape correspondences are often considered to be outcomes of object-related knowledge (e.g., Jacobsen, 2002). Grapheme-colour synaesthesia can generalize to previously unseen letters through shape similarity (Brang, Rouw, Ramachandran & Coulson, 2011), but the semantic category (letter vs. number) can be a driving factor over and above shape as well (Dixon, Smilek, Duffy, Zanna, & Merikl, 2006). Additionally, both sound and higher-level semantic factors can likely also contribute (Jürgens & Nikolić, 2012; Shin & Kim, 2014). Furthermore, other more perceptual higher-order similarities such as letter shape and similarity, ordinality, and letter frequency can be linked to dimensions such as hue and colour (Brang *et al.*, 2011; Eagleman, 2010; Jürgens, Mausfeld, & Nikolić, 2010; Watson, M.R., Akins, & Enns, 2010, 2012).

Additionally, Simner *et al.* (2005) found that there are significant similarities between colour-grapheme associations between synaesthetes and non-synaesthetic controls. Indeed, Spector and Maurer (2008, 2011) have even reported that pre-literate children associate letters and nonsense shapes with certain colours, whilst other associations (such as the common 'a'-red association seen in grapheme-colour synaesthetes as well,

cf. Root *et al.*, 2018), are only seen in literate children and adults. Since the associations found in preliterate children are also found in adults, they suggest that synaesthetic and non-synaesthetic mappings in adulthood originate from the interaction of both natural biases and learning. Looking at cross-language effects, Root *et al.* (2018) found evidence for the fact that the unique ordinal position of the first letter 'a' of the alphabet, and the unusual distinctness of the colour red, was the only explanation when contrasted to semantic, acoustic, and shape effects, that could account for this colour-grapheme consistency across all five examined languages.

Grapheme-colour associations in adults may be driven by qualitatively different mechanisms in synaesthetes versus non-synaesthetes, suggest Simner *et al.* (2005): whilst grapheme frequency in the English language does not appear to influence such associations in non-synaesthetic controls, they do appear to have a significant effect on synaesthetes' grapheme-colour correspondences (see also Rich, Bradshaw, & Mattingley, 2005). Other mechanisms by which graphemes and colours could be associated is ease-of-generation and the ordering of the alphabet, such that as participants go through letters in a specific order, they choose the most easily generated, prototypical colours first (cf. Battig & Montague, 1969; Berlin & Kay, 1969). Simner *et al.* (2005) did not find that such ordering or ease-of-generation mechanisms adequately explained colour-grapheme associations for synaesthetes but they were found to play a larger role for non-synaesthetes. Nevertheless, some researchers have found specific relations between frequency of graphemes found in print

and colour characteristics such as brightness and saturation (e.g., Beeli, Esslen, & Jäncke, 2007; Cohen Kadosh, Henik, & Walsh, 2007; Simner & Ward, 2008; Smilek, Carriere, Dixon, & Merikle, 2007).

Mixed opinions exist about how synaesthesia relates to the crossmodal correspondences and non-synaesthetic associations found in the wider population. Some researchers highlight that they are distinct phenomena (Deroy & Spence, 2013) and others refer to crossmodal correspondences as a weak form of synaesthesia (Martino & Marks, 2001). Nevertheless, it certainly appears that studying how and where they differ and intersect could offer insights into the aetiology of each of them, in turn. As such, for example, it is interesting that overtraining non-synaesthetic individuals in grapheme-colour associations can result in training-induced reports of synaesthetic phenomenology, as well as synaesthesia-like performance on Stroop tasks, and corresponding cortical changes (Rothen, Schwatzman, Bor, & Seth, 2018). However, it is also clear that the cognitive and neural processes involved in grapheme-colour bindings may have both similarities and differences between grapheme-colour synaesthetes and non-synaesthetes (Esterman, 2006). As such, it certainly feels likely that a lifetime of experience with shapes and colours and the possibility to make associative connections could give rise to phenomena such as colour-shape correspondences, even if a conscious 'concurrent' is not elicited as it would be for a synaesthete.

1.1.4 Potential causal mechanisms of association.

In many ways, the explanations explored in the context of graphemes and colour highlight that both low-level and higher-level, as well as innate and learnt, processes may underlie correspondences between sensory features. Separate from work in grapheme-colour synaesthesia, Spence and his colleagues have suggested four explanations that may underlie the acquisition and nature of many crossmodal correspondences. These can perhaps further guide our thinking about the causal basis of colour-shape correspondences. These suggested mechanisms are: affective, semantic, statistical, and structural (for further details see Parise & Spence, 2013; Spence, 2011, 2018). These are not to be considered as mutually exclusive – after all, any correspondence could find its causal origins in one or more of these explanations:

1. Affective correspondences are acquired and/or made through the association of two stimuli or stimulus dimensions based on similar valences of emotions, pleasantness, or hedonic responses that they are associated with or evoke in an individual.
2. Semantic correspondences, or lexical correspondences, are linguistically or conceptually mediated: associated features are linked because they are described using, or associated with, a similar semantic dimension and common label (e.g., weak/strong).
3. Statistical correspondences depend on sensory and memory systems tracking the regularities in the patterns of sensory signals we receive through experience.

4. Structural correspondences are either innate or else exist due to the maturing of sensory coding structures across development and are posited to depend on common coding systems (e.g., for stimulus intensity or magnitude) as well as interaction effects resulting from neural connections between sensory processing areas.

Two things should be noted here: First, positing affective mechanisms does not necessarily assume that links between colour-shape correspondences exist at the varied levels – cognitive appraisal, neurophysiological, motivational, motor expression, subjective emotional experience – of what can arguably be said to make up our emotions and emotional repertoire (e.g., Scherer, 2005). Under a dynamic and componential view of emotions, emotions include not only subjective experiences and the appraisal of events or stimuli, but an inter-related constellation of motor, physiological, and regulatory responses (Fontaine, Scherer, Roesch, & Ellsworth, 2007; Scherer, 2009). Analysis in the realm of correspondences, especially in matching tasks, restricts itself to the cognitive appraisals of emotion. These may or may not have knock on effects on other levels of our emotional experience and are evaluated within a network of memories, motivations, expectations, notions of self-construal, and so on (Scherer, 2009). The core affects which are most commonly focused on in the realm of crossmodal correspondences research are: valence (framed as a dimension that differentiates between positive, approach, and attraction on the one hand, and negative, withdrawal, and aversion on the other) and arousal (a general sense of energy

and activation). Both have been central to many models of emotions in one incarnation or another (e.g., Barrett, Mesquita, Ochsner, & Gross, 2007; Osgood, Suci, & Tannenbaum, 1957; Russell, 1980, 2003; Russell & Bullock, 1985).

Second, the notion of semantic correspondences can be expanded by considering Martino and Mark's (2001) explication of their semantic-coding hypothesis. They argue that crossmodal correspondences (though see Walker, P., 2012a, for how this occurs intramodally too) function by recoding sensory features into semantic and abstract representations based on a network of connotative meanings that has been created in a post-sensory, meaning-making mechanism in linguistic children and adults through associations made between perceptual experiences and the language that is used to describe them.

In practice, of course, these mechanisms are likely not to be mutually exclusive and, in addition, are also likely to be intimately linked. For one, it is often difficult to differentiate affective and semantic mechanisms since affective appraisals are often probed using semantic differential techniques that use verbal labels. Furthermore, if affective and semantic associations exist, they are highly likely to be influenced, at least to a certain degree, by the statistical internal appraisal and sensory information obtained as a result of previous experience when interacting with such stimuli, which ultimately leads to their associative strength increasing. Finally, as indicated by Rothen *et al.*'s (2018) study, synaesthetic-like structural changes may even occur as a

result of repeated exposure to associations of pairs of stimuli. As will be seen below, the colour-shape and crossmodal correspondence fields, have not yet grappled experimentally or theoretically with the full complexity that such causal explanations offer. A fruitful theoretical groundwork that is sensitive to the complexities and issues at stake will undoubtedly be essential for the field to progress.

1.2 Systematic Review 1A

Having set the historical backdrop of colour-shape correspondences and how colour-shape associations intersect with other topics in multisensory perception, such as crossmodal correspondences and synaesthesia, next, a comprehensive review of the literature on the associations between colours and shape to date is conducted. Results from some of the following experiments of this thesis, will be included where applicable so as to give the most comprehensive overview of the field as possible.

1.2.1 Method.

1.2.1.1 Search criteria.

A systematic review was conducted with broad search terms. This was necessary in particular since the phenomenon has no accepted terminology in the literature. PsycINFO and Web of Science databases were searched using the following criteria: (“colour” OR “colour” OR “hue” OR “colours” OR “colours” OR “hues”) AND (“shape”

or “shapes” or “form” or “forms”). No time limits were placed on either search. For the PsycINFO database, title, abstract, heading word, table of contents, key concepts, original title, tests and measures were searched. Since Web of Science accesses a much larger range of scientific topics, the same search criteria for title alone generated 82,404 results and are made up almost entirely of material and technological sciences. As such, the same search terms applied to title were included but the ‘science technology’ domain was excluded, whilst the ‘social sciences’ and ‘art humanities’ research domains were included. To make sure no articles were being excluded by the stricter search terms, the title had to include only one half of the AND operator equation (i.e., titles that only included the word colour but not variants of the shape search terms were also included in the search results).

Web of Science results were exported to, and examined with, RefWorks, whilst PsycINFO results were downloaded and evaluated using Microsoft Excel. The 919 (PsycINFO) and 1198 (World of Science) titles and abstracts were examined, and if ambiguity remained, the article was read to ascertain whether the research therein empirically investigated the associations between colour and shape. The final inclusion criterion was any article that investigated associations that individuals made between colour and shape, including matching experiments, as well as indirect experiments that aimed to specifically probe colour-form associations. As such, no experimental designs were excluded provided the article addressed the narrow scope of the final inclusion

criterion. A total of 34 articles were taken forward from the PsycINFO search, and 18 articles were taken forward from the World of Science database search.

1.2.1.2 Exclusion criteria.

At a minimum, sample sizes or some sort of data had to be presented and the research had to be experimental in nature rather than merely asserting the believed or felt associations of the author. Whilst this may go without saying in most fields of psychology, the rich historical context of colour-shape associations means that some instances of such articles from several decades ago did show up in the literature search (e.g., Birren, 1955). The large majority of excluded articles were not included based on not fitting in with the narrow scope of the research question captured by the final inclusion criterion noted above. A technical exception was made when an additional study in an article combined new emotional mediation results with the previously acquired colour-shape associations since this allowed for the probing of the causal mechanisms underlying colour-shape associations (e.g., Chen, N., Tanaka, Matsuyoshi, & Watanabe, 2015a, Experiment 2).

Research of how colour and form relate to the diagnostic use of Rorschach inkblots and the categorizing of individuals as colour-raters and form-raters, both research areas popular in the 20th century, were also excluded. References to these related research fields include terms such as colour-form attitudes, colour-form tests, and colour-form preferences and paradigms used are both tachistoscopic memory and colour-form

sorting tasks (e.g., Abramson, 1989; Grewal, 1988; Keehn, 1955; Oeser, 1932a, 1932b; Taylor & Eisenman, 1968). This decision was made based on reading several of these papers to verify that they were not specifically interested in colour-shape correspondences.

Research that examined the emotional and semantic associations of colour, shape, or colour-shape combinations were not included in the systematic review of colour-shape correspondences but collected for further insight to the emotional mediation hypothesis of colour-shape correspondences. The literature on grapheme-colour association in non-synaesthetes and grapheme-colour synaesthesia were similarly collected but excluded from the final set of articles.

Those articles that focused on how colour and form are processed within our cognitive architecture at either the behavioural and/or neuroscientific level were also excluded, but similarly collected to give an overview of the way in which interactions between colour and shape processing has been investigated in the literature. Many such articles used colour and shape stimuli in a variety of paradigms to gain insight into the workings of, for example, attention, feature integration theory, and working memory. In turn, others focused specifically on how colour and shape are perceived, processed, and integrated within our cognitive architecture. Some of the main findings of these have been discussed above already. All were excluded based on not fitting with the research question even if, arguably, such articles do probe how colour and shape are

associated on a different level. However, if titles or abstracts did not indicate that articles reported anything about the way features or types of shapes were related to features or instances of certain colours, nor probed these associations using indirect methods, they were excluded.

Finally, articles not in English, German, or Spanish had to be removed due to the current author (nor anyone in the University of Oxford Crossmodal Research laboratory) being fluent in languages outside of these three. However, this resulted in the exclusion of only one article that related to the research question (Josefin, Damajanti, & Irianto, 2016), although it did not appear to report any usable statistical analyses either. Non-empirical studies (i.e., did not make use of the scientific method) or those which asked a subset of individuals who would be intimately familiar with Kandinsky's correspondences and know specifically why they are being prompted with the three Kandinsky shapes and colours were not included (Lupton & Miller, 1993, and the results of a preliminary study reported in passing in Jacobsen & Wolsdorff, 2007). Some lenience was given here for the art educators in Jacobson and Wolsdorff's (2007) study since only one reported being familiar with Kandinsky's theory and assignment.

1.2.1.3 Further sorting and searches.

After duplicates were removed, the bibliographies of the articles were checked for further relevant materials. Google Scholar was used to evaluate all articles that cited

the articles from the database search for inclusion based on title and abstract. Additionally, an effort was made to contact a majority of the researchers who have published in the field since 2000 in order to request any unpublished and otherwise relevant research materials or contact details of other researchers who may have relevant data. This was done in order to have the most up-to-date collection of the research conducted and to address the 'file drawer problem' (Rosenthal, 1979). A further two studies currently submitted were received in this way (Chen, N., Matsuyoshi, & Watanabe, submitted; Chen, N. & Watanabe, submitted). The search results included three completed PhD dissertations (Chen, N., 2015; Dadam, 2010; Malfatti, 2014), as well as the current thesis that was in preparation at the time. Two of these (Chen, N., 2015; Dadam, 2010) were not included in the final count since relevant studies therein were all found in published articles, although the dissertations were checked for any additional statistical analyses that might not have not been included in the published version.

Where applicable, the duplicated studies and references are indicated in Appendix 6.3. Two articles were excluded (Chen, N. *et al.*, 2014; Chen, N., Tanaka, Matsuyoshi, & Watanabe, n.d.) since they appeared to be early work that was later published more fully in other articles or dissertations. Two posters and one abstract were also found (Holmes & Zanker, 2008; Malfatti, Schloss, Albertazzi, & Palmer, 2014a, 2014b), which similarly presented research either found in articles or dissertations and, as such, these were not included. A final article had to be removed due to lack of clarity in terms of

sample sizes and methodology (Reisinger, Tobin, & Huedo, n.d.). Additionally, as an outlier, the studies therein used luminous stimuli. This resulted in a final set of 28 articles or dissertations and 50 separate samples with a total participant number of $N = 4599$.

A further six experiments (Experiment 2D, 3A, 3B, 3C, 4A, and 4B) were conducted for this thesis after conducting this literature search in early 2019, which are thus not included in the official systematic review in terms of effect size extractions and tables, however, where relevant, results will be mentioned where they contradict or support findings reported within the context of the systematic review. Finally, I was made aware in the later summer of 2019 of an article that may be of relevance (Walter, 2018), but every attempt to get access to the article, book, or author in question through their institutional affiliations failed.

1.2.1.4 Effect size extraction.

Effect sizes were rarely reported for direct matching experiments, whilst indirect experiments were more likely to report d scores, mean D scores, or partial eta squared values. In order to evaluate the field better, especially in the light of ongoing debates about the utility of p-values (e.g., Wasserstein, Schirm, & Lazar, 2019), an effort was made to re-analyse direct matching experiments, where possible, by working backwards from the percentages or frequencies of choices often reported in the literature. This allowed the calculation of Cramér's V values from Chi-square analyses of cross-

tabulations of full contingency tables of studied colours and shapes. When a study reported a Chi-square statistic of association between colours and shapes but no frequency information, the following equation was used to calculate Cramér's V (Cohen, 1988, pp. 223-224):

$$V = \sqrt{\frac{\chi^2}{N(k-1)}}$$

Equation 1.1

Where N is the sample size, k is the smaller integer of the number of rows and columns there are, and χ^2 is the Chi-square test statistic. For one-way Chi-square analyses, or goodness-of-fit Chi-square analyses, of frequencies extracted from studies, the Cramér's V effect size (where $V = W$ or phi*)* was calculated using the following equation:

$$V = \sqrt{\frac{\chi^2}{N}}$$

Equation 1.2

Following Rea and Parker (1992), Cramér's V values were interpreted as a measure of effect size as follows: negligible association (.00<.01), weak association (.10<.20), moderate association (.20>.40), relatively strong association (.40<.60), strong association (.60<.80), and very strong association (.80<1.00).

If Cohen's d was not reported, an effect size calculator was used (Becker, 2000) to calculate Cohen's d if a t-value and the degrees of freedom were reported for a t-test,

such as in Spector and Maurer (2008, 2011). No studies reported parameters that would have allowed for other calculations of Cohen's *d*. Cohen's *d* scores were interpreted along the following guidelines for effect size (Cohen, 1988): small (.2), medium (.5), and large (.8). However, as with any effect size, such break points and guidelines should not be interpreted as strict cut-off points (Thompson, 2007).

Mean *D* scores were provided by some Implicit Association Test (IAT) indirect studies. Mean *D* scores are different to Cohen's *d* but also have considerable similarities:

> [The *D* score measure] divides the difference between test block means by the standard deviation of all the latencies in the two test blocks. Division of a difference between means by a standard deviation is quite similar to the well-known effect-size measure, *d* (Cohen, 1977). The difference between the present *D* measure and the *d* measure of effect size is that the standard deviation in the denominator of *D* is computed from the scores in both conditions, ignoring the condition membership of each score. By contrast, the standard deviation used in computing the effect size *d* is a pooled within-treatment standard deviation. (Greenwald, Nosek, & Banaji, 2003, p. 201)

Project Implicit, notes that based on 723,881 race task IAT scores, *D* scores, measuring the IAT effect, have a possible range of -2 to 2 and have the following conservatively chosen break points: .15 = 'slight', .35 = 'moderate', and .65 = 'strong' ('Race attitude', n.d.).

Daniel Lakens' calculator (see also Lakens, 2013) for calculating partial eta squared was used for Analysis of Variance tests that only reported the F-value and degrees of freedom values and it is available for download on the Open Science Framework (http://opensciencefframework.org/project/ixGcd/). Partial eta-squared values were

interpreted along the effect size guidelines of .01 being 'small', .06 'medium', and .14 'large' (see 'Rules of thumb on magnitudes of effect sizes, n.d.; Cohen, Cohen, West, & Aiken, 2003).

For a limited number of studies, there were no parameters reported or calculable that to the author's knowledge allowed for the calculation of any type of effect size measure (e.g., Dumitrescu, 2011; Lindauer, 1973). Since the aim was to conduct a systematic literature review rather than a full meta-analysis, these small number of studies were simply discussed based on the merits of the results that were reported therein.

1.2.1.5 Terminology.

To simplify the discussion, it is useful to set out some terms that refer to specific sets of shapes and colours. If the Kandinsky shapes and colours are mentioned anywhere in this thesis, these refer to the triangle, square, circle, blue, yellow, and red that were tested in Kandinsky's original 1923 questionnaire or some derivation thereof. When the possible six combinations the Kandinsky colours and shapes can form if one colour is matched to each shape are discussed, three terms will be used to refer to the ones that have been most commonly found evidence for in the literature (Kandinsky, association, and dissident correspondences), whilst simply referring to the numbers (Combination 2, Combination 4, Combination 6) where no name has been assigned. These can be referred to in Table 1.1.

Table 1.1. Descriptions and depictions of the six possible combinations that can be made from the Kandinsky shapes and colours. Combination 1, or the Kandinsky correspondences (blue triangle, red square, yellow triangle), Combination 2 (blue circle, yellow square, red triangle), Combination 3, or dissident correspondences (red circle, blue square, yellow triangle), Combination 4 (red circle, yellow square, blue triangle), Combination 5, or association correspondences (yellow circle, blue square, red triangle), and Combination 6 (yellow circle, red square, blue triangle).

Combination	Name within article	Colour-shape associations	History or origin
1	Kandinsky correspondences		Set out in Kandinsky's original theories as discussed above.
2			
3	Dissident correspondences		An opposing view within the Bauhaus and considered by N. Chen and colleagues to be prevalent in the Japanese population and such they refer to them as the "Japanese colour-shape association" (Chen, N., Tanaka, & Watanabe, 2015, p. 2), originating arguably in the salience of the red circle in the Japanese flag.
4			
5	Association correspondences		Named after Jacobsen's (2002) finding them to be prevalent in a German sample that commonly made reference to a red warning triangle and yellow sun association in their rationales for their choices.
6			

1.2.2 Findings.

Below, the extracted studies will be explored in three broad categories: 1) matching experiments that involve colours and shapes being explicitly matched with one another by participants (see Appendix 6.4 for Table 6.2 describing all direct matching experiments); 2) Experiments that probe the mechanisms that could potentially underlie colour-shape correspondences (e.g., affective mediation) and potential individual differences in colour-shape associations, and 3) Indirect experiments exploring the association between colour and shape through paradigms, such as priming tasks and IATs, that explore the associative connection between colours and shape on a more implicit level (see Appendix 6.5 for Table 6.3, which details all indirect experiments). When approaching the studies extracted through the systematic review, a useful and concise overview of whether and which colours and colour properties may be associated with shapes and shape characteristics will be presented. Beyond this, though, space is dedicated to the questions of: 1) what perceptual, emotional, and semantic characteristics may drive colour-shape associations, and 2) what insights into the nature of colour-shape correspondences implicit experiments, in particular, can offer in order to begin incorporating colour-shape correspondences into the broader field of perceptual psychology at a theoretical level.

1.2.2.1 Colour-shape correspondences: Matching experiments.

1.2.2.1.1 Are specific shapes associated with specific colours or categories of colours?

The majority of experiments in the colour-shape correspondence field follow a simple paradigm – participants are shown different shapes and asked to choose the colour that they feel best matches the shape[3] (Campbell, 1942, is a notable exception, as is Lindauer, 1973, since they present colours and ask for shape matches or shape creations). Before turning to the question of whether specific shapes are associated with certain colours across experiments, the question arises as to whether there is, in fact, a general association between colours and shapes. In other words, are the cross-tabulations of colour choices for each shape significantly different from what would be expected by chance when tested using Chi-square analyses. The effect sizes for the association between shapes and colours ranged from a weak to relatively strong, as can be seen in Table 1.2. The average Cramér's V effect size of .24 falls into the category of what has been designated by Rea and Parker (1992) as a moderate association.

In the light of the fundamental statistical issues that Chi-square analyses of this type of data runs into (see Section 1.2.4.1), such findings should be taken with a grain of salt. Nevertheless, the best possible estimation that can be made currently on the existence of colour-shape correspondences, suggests that it is a phenomenon with an,

[3] See Appendix 6.6 for Table 6.4, which details the different types of instructions used.

on average, moderate effect size, that can, in many instances, also fall into the weak effect size range (the mode effect size category of the studies detailed in Table 1.2 is a weak association). On the question of power, it is clear that several studies are underpowered, although there is little guidance as to how to interpret this due to the inflated sample size that is needed to calculate power (the number of observations). This is a result of the violation of the assumption of independence that all direct matching studies analysed here are necessarily guilty of when such full-contingency table analysis methods are used whether in the form of Chi-square or log-linear analyses. It should be noted, though, that even when studies with a power of .80 or higher (Cohen, 1992) only are taken into account, the average effect size remains in the same range (.28).

Table 1.2. This table summarizes the effect size, significance, number of observations, power, and degrees of freedom for the one-to-one association of shape to colour stimuli in the experiments which had the required frequency information available to calculate them, unless otherwise noted. However, often the colours are categorized into further divisions by researchers to avoid having too many cells with an expected observation count under 5. Notably, the 40 hue NCS colour wheel is divided into 8 colour categories for analysis. For all other stimuli the ultimate number of levels used in the analysis have been noted in the table itself.

Study	Experiment	Sample size	Shape stimuli	Colour stimuli	Effect size (Cramér's *V*)	Significance (p-value)	Number of observations	Power[a]	Df
Albertazzi, Da Pos, *et al.* (2013)	1	60	12 geometric shapes	40 hue NCS colour wheel	.136/ .135[bc]	.091 / .000[c]	727 / 1440[c]	.599	77

Albertazzi, Malfatti, Canal, & Micciolo (2015)	1	56	6 angles: 22.5°, 45°, 90°, 135°, 157.5°, 180°	40 hue NCS colour wheel	Black background: .399[d]	N/A	360	.829	195
					White background: .420[d]	N/A	360	.884	195
Campbell (1942)	1	122[e]	12 designs divided into three groups: Rectangular, curved, and angular	Black-red, blue-green, blue-yellow, green-red, blue-yellow, green-yellow	Shown colour, choose design: .331[b]	Shown colour, choose design: .000	Shown colour, choose design: 732	1.000	10
					Shown design, choose colour: .507[b]	Shown design, choose colour: .000	Shown design, choose colour: 366	1.000	
N. Chen, Tanaka, Matsuyoshi, & Watanabe (2015a)	1	128	12 geometric shapes	40 hue NCS colour wheel	.121 /.121[bc]	.000 /.000[c]	1518 / 3053[c]	.905	77
N. Chen, Tanaka, Namatame, & Watanabe (2015a)	2	16	Based on 9 of the 12 geometric shapes	40 hue NCS colour wheel	.148[f]	.844	294	.152	56
N. Chen, Tanaka, Namatame, & Watanabe (2016)	1	186	Circle, square, triangle	Red, blue, yellow, green	.482[b]	.000	558	1.000	6
Dadam, Albertazzi, Da Pos, Canal, and Micciolo (2012)	1	60	32 achromatic natural shapes taken from Haeckel's (1904/2004) *Art Forms in Nature*	40 hue NCS colour wheel	.150 [b]	.000	1920	.614	217
Current thesis	Chapter 2, Experiment 2A	31	Circle, square, triangle	Red, blue, yellow	.270	.009	93	.525	4
Current thesis	Chapter 2, Experiment 2B	94	Circle, square, triangle	Red, blue, yellow	.211	.000	282	.822	4

Current thesis	Chapter 2, Experiment 2C	200	Circle, square, triangle	Red, blue, yellow	.169	.000	555	.909	4
Dreksler & Spence (2019)	1	64	58 geometric shapes	36 hues divided into 12 categories	.161	.000	3712	.818	627
Dreksler & Spence (2019)	2	68	16 mandala shapes	36 hues divided into 12 categories	.123	.175	1088	.228	165
Dreksler & Spence (2019)	3	75	12 radial frequency shapes	36 hues divided into 12 categories	.151	.000	900	.352	121
Dumitrescu (2003)	1	686	Circle, square, triangle	Red, blue, yellow	.249[b]	.000	2058	1.000	4
			Hexagon, half hexagon-half circle, half circle, half-square	Orange, green, violet, red, yellow, blue, brown, white, grey, black	.111[b]	.000	2058	.903	18
			Circle, ellipse, triangle, square, pentagon, hexagon	Orange, yellow, green, blue, violet	.331[b]	.000	4118	1.000	25
Kharkhurin (2012)	1	284	Circle, square, triangle	Red, blue, yellow	.177 [b]	.000	852	.993	4
Kharkhurin (2012)	2	60	Circle, square, triangle	Red, blue, yellow, green, white, black	.165[b]	.456	180	.262	10

[a] Power estimates were calculated using G*Power 3.1. Using the '$\chi 2$ Goodness-of-fit tests: Contingency tables', the calculated effect size, .05 alpha value, degrees of freedom, and total sample size were used to calculate the power value. It should be noted though that the number of observations (number of shapes * sample size * number of sessions) as noted in the previous column were used as a measure of sample size. This, strictly-speaking, as discussed in Section 1.2.4.1, is a direct effect of a $\chi 2$ analysis of

cross-tabulation violating the assumption of independence for a $\chi 2$ test. As such, again, these effect size and power analyses need to be taken with a grain of salt and merely as a suggestion that there may well be a meaningful association between colour and shape that is worth studying.

[b] Cramér's V values and related p-values were calculated by using sample sizes and relative frequency tables reported in articles to create estimated frequency data. Non-integers were rounded before the cross-tabulated data was re-analysed in SPSS using a Chi-square analysis.

[c] The first value corresponds to one session of choices for each shape extrapolated from the relative frequency of the two sessions or instances of matches for each shape which were found to not be significantly different from one another. The second value corresponds to two sessions, or instances, of matches for each shape extrapolated from the relative frequency of the two sessions. Only the p-value is affected by this increase in observations.

[d] These Cramér's V values were calculated based on reported Chi-square values using Equation 1. According to Rea and Parker (1992) Cramér's V can be interpreted as a measure of effect size as follows: negligible association (.00<.01), weak association (.10<.20), moderate association (.20>.40), relatively strong association (.40<.60), strong association (.60<.80), and very strong association (.80<1.00).

[e] Due to the high complexity of the different phases of this experiment, and unclear overlap between participants between phases, the analysis of the effect size for this experiment was combined into one large contingency table. This is statistically and experimentally questionable at best and, as such, should be seen as merely a best attempt at extracting an effect size from this experiment.

[f] Based on two sessions and the data reported for 9 of the 12 shapes for which the researchers found consistent colour-shape associations between sessions. Also note that this result is based on a Chi-square test where 81.9% of cells and expected cell counts were below 5. Furthermore, it was not possible to calculate effect sizes for interaction effects since it was unclear what sample size or number of observations would have been appropriate for the denominator.

The shapes and colours that have been most consistently researched, with a clear nod to the historical roots of colour-shape correspondences, have been the Kandinsky shapes and colours. When looking at the residual analyses of the cross-tabulations that were evaluated above in terms of their effect size and power, some clear positive and negative colour-shape associations can be seen for these shapes and colours.

The most replicated binding is the positive association between a triangle and yellow (Albertazzi, Da Pos, *et al.*, 2013; Chapter 2, Experiment 2C; Chen, N., Tanaka,

Matsuyoshi, & Watanabe, 2015a; Chen, N., Tanaka, Namatame, & Watanabe, 2015, 2016; Dumitrescu, 2003; Kharkhurin, 2012), even in experiments that expand the shape and colour stimuli sets beyond the Kandinsky colours and shapes (e.g., Albertazzi, Da Pos, *et al.*, 2013; Dreksler & Spence, 2019, Experiment 1). Notably, no experiment found a negative association between yellow and a triangle. Indeed, the yellow-triangle association is also in line with findings from studies which are more difficult to evaluate statistically due to only incomplete frequency data being reported (Hantzsch, 1935; Welsh, 1974). The only other significant associations found in residual analyses for the triangle are a negative association with blue (Dumitrescu, 2003; Experiments 2A, 2B, and 2C of this thesis).

Circles appear to be positively associated most commonly with red (Albertazzi, Da Pos, *et al.*, 2013; Chen, N., Tanaka, Namatame, & Watanabe, 2015; Chen, N. *et al.*, 2016; Chen, N., Tanaka, Matsuyoshi, & Watanabe, 2015; Dumitrescu, 2003; Dumitrescu, 2011, finds the same trend but did not verify this statistically), and yellow (Albertazzi, Da Pos, *et al.*, 2013; Chen, N., Tanaka, Matsuyoshi, & Watanabe, 2015a; Dumitrescu, 2003, Kharkhurin, 2012). Sometimes circles are also found to have a negative association with the colour blue (Dumitrescu, 2003; Kharkhurin, 2012).

Finally, squares tend to be positively associated with the colour blue (Albertazzi, Da Pos, *et al.*, 2013; Chen, N. *et al.*, 2016; Dumitrescu, 2003, 2011, in the latter paper the same trend is found but is not verified statistically; Experiments 2A, 2B, and 2C of

this thesis; Kharkhurin, 2012;). They are negatively associated with both red (Dumitrescu, 2003, though see Chapter 2) and yellow (Albertazzi, Da Pos, *et al.*, 2013; Dumitrescu, 2003, Experiments 2A, 2B, and 2C of this thesis; Kharkhurin, 2012). For the sake of exhaustiveness, the re-analysis of only one study (Kharkhurin, 2012, Experiment 2), found no significant association between Kandinsky's colours and shapes, thus making a residual analysis inappropriate.

The associations between the Kandinsky colours and shapes are often evaluated as the combinations of colour matches that are created between the three shapes and three colours. In Table 1.3, all studies that report information for the frequency of such Kandinsky combinations are detailed. They were re-analysed separately in Chi-square goodness-of-fit analyses to determine whether the distribution of choices was different from an equal distribution. For all studies considered separately, the combination distribution was significantly different from chance, with effect sizes ranging from weak to very strong associations (Rea & Parker, 1992). Additionally, the distribution of combinations was weakly associated between the studies (χ^2 (35, $N = 1233$) = 232.29, $p < .001$, $V = .194$), suggesting a degree of consistency on Kandinsky colour-shape combination choices across studies, whilst there was also a small and significant effect of study on the frequency of combinations.

Table 1.3. This table is a summary of all studies that report frequency or relative frequency information on what combinations of the Kandinsky shapes and Kandinsky colours are chosen. The effect size, significance of the Chi-square goodness-of-fit test for each separate study, and the calculated power of the specific test is reported. A

Chi-square test of independence was conducted to determine whether the distribution of choices for each combination differs between the studies and the residual analysis is reported by ***bolding*** *percentages if the adjusted residual was 2 or higher, indicating the combination was just chosen more commonly than would be expected by chance, and underlining the adjusted residual if the it -2 or less, indicating that the combination was chosen less often than would be expected by chance. The total signifies the distribution weighted by total frequency across studies.*

	Combination		N. Chen, Tanaka, & Watanabe (2015) - 1	N. Chen, Tanaka, & Watanabe (2015) - 2	Chapter 2 – Experiment 2A	Chapter 2 – Experiment 2B	Chapter 2 – Experiment 2C	Dumitrescu (2003)	Jacobsen (2002)	Jacobsen & Wolsdorff (2007)	Total
1	Kandinsky		**36.8%**	12.5%	**29.0%**	9.8%	**18.6%**	8.7%	5.0%	14.9%	10.80%
2			5.3%	12.5%	9.7%	15.9%	8.2%	**21.4%**	14.0%	2.7%	16.72%
3	Dissident		**36.8%**	**54.2%**	12.9%	26.8%	24.7%	19.0%	15.5%	**50.0%**	22.32%
4			7.9%	16.7%	6.5%	6.1%	9.3%	**19.8%**	7.0%	9.5%	14.61%
5	Association		5.3%	0.0%	35.5%	26.8%	18.6%	20.1%	**46.0%**	21.6%	24.27%
6			7.9%	4.2%	6.5%	14.6%	**20.6%**	11.1%	12.5%	1.4%	11.36%
	Sample size		38	24	31	82	97	686	200	74	1233
	Cramér's *V* / *W*		.86	.88	.68	.47	.36	.29	.82	.99	.31
	Significance		.000	.001	.013	.003	.029	.000	.000	.000	.000
	Power		.99	.95	.85	.93	.79	1.00	1.00	1.00	1.000

When the frequencies are summed across all studies (including Jacobsen's, 2002, re-test), a Chi-square goodness-of-fit analysis finds that the distribution of the chosen

combinations is significantly different from equal (χ^2 (5, $N = 1233$) = 115.67, $p < .001$, $V = .31$). When the data is treated in this way, the association (24.27%) and dissident correspondences (22.32%) are the most commonly chosen across all studies, whilst the Kandinsky correspondences are the least chosen (10.80%). With one exception, namely Dumitrescu (2003), across all studies combining a variety of different cultures and ethnicities in their samples, the most commonly chosen combination is always one of the Kandinsky, dissident, or association correspondences.

Taking into the account both the results discussed in relation to the Kandinsky combinations, as well as the residual analysis of the one-to-one colour-shape associations for the Kandinsky shapes and colours, it appears that: 1) the dissident and association correspondences, and 2) the associations of a square with blue, and of triangles and circles with either red or yellow, are the most likely colour-shape associations when participants are presented with this limited stimuli set. With effect sizes in the weak to moderate range, it appears that similar to grapheme-colour synaesthesia, that despite inter-individual differences, there are certain regularities in terms of how individuals associate shape with colour (cf. Simner *et al.,* 2005).

However, the way most of the studies, with some exceptions (e.g., Experiment 2C in Chapter 2 of this thesis), test the Kandinsky shapes and colours is by using instructions or experimental procedures that prohibit the participants from choosing one colour more than once. As such, this can result in forcing a third choice (e.g., when

participants have strong intuitions for two shapes and as such are simply left with the final colour to assign to the third shape). This is of course interesting, since the square, triangle, and circle are prototypical shapes, which may play a special role in our shape perception and processing as discussed previously in the context of grapheme-colour synaesthesia. Yet it is also important to test colour-shape associations in a context in which participants have the freedom to pick any colour for a shape that is presented in order to get a clearer and less restricted view of colour-shape associations.

Finally, certain studies, detailed in the table found in Appendix 6.4, have introduced some geometric shapes and colours beyond the three Kandinsky shapes and colours in their experimental paradigms. However, limited in number and not as consistent in results as the Kandinsky colour and shape associations, they allow few if any direct conclusions to be drawn about colour-shape associations since they often depend on a researcher's classification of their nature (e.g., having sharp vs. acute angles), rather than being part of a subset of shapes specifically designed to test for the effects of specific shape properties. Nevertheless, it should be considered whether certain shape characteristics predict what colours or kind of colours are chosen for them.

1.2.2.1.2 Do certain shape characteristics predict what colours or colour characteristics are chosen to match them?

Few researchers have tried to create sets of counterbalanced shapes that can be categorically or continuously divided into specific perceptual characteristics that allow

analysis to go beyond the shapes and colours of the 1923 Kandinsky questionnaire and prototypical geometric shape associations. The notion that round versus angular shapes, may be associated with different colours is by no means a recent proposition (Campbell, 1942), but proper analysis of such propositions requires more extensive shape stimuli than are usually tested.

One popular theory has been that the warmth or coldness of the colour chosen for the shape depends on the angles and general angularity of the shape (e.g., Albertazzi, Da Pos, *et al.*, 2013; Albertazzi, Malfatti, *et al.*, 2015; Chen, N., 2015). Using correspondence analysis, Albertazzi, Da Pos, *et al.* (2013) found that both the triangle and circle were warm shapes, whilst the rhombus was located towards the cooler end of the factor the researchers had termed to be indicative of 'warmth'. However, the decision of what factors are indicative of in a correspondence analysis can be difficult and subjective[4] and no systematically varied shape stimuli were used. Additionally, since the most angular and the roundest shapes were found on the warm end of the first factor axis, other experiments must be considered to evaluate the perceptual predictors of colour-shape associations. Albertazzi, Malfatti, *et al.* (2015) homed-in on theory that warmth may be associated with acute angles, whilst more obtuse angles are matched with colder colours. Indeed, this is what was found: acute angles were

[4] It is, in part, for this reason that other statistical analyses are sought out in Chapter 3 that go beyond such multivariate descriptive methodologies as correspondence analysis. Whilst they allow a reduction of dimensionality and simplification of large sets of data, the sometimes difficult act of adding labels to such dimensions as well additional subjectivity in further reading of the visualised data were the main driving force in seeking out other analysis methods later on in the thesis.

positively associated with warm colours and negatively associated with cool colours, whilst the reverse was true for obtuse angles. Overall, they found that the effect size of the association between all of the examined angles and all of the individual colour stimuli was relatively strong (Rea & Parker, 1992). N. Chen (2015) too found that warmer colours, such as red, were associated with circles and ovals, whilst cooler colours like blue were more likely to be associated with shapes like the trapezoid or hexagon.

In two experiments, Malfatti (2014) investigated a set of both line and geometric shapes that varied in pointedness, roundedness, closure, number of intersections, and concavity. This allowed her to test the effect of these shape characteristics, both as geometric categories and as rated perceptually by another group of participants, on the colour choices of individuals. Using repeated measures (RM) ANOVAs, it was found that for line shapes more intersections were associated with redder ($\eta_p^2 = .15$), more saturated colours ($\eta_p^2 = .64$) and that angular (vs. curved) lines were associated with darker ($\eta_p^2 = .33$), redder ($\eta_p^2 = .22$), yellower ($\eta_p^2 = .10$), and more saturated colours ($\eta_p^2 = .17$). Symmetry did not appear to affect colour choice dimensions. For both perceptual and geometric shape ratings, stepwise multiple linear regression models found that shape characteristics accounted for considerable amounts of variance in chosen colour dimensions. Pointedness was associated with increased saturation (36% of variance explained), darkness (66%), redness (30%), and yellowness (10%) for both geometric and perceptual models (the corresponding variance explained, respectively,

for each dimension for perceptual models were: 47%, 70%, 36%, and 14%). For geometric and perceptual models, respectively, closure was associated with increased saturation (37%, 25%) and increased redness (20%, 19%). Notably, the fact pointedness explained considerable variance in darkness in both models is in line with Spector and Maurer's (2011) finding that preliterate toddlers, older children, and adults, associate jagged shapes with black and rounded shapes with white.

For closed shapes, Malfatti (2014, Experiment 5) found, using repeated measures ANOVAs, that symmetry-axes were associated with higher saturation ($\eta_p^2 = .14$) and redness ($\eta_p^2 = .16$). More convex shapes were associated with lighter colours ($\eta_p^2 = .29$). Pointier shapes were associated with more saturated ($\eta_p^2 = .25$) and lighter colours ($\eta_p^2 = .10$). Interaction effects were also found, notably: For closed shapes with no concavities, pointedness was associated with lightness, whilst for shapes with one or more concavity/concavities, pointedness was associated with darkness, as in the previous experiment ($\eta_p^2 = .21$). Like for line shapes, pointedness explained a moderate amount of variance in terms of saturation (30%, 31%) and redness (23%, 24%) in both geometric and perceptual models. However, some differences existed – symmetry, explaining no variance in lined shapes, did appear to explain small amounts of variance in saturation (8%, 6%), lightness (8%, 0%), and redness (8%, 19%) for closed shapes. Complexity also only explained variance in closed shapes, with more complex shapes being associated with darker shapes (23%). This was replicated more recently with a similar set of shape stimuli by Dreksler and Spence (2019), whilst they found the

reverse trend in Experiment 3 with a different kind of shapes, where 36.2% of the variance in lightness was associated with higher complexity. The dimension of yellow/blue was not accounted for in terms of variance by any of the measured shape characteristics for closed shapes (Malfatti, 2014).

The fact that redness was associated with pointedness in both studies (Malfatti, 2014, Experiments 4 and 5), is in line with the findings of Blazhenkova and Kumar (2018), as well as the findings of Experiment 4A and 4B that are reported in Chapter 4. Blazhenkova and Kumar (2018) conducted two experiments involving a forced choice paradigm between pairs of shapes that were matched except on their angularity. They found that the majority of individuals matched according to the prevalent associations of curved shapes with the colour green, and angular shapes with the colour red, regardless of whether the colours were presented as verbal labels (78.3%) or actual coloured sheets of paper (68.9%). The above findings all highlight a reasonably strong effect of shape perceptual characteristics on colour dimensions, with some associations, such as between pointedness/red and pointedness/darkness (for those shapes with concavities), replicating across experiments. Indeed, the association between angularity and redness was also found in Experiment 3D, 4A, and 4B in the current thesis. However, for different stimuli sets and other experiments with the same sets of stimuli, contrary findings have been found as well. For example, Dadam, Albertazzi, Da Pos, Canal, and Micciolo (2012) when using complex natural forms, and Dreksler and Spence (2019, Experiment 1 and 3; Chapter 3, Experiment 3A and 3C) when using

geometric and radial frequency pattern (RF) shapes, found that red was, in fact, associated with roundedness. Perhaps this is not surprising on some level since red is consistently associated with both the circle and the triangle in experiments testing the Kandinsky colours and shapes.

Furthermore, Dreksler and Spence's (2019) findings, further underlined by the expanded results of Chapter 3 of some of the same experiments found in the article, highlight that finding replicable effects for what shape properties predict what colour dimensions can be difficult. In particular, the aim of the set of three experiments reported by Dreksler and Spence (2019) and in Chapter 3 was to test whether replicable effects could be found for shape characteristics (pointedness, symmetry, and complexity) predicting colour dimensions. In particular, it was tested whether trends could be found across three shape stimuli sets that varied quite drastically (geometric shapes, snowflake- shaped mandala forms, and RF shapes). Not only did Dreksler and Spence (2019) find few results that coincided with those of Malfatti (2014) using stepwise multiple linear regressions, even when similar shapes were used (Experiment 1), but often found negligible effect sizes when ANOVAs were conducted. Only Experiment 2, for example, replicated the pointedness/darkness association discussed above. The authors concluded that it may be possible that colour-shape associations at the predictive property level could be somewhat stimuli-dependent, in the sense that different kinds of shape may have different colour-shape associations. This is, to an extent, also highlighted by the differences in findings between line and closed shapes

in the experiments conducted by Malfatti (2014). Another reason for Dreksler and Spence (2019) not finding replicable results in terms of predictive perceptual characteristics could have been the use of an online methodology that did not hold constant the environment in which the stimuli were presented. In Chapter 3 (Experiment 3D), however, even when each individual rates the perceptual characteristics of the colours on their own screen, it remains impressively difficult to find a consistent trend concerning how angularity, symmetry, and complexity, in particular, predict colour properties across a more varied set of stimuli. Indeed, analyses conducted to test the effect of stimuli sets, highlight the fact that these can have a significant effect on chosen colour characteristics (Chapter 3, Experiment 3D).

Future researchers may also want to consider that the association that is triggered by a shape to one of a variety of colours could be affected by not yet investigated stimuli, context, changes in psychological functioning, or mood modulating factors (e.g., Akers *et al.*, 2012; Elliot & Maier, 2014; Schietecat, Lakens, IJsselsteijn, & de Kort, 2018a, 2018b). In sum, though, whilst this area of delving into the shape characteristics rather than focusing on only a few shapes appears to be a fruitful one, it is also one that will require further study before stronger conclusions can be drawn. Indeed, these inconsistencies will be demonstrated and discussed in more depth in Chapter 3. Ultimately, though, at this stage, too few studies exist that have gone beyond classic geometric shapes to determine whether there are higher-order perceptual shape characteristics that predict colour choices, especially across a range of shape stimuli.

1.2.2.1.3 Stability of colour-shape correspondences.

Not many studies have looked at test/re-test reliability for colour-shape correspondences. N. Chen, Tanaka, Namatame, and Watanabe (2015) found a significant interaction between shape, colour, and the two sessions conducted 6 months apart in a relatively small sample of 16 deaf participants. A Chi-square test revealed that for the parallelogram, the cone, and the truncated cone, the colour choices changed significantly between the two sessions. The other 9 shapes showed no significant differences between the two sessions, pointing to, at least, a degree of stability in colour-shape matches for the majority of the shapes. Since the sample size was so small, the study was underpowered, however, meaning that it is not possible to draw strong conclusions about these shapes since it may simply have not been possible to detect small significant differences that may be able to be found in a study with a larger sample.

However, two other studies have considered the test/re-test reliability of colour-shape associations. Jacobsen (2002) found that the contingencies between two sessions remained extremely high with regards to the matched correspondences (V values of between .50 and .62) as well as the type of rationale given to explain the choice ($V =$ .84) when they were re-tested one to twelve months later (average 4.8 months). Those who felt that their colour-shape combinations were stable were also more likely not to change their response.

Albertazzi, Da Pos, *et al.* (2013) also found no significant differences between two sessions spaced 4-6 weeks apart at the group level ($V = .41$, $p = .49$). At the individual level, up to a quarter of the colour choices remained the same across the two sessions (this is more than the 13% that would have been expected if random choices were being made). The concordance between the two sessions also depended on the shape, with the same colour choice being made more often for the circle (48%), triangle, (37%), and square (33%), than for other shapes. Whether prototypicality and ease of generation effects, such as those suggested may play a role in colour-grapheme associations (see Section 1.1.3.1), lead to stronger and more replicable colour-shape associations for shape such as the circle, triangle, and square, has yet to be investigated.

In sum, the limited evidence does speak to a certain degree of temporal stability in an individual's colour-shape choices. Especially for the three Kandinsky shapes there appears to be evidence for reasonable stability over time. However, it should be noted that the confounding factor of memory of past choices cannot be eliminated by any of the studies mentioned above. No study used more than 12 shapes and the study that averaged longer periods used only the three Kandinsky shapes, again making it more likely that a participant could have potentially remembered their responses. As such, studies with large numbers of shapes as well colours, especially less memorable, less prototypical ones, that introduce longer periods between test/re-test sessions and hold constant the context of the experiment (cf. Schietecat *et al.*, 2018a, 2018b) will be needed to truly determine the temporal stability of colour-shape associations.

1.2.2.1.4 Colour-shape correspondences: Mechanisms and individual differences.

1.2.2.1.4.1 Object knowledge.

Learned or colour-shape associations that people have for specific prototypical objects brought to mind by shapes are one potential causal origin for colour-shape correspondences. Jacobsen (2002) highlights the importance of object-associations when discussing colour-shape correspondences. He notes that participants' often made reference to their real-world experience in their rationale, with 56% of individuals who had chosen the association correspondences referencing both a traffic sign/warning sign being triangular and the sun in their rationale. Indeed, when his instruction did not ask individuals to choose the most aesthetic match, but rather just to match colours and shapes, this specific object-related rationale was twice as common.

In Kharkhurin's (2012) study too, 90.2% of participants noted in their explanation for their choices, what the authors describe as, a pragmatic association (such as the yellow being chosen for the circle because it looks like the sun). A much smaller percentage noted something about the visual or felt properties of the stimuli (such as a circle feeling yellow, 9.8%). It is unclear, however, whether these were spontaneously elicited responses, or chosen from a list of options. With a much wider stimuli set of abstract open line shapes, Malfatti (2014) found in her doctoral dissertation that 31% of colour choices were reported by participants to have been influenced by shape-object

associations. However, no doubt because it is difficult to truly test whether the wide-range of elicited objects in fact influenced colour choices, object-shape questionnaire elicit responses were not analysed any further in the study.

Experiments 2A and 2B (Chapter 2) probed what rationales people offered for their matches on a Kandinsky shape and colour questionnaire, what object-colour associations they had for all shapes, and, in turn, whether they felt this affected their responses. Whilst object-related rationales were most common across the two experiments, reference to emotional and semantic associations as well as choices simply feeling right made up the majority of the other two third of responses. Most individuals felt that the object associations they reported did not affect their colour-shape matches, although, individuals were, for example, more confident of that for the square than the circle. Interestingly, the likelihood that a participant felt that an object association affected their colour-shape match was more than doubled for a circle versus a square or triangle.

There are, of course, issues with exploring object-associations as a causal mechanism. First of all, an individual may not be aware if an object association affects them at a subconscious level, or, specifically, which particular one. Second, whilst Jacobsen (2002) found very consistent colour-object matches, Experiment 2A in Chapter 2 finds that even when individuals agreed on an object that a shape reminded them of (e.g., a ball), the colour associations were often not consistent (since, of course, often objects

can have many colours, and even several stereotypical colours). Other times, associations were as previous researchers have suggested – 12 out of 13 of the participants who mentioned the sun associated it with yellow in Experiment 2A. Across the triangle, circle, and square, 31 participants came up with 40-57 objects, which could be further divided into several categories. The most common associations were not always obvious: only 6 of 31 individuals, for example, associated triangles with road signs, which are often mentioned as explanations for Kandinsky shape and colour associations.

Thus, simply chalking up colour-shape correspondences to object associations in a simplistic, and often post-hoc manner, feels like a hasty and simplistic conclusion for a phenomenon that is likely to have other causal influences. Indeed, even if difficult to investigate, it may be that more large-scale and systematic studies of object-colour associations will need to be conducted to determine the role of object associations (cf. Palmer & Schloss, 2010).

1.2.2.1.4.2 Cultural influences.

Cultural influences remain largely unexplored in relation to colour-shape correspondences. However, they were assumed to be highly influential by the first researcher who picked up the topic of colour-shape correspondences in this century (Jacobsen, 2002). Indeed, they have been found to be a modulating factor in other

crossmodal correspondence research (e.g., Bremner *et al.*, 2013; Chen, Y.-C., Huang, Woods, & Spence, 2016). Jacobsen (2002) underlines that:

> A framework of factors influencing colour-form assignments can be assumed, reflecting cultural and subcultural relativity. It consists of historical and cultural change, individual education and experience, fashion, and the presence and strength of individual, group-specific, and societal motifs. It is argued that the contemporary peculiarity of these factors led to the present results. (p. 912)

If this is true, culture investigated properly and with nuance, presents a complex undertaking for the colour-shape correspondence researcher that goes far beyond simple object-related associations.

For the few studies that do make mention of it in the context of colour-shape correspondences, culture is often used straightforwardly as a post hoc object-related explanation, especially for the prevalence of the dissident correspondences in Japanese samples due to the motif of the Japanese flag. However, N. Chen, Tanaka, and Watanabe (2015) found that when comparing their study with Japanese participants, to a study conducted with Italian participants using the same shapes and colours (Albertazzi, Da Pos, *et al.*, 2013), there was no significant interaction ($p = .58$) between study, shape, and colour choices once they adjusted for sample size differences between the studies. The effect size of the association could not be calculated with certainty but assuming the sample size the log-linear analysis was based on was a summation of the two samples, V, or W, is most likely equal to .23. This moderate association reflects

a range of effect sizes that have been found relatively consistently across colour-shape association studies.

To truly determine whether culture has an effect and whether this is mediated through variables such as varying object-related associations or other psychological determinants, will have to be tested by future researchers using larger-scale, cross-cultural studies. Specifically, researchers will have to wrestle with the question of whether variation in colour-shape matches is greater across cultures than within: It may simply be that a considerable amount of non-culturally mediated inter-participant variation in colour choices gives rise to the effect size of colour-shape associations not being stronger. Beyond this, addressing culture in the nuanced way set out by Jacobsen (2002) would be a complex undertaking but highlights how considering culture as a simple category is a superficial way of introducing a modulating variable that likely skims over the fine-grained influences any psychological phenomena are likely to have. Indeed, in Chapter 3's Experiment 3D, the factors of nationality and the country someone has grown up in do not improve models that try to account for chosen colour characteristics beyond those with only angularity, symmetry, and complexity entered as predictors. The fundamental notion of treating an entire culture of individuals as a monolith to be compared to another monolith, seems fundamentally wrong-headed considering there are ample individual differences even within cultures that also need to be taken into account that could be just as important (see, for example, Henrich, 2014; Talhelm *et al.*, 2014), and, additionally, may cross cultures. Simplistic 'culture'

explanations will be one potential modulator for colour-shape correspondences but are unlikely to be the nuanced or complex answer needed to determine differences between studies and individuals in terms of colour-shape matching responses.

1.2.2.1.4.3 Age and gender.

Most studies do not report statistical results for differences in age or gender. One of the few that do, Jacobsen and Wolsdorff's (2007) study, did not find any significant differences in frequencies of choices for the full combination of possible colour-shape choices for gender ($p > .05$, calculated by current author: $V = .213$), nor age group ($p > .05$, calculated by the current author: $V = .311$).

Dumitrescu (2003), whilst reporting only percentages, does point to some differences – such as to the circle being more commonly associated with red for women, and more often with blue for men. By using the reported percentages in the article, a more in-depth analysis of the data could be made. For the Kandinsky combinations a full-contingency table analysis revealed no significant relationship between combination choice and gender ($V = .063$, $p = .744$). Looking at each combination one-by-one (Combinations 1 ($V = .030$, $p = .439$), 2 ($V = .063$, $p = .100$), 3 ($V = .003$, $p = .930$), 4 ($V = .039$, $p = .303$), 5 ($V = .010.$ $p = .798$), 6 ($V = .035$, $p = .359$), there is no evidence for a difference in choices when the associations between the combinations of Kandinsky shapes and colours are examined. When looking at the circle as a separate Chi-square analysis, there is indeed a significant difference between choices for the

circle between genders ($V = .112$, $p = .013$), with an inspection of the adjusted residuals showing that women were more likely to choose red for the circle and less likely to choose blue, with the reverse effect being seen for men. No such significant differences in colour choices (both V values were below .1) were found for the triangle and square.

The effect for the circle, Dumitrescu (2003) suggested, could be driven by a higher incidence of red/green colour blindness in men (there is an 8% male prevalence versus .4% female prevalence of red-green colour-blindness in European Caucasians, and 4-6.5% versus .7-1.7% in Asians, for example; Birch, 2012). Alternatively, it may that there are culturally instilled gender preferences for specific colours that are driving this difference in association. However, since the effect is not found for the other two shapes, it would seem that neither explanation appears adequate. Another possibility could be that men and women simply have different object-related colour associations for circular shapes. Further experiments will be needed in order to make any judgments as to whether gender effects exist, although initial evidence highlights that shape-by-shape analyses are more likely to uncover differences, rather than looking at the combination of choices across shapes. Gender was not found to be a decisive factor in explaining chosen colour characteristics in Experiment 3D either, except to some degree, yellow/blue and lightness. Some of these effects were driven by initial differences in how genders rated colours to begin with, but some interactions with how shape characteristics interacted with gender were also found (see Section 3.3.1.5).

1.2.2.1.5 Semantic and emotional mediation of colour-shape associations.

It is the evidence for affective and semantic mechanisms – such as valence judgments but also more conceptual associations – that could underlie colour-shape correspondences that will be evaluated in this section. The technique and terms used to evaluate the semantic and emotional space derive from the semantic differential technique developed by Osgood (1952; Osgood *et al.,* 1957). This technique is commonly used in the field of crossmodal correspondences research, including those correspondences involving colour or shape, to test the emotional mediation hypothesis (e.g., Gilbert, Fridlund, & Lucchina, 2016; Palmer, Schloss, Xu, & Prado-León, 2013; Salgado-Montejo, 2018; Schifferstein & Tanudjaja, 2004). Put simply, the question the emotional mediation hypothesis attempts to answer is this: is there a correlation between the hedonic or semantic appraisals individuals make for a shape and the appraisals of the colour they choose to best match that shape? The argument follows that if this is the case, the cross-activation of similar locations on such emotional and semantic dimension scales contributes to intramodal and crossmodal correspondences (Karwoski, Odbert, & Osgood, 1942; Walker, P., 2012a).

Emotions are notoriously difficult to conceptualize and throw-up various measurement issues (Frijda, 2009; Mulligan & Scherer, 2012; Scherer, 2005). Furthermore, it can be difficult to conceptually differentiate between the dimensions that are tested.

Generally, they seem to fall into two groups in colour-shape correspondence research: one which makes a semantic reference to a perceptual quality, such as warmth (cold/warm), complexity (simple/complex), and roughness (smooth/rough). The other group is a difficult-to-separate mix of affective and semantic polar dimensions of qualities such as liking, arousal, anger, agitation, harmfulness, happiness, strength, and beauty. Under Osgood's semantic differential model, such varied affective appraisals could be captured by the overarching dimensions of evaluation, activity, and potency (Osgood *et al.*, 1957).

Looking at semantic mediation based on perceptual concepts, N. Chen, Tanaka, Matsuyoshi, and Watanabe (2015a, Experiment 2), found that choice frequency of certain warm colours, such as red or yellow/red, was positively associated with the warmth ratings of the shapes that these colours were chosen for. Conversely, for shapes with colder warmth ratings, colder colours, such as blue, green, and green/yellow, were chosen more frequently. This was replicated in Experiment 2B in Chapter 2, finding that similarities in ratings on the cold/warm dimension for colours and shapes mediated colour choices (cold/warm; $r(280) = .23$, $p < .001$), but was not replicated in Experiment 2A. Pointedness ratings (rounded/pointed; $r(88) = .45$, $p < .001$, $r(280) = .25$, $p < .001$), however, consistently mediated colour-shape matches in Experiments 2A and 2B.

Malfatti (2014) has most extensively explored the potential emotional mediation of colour-shape associations with a wide-range of colour and shape stimuli as well as semantic and affective dimensions. In her experiment with line shapes, large, significant correlations were found between the emotional associations of shapes and colours chosen to best match them, although this was not the case for happiness: agitation (r = .81), angriness (r = .82), activity (r = .72), strength (r = .84), harmfulness (r = .84), and preference (r = .58). For closed shapes too, large significant correlations between shape and chosen colour ratings were found: agitation (r = .63), angriness (r = .62), activity (r = .46), strength (r = .48), harmfulness (r = .68), and happiness (r = .59). Work by the current author for both the Kandinsky shapes and colours, and three sets of varied shape stimuli, verified that the liking and arousal ratings of shapes were consistently correlated with the liking and arousal ratings of the colours chosen to best match those shapes (Chapter 2, Experiment 2A, 2B; Chapter 3, Experiment 3A, 3B; Dreksler & Spence, 2019).

Further still, Malfatti's (2014) use of multiple stepwise linear regressions highlights the strong effect size of this emotional mediation: For line shapes, 72% of the variance in colour saturation could be explained by shape strength (positive association) and 67% of variance in lightness could be explained by shape angriness (negative association) and activity (positive association). Additionally, 49% of the variance in redness could be explained by shape strength (positive association) and 16% of the variance in yellowness could be explained by shape strength (positive association). For closed

shapes too, considerable variance was explained by affective appraisals: 59% of the variance in colour saturation could be explained by shape activity (positive association) and happiness (positive association), 53% of variance in lightness could be explained by shape happiness (positive association) and strength (negative association), and 39% of the variance in redness could be explained by shape strength (positive association) and activity (negative association). However, no variance in yellowness was explained by emotional shape dimensions.

However, when Malfatti (2014) first accounted for perceptual models (shape characteristics such as symmetry, complexity, and pointedness), emotional models only accounted for additional variance in the case of saturation (happiness – 12%, strength – 10%) for line shapes. For closed shapes, only happiness accounted for additional variance in the case of saturation (20%) and lightness (20%). In-and-of itself, this does not speak against emotional mediation explanations of colour-shape correspondences. Indeed, this effect is to be expected: geometric, perceptual, and emotional dimensions were found to have strong inter-correlations by Malfatti (2014). For line shapes, for example, pointedness correlated with strength (r = .67), anger (r = .61), harmfulness (r = .60), agitation (r = .55) and closure and intersections correlated with activity (r = .62), agitation (r = .49), harmfulness (r = .49), strength (r = .45), and anger (r = .44). Such correlations were similarly found for closed shapes. This is not unexpected – there is a wealth of research that looks at the affective associations of shapes (e.g., Bertamini, Palumbo, Gheorghes, & Galatsidas, 2016; Collier, 1996; Salgado-Montejo

et al., 2015; Salgado-Montejo, Salgado, Alvarado, & Spence, 2017; Watson, D.G., Blagrove, Evans, & Moore, 2012).

The number of emotional and semantic dimensions one could explore can sometimes feel unwieldy and unending. One attempt to simplify the variable space is the valence approach which considers the influence of approach and avoidance motivations (Krieglmeyer, Deutsch, De Houwer, & De Raedt, 2010) activated by features either signalling pleasure/reward or threat/punishment (e.g., Palumbo, Ruta, & Bertamini, 2015; Velasco, Salgado-Montejo, *et al.*, 2016). Osgood and his colleagues, on the other hand, derived three overarching factors from the numerous semantic differential polar dimensions that they termed activity, potency, and evaluation (Osgood, 1960; Osgood *et al.*, 1957).

For instance, Sakuta and Gyoba (2006) found that shapes and colours which were congruent in their rating direction on the dimensions of activity and potency, were considered to better match one another, whilst the reverse was true for the evaluation dimension. Additionally, as will be seen in the next section on indirect experiments, these semantic appraisals also affected performance on more implicit measures. It should be noted, though, that the fact that evaluation dimensions did not emotionally mediate what colours and shapes were found to best match, is at odds with previous research and the findings of the current thesis (see the results in Chapters 2, 3, and 4; Dreksler & Spence, 2019; Malfatti, 2014). However, it has been suggested that which

polarity dimension is made most salient is context-dependent, thus making task a relevant variable that could determine which bipolar affective and concept pairs are most relevant in determining intramodal and crossmodal associations (Schietecat *et al.*, 2018a, 2018b).

Overall, there is much promise in the emotional mediation approach to colour-shape correspondences. Even the strong relationship of emotional dimensions with perceptual characteristics can speak to a complex associative network between affective, semantic, and perceptual shape and colour features that could underlie colour-shape correspondences.

1.2.2.2 Colour-shape correspondences: Indirect experiments.

Whilst, not explicitly conducted within the context of studying the colour-shape correspondences *per se*, P. Walker (2012a, Experiment 4), found that individuals reacted more quickly on a speeded classification task where angularity was irrelevant, when lightness was congruent with angularity (i.e., angular-brighter). This particular association was tested and judged as congruent based on the associations that both high and low pitch have been found to have with a variety of sensory features (e.g., sharp and smooth, hard and soft, bright and dark, respectively; Karwoski *et al.*, 1942). Sensory features thus can activate this network of interconnected connotative meanings, as suggested by the semantic-coding hypothesis (Martino & Marks, 1999,

2001; Walker, P., 2012a; Walker, P. & Smith, 1984), and in turn, result in faster processing of semantically congruent stimuli.

A number of experiments have also used more indirect methods (typically requiring speeded responses) to investigate colour-shape correspondences specifically. They lean not on the transitive sensory and semantic associations that have been found between low and high pitch, as the experiments of P. Walker and L. Walker (e.g., Walker, P., 2012a; Walker, P., & Walker, L., 2012), but rather take the associations found for the Kandinsky shapes and colours as a starting point. That being said, there are indications that similar correlations in connotative meanings may exist for colour and shape (Chen, N., 2015, Experiment 2), that could similarly drive colour-shape associations. The experiments reviewed below offer further insights into what processing level colour-shape correspondences may occur at, and whether they can be considered, in any sense, 'automatic' (see Spence & Deroy, 2013a, for a review). Whilst higher-level conceptual or object-related knowledge can, of course, affect responses on such tests as well in a downstream manner, they do at the very least reduce the influence of semantic verbal labels and potential meta-cognitive consensus effects on colour-shape associations. Full details of the studies including sample size, presentation, controls, and main findings can be found in Appendix 6.4 as an additional resource, allowing a focus here instead on the major pitfalls and generalizable conclusions across the studies.

1.2.2.2.1 IAT experiments.

IAT experiments have focused on investigating the colour-shape associations between a triangle, square, and circle with the colours red, blue, and yellow, like the original stimuli set used in the 1923 Kandinsky questionnaire. Experiments have only been conducted to explore the Kandinsky and dissident correspondences, which, in turn, also involve testing for the colour-reverse of each of the three pairs that can be made from the three coloured-shapes found in each of these correspondences (see Table 1.4). This does not cover all possible combinations of the colour-shape matrix of the three colours and three shapes. Especially some association correspondences pairs have not appeared in the IAT experiments conducted to date (for example, red triangle – with a blue square or circle is never tested, nor the yellow circle with a blue square). Additionally, whilst the presented stimuli that are to be sorted are actual instances of the shape or colour in question, all experiments to date have used verbal labels to train and remind participants at the top of the page of the categories associated with 'left' and 'right' responses. This makes it more difficult to evaluate whether such effects occur at the sensory and perceptual level, or rather are indicative of associations originating in higher-level processes such as judgments, memory, response biases, or meta-cognition (see Firestone & Scholl, 2014, 2016).

Table 1.4. Colour pairs tested in IAT paradigms discussed in this section.

	KANDINSKY CORRESPONDENCES		DISSIDENT CORRESPONDENCES	
	Kandinsky correspondences pairs	Colour-reversed Kandinsky correspondences pairs	Dissident correspondences pairs	Colour-reversed dissident correspondences pairs
1				
2				
3				

The four experiments that have been conducted all occurred in rooms with controlled lighting conditions that ensured that the hue and luminance of presented colours were constant. Additionally, the experiments were conducted in line with the recommendations of Nosek, Greenwald, and Banaji's (2007) conceptual and methodological review of IAT procedures, and the later studies were procedural replications of Makin and Wuerger's (2013) original study. In regard to the Kandinsky correspondences pairs, two studies have tested the above pairs and their colour-reversed opposites. Makin and Wuerger (2013) found that the mean *D* scores for Kandinsky pairs in rows 1 and 2 of Table 1.4 were not significantly different from zero (both being small indicators of effect size, mean *D* scores were -.08 and -.04, respectively). This was also reflected in there being no significant differences in RTs between congruent and incongruent blocks for the aforementioned pairs. For row three

of the Kandinsky and colour-reversed Kandinsky pairs in Table 1.4, minimal effects for the Kandinsky congruent pairs being responded to faster and more accurately were found (mean *D* score = .13). The authors suggest, however, this effect would disappear if they corrected for multiple comparisons, and indeed are remarkably low in comparison to other IAT scores in the field of aesthetic science which are considered to be meaningful results.

Makin and Wuerger (2013) argue that because their sample size is larger than those used in other IAT experiments in the field, and yet even the largest mean *D* score in their experiment (.13) lies considerably below other values in the field[5], their null results cannot be based on an underpowered experimental study. Whilst it cannot be verified based on the data available in the article, it seems prudent to remember that if colour-shape associations as measured by the IAT simply have a minimally meaningful effect in terms of size, it would, in fact, require a *much larger* (most likely more than 36 participants) sample size to increase power to .8. This is crucial in order to avoid Type II errors and for making reliable significance judgments (Sullivan & Feinn, 2012). As such making comparison to phenomena with larger effect sizes does not immediately justify the power of the experiment at hand.

[5] Mean *D* scores of around .50 are found for implicit preferences for symmetry versus randomness (Makin, Pecchinenda, & Bertamini, 2012) and scores between .2-.4 for a study looking at semantic associations and car brands (Gattol, Sääksjärvi, & Carbon, 2011).

Nevertheless, the fact that the procedure inherently exposed individuals to Kandinsky congruent pairs more often across the different IAT blocks, should have biased individuals towards making implicit congruent judgments. However, this was not found in any convincing manner, at least when reflecting on the mean *D* scores presented. This speaks against the strength of the Kandinsky correspondences. The fact that increased exposure to certain pairs can have an effect on *explicit* matching behaviour though is highlighted by the two experiments conducted by N. Chen, Tanaka, and Watanabe (2015). The authors replicated Makin and Wuerger's (2013) experiment in their Experiment 1 and replicated it for the dissident correspondences and their colour-reversed pairs in Experiment 2. In both cases, the most commonly chosen combinations on the explicit matching questionnaire differed based on the IAT that preceded it: when it was the Kandinsky version, both the Kandinsky and dissident correspondences were chosen most often by participants (36.8% each). After the dissident version, over half of participants chose the dissident correspondences (54.2%) and only 12.5% now chose the Kandinsky correspondences (see Table 1.3 for further information on the effect sizes of these differences). This speaks to the possibility of a rapidly adapting mechanism of statistical association that can affect colour-shape and other correspondences, at least in the short-term. These have been shown to exist across various senses and multisensory processes (Fiebelkorn, Foxe, & Molholm, 2010; Seitz, Kim, Van Wassenhove, & Shams, 2007; Wozny & Shams, 2011).

In their first experiment of a comparable sample size ($N = 38$), N. Chen, Tanaka, and Watanabe (2015) replicated Makin and Wuerger's (2013) study on the Kandinsky correspondences. For row one pairs (Table 1.4), they found a very low D score (.06) that was not significantly different from zero. For row two pairs, the moderately-sized D score (-.26), indicated an association opposite to the Kandinsky pair, and instead favoured the colour-reversed pair, which forms part of the dissident correspondences. For row three, the moderately-sized D score (.38) showed an association that was congruent with the Kandinsky correspondences. In N. Chen, Tanaka, and Watanabe's (2015) second experiment, with 24 participants exploring the dissident correspondences, all three IATs represented by the three rows in Table 1.4, showed moderately-sized D scores (.31–.35) and significantly faster RTs for dissident correspondences congruent blocks. These findings indicated that the participants exhibited an implicit association between red-circle, blue-square, and yellow-triangle.

When N. Chen *et al.* (2016) replicated this second experiment with deaf participants, the significant effect disappeared (although mean D scores varied between .06 and .21). This suggest that the dissident correspondences colour-shape associations found support for using an IAT paradigm in hearing Japanese individuals, are not found in the same way in deaf participants using this particular type of experimental paradigm. This is at odds with the congruency that the authors found in the explicit matching between deaf and hearing participants. Since the sample size was very small, the experiment by N. Chen *et al.* (2016) may simply also not have had sufficient power to

detect the differences for the minimal to small mean D score. It is yet unknown if this effect, a difference in implicitly measured colour-shape association between hearing versus deaf individuals, would replicate in larger sample experiments. If it does, however, this would warrant further theoretical consideration in terms of what processing systems may be influencing the associations in the first place.

In sum, IAT tests have their limitations in that they cannot test one-to-one colour-shape associations, and many would have to be conducted in order to cover the colour-shape option matrix that even the restricted three shapes and three colours create. Furthermore, the use of verbal labels for labelled categories, should perhaps be reconsidered by future researchers since it is within the realm of possibility to also conduct IATs with sensory stimuli instead of verbal labels (e.g., Demattè, Sanabria, & Spence, 2006, 2007). The IAT results to date do not speak strongly in favour of the Kandinsky correspondences, or rather, speak against them. It would be hasty to make judgments on the dissident correspondences tested using this paradigm based on the one experiment that has found positive results, even if non-negligible effect sizes were obtained. Nevertheless, experiments on Japanese participants conducted by the same research group found further consistent evidence for the dissident correspondences having an effect on implicit outcomes measures, which will be discussed below. As such, with limited evidence of which associations are actually exhibited using this implicit paradigm, it at least shows that it is possible to test for colour-shape associations in a way that does not involve an explicit matching task.

1.2.2.2.2 Visual search and feature binding.

Illusory conjunctions and visual search behaviour offer insights into how features are processed, associated, and integrated in our cognitive architecture and the nature of our feature locations in our visual feature maps (see Quinlan, 2003, for a review). Illusory conjunctions refer to the incorrect combining of features from two separate stimuli that can occur when attention is diverted or overloaded (Treisman & Schmidt, 1982). More broadly, such paradigms have been used to address the question of whether synaesthetic-bindings can be processed pre-attentively (Palmeri, Blake, Marois, Flanery, & Whetsell, 2002; Ramachandran & Hubbard, 2001a; Rich & Karstoft, 2013; Rothen & Meier, 2009; Sagiv, Heer, & Robertson, 2006; Smilek, Dixon, Cudahy, & Merikle, 2001; Ward, Jonas, Dienes, & Seth, 2010).

Using tasks where individuals search for stimuli amongst distractors has resulted in mixed results, that Arend and Henik (2017) summarize thus:

> Synaesthetes are overall faster in reporting a target embedded in a cluttered array of distractors when the stimuli are congruent with that of the synaesthetic experience, but there is no evidence of a 'pop out' effect since performance decreases as the set size of the stimuli increases. The fact that synaesthetic stimuli do not 'pop out' suggests that synaesthetic bindings do not constitute pre-attentive binding. (p. 237)

Here 'pop out' refers to the effect seen in visual search tasks, whereby a target item appears to jump out of the display, grabbing an individual's attention (Wolfe, 1994). Pre-attentive binding suggests that features are processed and bound together before

a more effortful, detailed, and attentive search of the visual display is made (for a brief summary of pre-attentive selection, see Zhaoping & Dayan, 2006). More broadly, as Arend and Henik highlight, research in synaesthesia has shown that focused attention is crucial for synaesthetic bindings to occur (e.g., Laeng, Svartdal, & Oelmann, 2004; Mattingley, Rich, Yelland, & Bradshaw, 2001; Mattingley, Payne, & Rich, 2006; Mattingley, 2009; Rich & Mattingley, 2010; Sagiv *et al.*, 2006)

In their own study, Arend and Henik (2017) found that in a number and colour speeded recognition task with diverted attention, illusory conjunctions were more likely to occur for synaesthetes between number-colour combinations that were incongruent with their synaesthetic associations, whilst the same was not true for non-synaesthetic controls. The number of experienced illusory conjunctions on those trials congruent with the synaesthetes' number-colour associations was not different between synaesthetes and controls. According to the authors, the increase in illusory conjunctions for synaesthetes on incongruent trials is suggested by feature integration theory (Treisman & Schmidt, 1982). As such, illusory conjunctions may occur because the incongruent stimuli co-activate two separate feature maps, with both spatial locations containing a feature that activates the synaesthetic association, which influences the increase in illusory conjunctions in a top-down manner.

Whilst this was a very small sample study, it does raise the question whether a similar effect could be replicated for colour-shape associations. Using a procedure from Arend,

Naparstek, and Henik (2013), N. Chen and Watanabe (submitted, Experiment 1) attempted to investigate this illusory conjunction effect in a sample of Japanese participants which they argue have a consistent colour-shape association in line with the dissident correspondences. Overall, they found, with large effect sizes, that participants made more illusory conjunction errors in incongruent conditions than congruent conditions ($d = 1.06$), much like the synaesthetic participants in Arend and Henik's (2017) study. Additionally, participants made significantly more hits (correct colour responses) in congruent versus incongruent trials ($d = 1.02$).

In a second visual search experiment (Chen, N. & Watanabe, submitted, Experiment 2), also with Japanese participants, visual search was faster for a target among distractors that were congruent with the dissident correspondences, with the search slope being significantly larger with a moderate effect size for incongruent distractors ($d = .35$, $\eta_p^2 = .11$). However, the effect on RTs was found to be minimal and only to be present for target absent trials ($\eta_p^2 = .05$) and large distractor set sizes of 16 items ($\eta_p^2 = .06$). As such, this set of studies offers support, even if sometimes not with a considerable effect size, for the fact that colour-shape associations could act similarly to synaesthetic bindings in terms of feature binding. This effect on feature integration could occur in a top-down manner from existing colour-shape correspondences, and, additionally, as N. Chen and Watanabe (submitted) point out, there is evidence that higher-level semantic associations can modulate lower level feature binding and even eye-movements in a top-down manner (e.g., Belke, Humphrey, Watson, Meyer, &

Telling, 2008; Hwang, Wang, & Pomplun, 2011; Moores, Laiti, & Chelazzi, 2003; see also Gilbert & Li, 2013, for a review concerning how top-down influences affect visual cortical pathways).

1.2.2.2.3 Go/no-go tasks.

Again, capitalizing on the assumed strong association in Japanese participants of the dissident correspondences, N. Chen, Matsuyoshi, and Watanabe (submitted), conducted two studies using a go/no-go tasks. They tested whether when the target colour or shape (e.g., circle) was presented either as a verbal label (Experiment 1) or spoken verbal label (Experiment 2), RTs to 'go' and 'no-go' trials differed when the coloured shape that was presented belonged to the dissident correspondences (e.g., a red circle, congruent trial) or did not (e.g., a blue circle, incongruent trial). Across both studies, no significant differences in error rates were found on 'go' trials between the congruent and incongruent trials. In both experiments, colour and shape targets showed moderate to strong effect sizes for RTs being faster for those conditions congruent (vs. incongruent) with the dissident correspondences.

Looking at specific colour-shape associations, in both experiments, a circle target improved recognition for red and vice versa and a yellow target improved recognition efficiency for a triangle but not vice versa. There were, however, no improvements in recognition efficiency for blue or square. Finally, whether the target colour or shape was presented as a visual word or spoken word had no effect on recognition efficiency

(η_p^2 = .017, p = .33), nor did task interact with condition (η_p^2 = .001, p = .84). In essence, the paradigm elegantly tests whether the semantic activation of a specific colour or shape category biases downstream feature recognition depending on whether the presented shape combines features that belong to the same postulated feature map of colour-shape associations or does not, which, in turn, would, arguably make it more difficult to process.

1.2.2.2.4 Speeded recognition tests.

Other experiments have used speeded recognition tests to explore colour-shape correspondences, specifically the Kandinsky correspondences. In a series of two experiments conducted by Kharkhurin (2012), the participants were required to make a speeded response to whether they recognized the target shape (or colour, Experiment 2) in the presented stimulus. In Experiment 1, the shape to be evaluated was shown after a 1000ms coloured screen was presented as a colour prime to see if this resulted in Kandinsky correspondence-congruent shapes being recognized faster and more accurately. Neither experiment showed significant differences in RT or accuracy between Kandinsky congruent and incongruent pairs and the calculated effect sizes were negligible. Unfortunately, Kharkhurin (2012), as far as can interpreted from the article, only reports on results that compare Kandinsky congruent versus all other possible pairs. Since, as seen above, the Kandinsky correspondences are not necessarily held by all individuals, or predominately across individuals, especially not the

blue/circle association, the two studies do little except speak against evidence of the Kandinsky correspondences when tested using speeded recognition tests with and without colour priming. Notably, in Experiment 2, not a single individual chose the Kandinsky correspondences in the explicit questionnaire. It is little surprise then, if the colour-shape binding was not represented in the participants as a strong association, that it did not show any effects in these implicit paradigms.

1.2.2.2.5 Emotional mediation of recognition.

In a task in which the participants had to memorize colour-shape pairs, colour-shape pairs which were congruent on the semantic differential factors of activity and potency, showed significantly higher recognition performance, which appeared to be verified by significance testing and small effect size results (Sakuta & Gyoba, 2006). This is the only indirect experiment to test the effect of the emotional associations between colours and shapes in colour-shape correspondences. Whilst the effect sizes of this experiment may not be large, this is not surprising, since likely other influences aside from shapes' and colours' ratings on these three semantic differential factors, likely contribute causally to their associative binding.

1.2.2.2.6 Evolutionary eye-gaze algorithms.

Using eye-tracking technology and a gaze-driven evolutionary algorithm, Holmes and Zanker (2013) had their participants look for the most pleasing target shape out of a

wheel of choices made up of circles, triangles, and squares presented in seven different colours. When the colour palette was restricted to Kandinsky's three colours, a robust preference was found for the yellow triangle. They found this effect to be disrupted, however, when shapes were presented in the 7 different colours. Some other findings reflect previous evidence for colour-shape correspondences as discussed above. So, for example, when individuals were presented with the three instances of the same shape coloured in red, yellow, or blue, there was a "slight trend" (Holmes & Zanker, 2013, p. 5) for yellow circles to be chosen over blue circles, a strong trend for yellow triangles to be increasingly chosen as red choices decreased, and no consistent trend for squares.

As the authors themselves point out, due to the small sample size, any results should be treated with caution. With a sample size of six participants and no reported or calculable effect sizes, this experiment probably adds little to the evidentiary base of how colours and shapes are associated. Rather it can be seen as indicative of a potential methodology to use in future experiments with larger sample sizes. Such research could point a light at whether crossmodally congruent colour-shape pairs are more pleasant and attention-grabbing, for example, thus leading to implicit approach behaviours.

1.2.2.2.7 Box searches.

A collection of studies that lie at the intersection of grapheme-colour associations and colour-shape-associations that have been conducted with preliterate toddlers (30-36 months), as well as with older children and adults, offer a novel insight that frees us

from any lexically rooted semiotic explanations for colour-shape correspondences. Additionally, they highlight how the associations of graphemes and shapes with colour can be interlinked (Spector & Maurer, 2008, 2011). In these studies, participants are familiarized with the task, before having to choose to search for a stimulus (a letter or shape, presented either visually or verbally) in one side of a box or another. Each side of the box is coloured in a different colour (black, white, red, green, yellow, or blue), which varies through the nine experiments conducted using this paradigm. In a series of experiments, Spector and Maurer (2008, 2011) highlighted that toddlers, who could not identify all of the letters tested, consistently were more likely to search for Xs and Zs in the black coloured side of the box, and for O's and I's in the white side. Additionally, such effects were eliminated when the letters were read out, rather than presented visually.

To test whether such associations may be based on natural biases of associating certain shape characteristics with specific colours, Spector and Maurer (2011, Experiment 4) repeated the experiment with angular and jagged versus rounded shapes, finding that the toddlers searched for angular shapes more commonly in the black side of the box, and for rounded shapes in the white side (Cohen's $d = .84$). This is in line with at least some of the experiments that have tested for the association of roundedness/pointedness with the colour properties of lightness/darkness (Dreksler & Spence, 2019, Experiment 2, although this relationship was not replicated in Experiments 1 and 3 using different shape and colour stimuli in adults; Malfatti, 2014,

Experiment 1 and 2). In the preliterate toddlers, effect sizes for the associations X/Z/jagged shapes – black, I/O/rounded shapes – white, C – yellow, were all large (Spector & Maurer, 2008, 2011), ranging from Cohen's *d* values of .75 to 2.27, and it appears from the testing of other age groups that such associations continue on into adulthood.

Whilst this series of experiments may not have controlled for the colour presentation of the boxes in an ideal way, the otherwise well-designed procedure with suitable controls, lends strong support for the existence of colour-shape associations (separate from lexical categories) and the possibility that certain perceptual characteristics of shapes can affect the colours that individuals choose to associate with them. The mechanism by which such shapes or perceptual characteristics become associated with colour properties is an open question. Spector and Maurer (2011) suggest that valence judgments and/or experience with how shapes interact perceptually with the world could play a role (e.g., jagged shapes are likely to have more shadows than rounded contour shapes). It would be interesting, to investigate with younger infants how early in our perceptual and semantic development associations between black/jagged and white/rounded may occur in order to determine the role conceptual object knowledge or even innate natural biases play in colour-shape associations.

1.2.3 Theoretical groundwork.

1.2.3.1 The cognitive architecture of intramodal and crossmodal correspondences.

Much like the more researched field of crossmodal correspondences, but also grapheme-colour associations in non-synaesthetes, the question of what intramodal correspondences are within our cognitive architecture, how they arise, and what levels of processing they occur at and can influence are crucial questions. Such questions are a challenge to address. Perhaps, one made more difficult in the case of colour-shape correspondences, by the task of untangling a field mired with the type of inconsistent results and individual differences that make quantifiable generalizable conclusions and how they may play out realistically in applied real-world settings a complex problem in its own right.

What the colour-shape correspondence field may need is a stronger theoretical groundwork that can be tested, rather than to remain focused on specifically what colours and shapes may be associated with one another. Wherever one may fall on this latter question, between the evidence presented by direct and indirect experiments, there does appear to be a small to moderate effect size for the association between colour and shape that warrants consideration at a deeper theoretical level.

All studies explored above, whilst usually not even using verbal labels but rather sensory impressions of colours and shapes, are arguably still subject to the

interpretation that semantic categories, object-associations, valence judgments, response biases and other top-down influences are the driving force for the colour-shape associations such studies find evidence for, rather than being truly perceptual effects (Firestone & Scholl, 2014, 2016). This, of course, is neither a condemnation nor technically a criticism either, since even if such effects are not based on sensory effects or innate natural biases, they can nevertheless still exert very real top-down influences on visual cortical pathways (Gilbert & Li, 2013). Even when audiovisual correspondences, often considered to be able to function at the automatic level, are carefully examined, both bottom-up and top-down processing appears to be involved (Getz & Kubovy, 2018; Spence & Deroy, 2013a).

The fact that such top-down influences can still have effects on more implicit measures that are often interpreted as occurring at lower processing levels, is seen most clearly in the evidence reviewed above for a variety of indirect experiments. Such findings should make those using colour-shape stimuli in their experiments take heed and take care when using them without considering potential intra- and inter-individually consistent colour-shape associations. Indeed, such inconsistencies, some of which have been discussed in regard to direct matching experiments above, may make taking them into account more complex, but are not unlike the diversity found in grapheme-colour synaesthesia. As Simner *et al.* (2005) point out about synaesthesia: "Like Day (2001, 2005) and Baron-Cohen *et al.* (1993) we found non-random patterns in the letter–colour associations of synaesthetes, suggesting that their responses, while often wide-

ranging and superficially diverse, are nonetheless structured." (p. 1081) Regardless of whether they are structured, or simple predictions can be found – e.g., pointedness is associated with darkness – the fact that colour-shape associations have minimal to moderate effect sizes mean they warrant further study since they thus may play a meaningful role in our cognitive architecture.

Additionally, such top-down influences could be capitalized on, for example, in ergonomics since, as there is initial evidence that colour-shape associations can affect how we interact with stimuli and the environment at the level of RTs, search behaviour, and processing fluency. If, similar to synaesthetic bindings and feature maps, colour-shape associations can have meaningful effects under conditions of focused attention, it is important to understand the effects that they can have within our cognitive architecture.

1.2.3.2 An integrative theory of colour-shape correspondences.

From our first moments, as we experience the world, we are presented with the co-occurrence of colours and shapes in the form of objects but also more de-lineated experiences (e.g., a colour palette used throughout a cinematic film to go along with a specific mood or aesthetic choice). As this occurs, general statistical learning of colour-shape associations takes place.

1. **Object-mediated learning**: This can take the form of explicit object-colour learning, where one colour may be most strongly associated through enhanced

and frequent exposure or through learning of prototypical, stereotypical depictions (e.g., the sun can be red during a sunset but is likely to be depicted as yellow if you ask children, teenagers, and adults to draw it). Indeed, colour-object knowledge, even appears to be a dissociable process, separate from general colour perception and naming (Miceli *et al.*, 2001).

2. **Perceptual effects**: The colour and luminance features we experience from certain shapes may differ as a function of simple facts of physics. So, for example, Spector and Maurer (2011) contend, jagged shapes may be associated more with shadows, and hence darkness, than more rounded shapes[6] (see Spector & Maurer, 2008, 2011).

3. **Valence and affective experiences**: Valence experiences with colours, shapes, and colour-shape combinations, may be object or contextually mediated, or even the results of natural biases. For example, we may experience danger with red due to warning signals, and it may generally be a colour with potent signalling power for evolutionary reasons (e.g., Elliot & Maier, 2012; Elliot & Niesta, 2008; Feltman & Elliot, 2011; Guéguen, Jacob, Lourel, & Pascual, 2012).

[6] Whether this is in fact the case remains untested, for example, through the use of natural image statistic methdologies.

4. **Conceptual and semantic categorization, associations, and biases**. Beyond the simple emotional appraisal of stimuli, further experience and learning allows us to strengthen the semantic associations between features, their instantiations in object categories, and how they relate to the complex semiotic interpretations that our minds are capable of.

Together these, and potentially other mechanisms, can result in cognitive associations between colour and shapes at the feature, property, and category level. These can be interpreted in at least two ways. According to feature integration theory (Treisman & Gelade, 1980; Quinlan, 2003), associated features may be united by feature maps. These affect the ease and speed with which features can be processed when they are presented in the future, in comparison to when features are presented that are located on incongruent feature maps. Initial evidence for this in the case of colour-shape correspondences has been found by the visual search and illusory conjunction studies by N. Chen and Watanabe (submitted). Complexities in how feature integration occurs in terms of: 1) short and long-term memory; 2) lower-level and object-levels of processing; and 3) interactions between these systems and levels (see Colzato, Raffone, & Hommel, 2006), will need to be considered and guide theories on colour-shape correspondence explanations that attempt to incorporate feature integration theory into theoretical frameworks of how colour and shape associations are activated and could affect attention and visual search behaviour.

Our cognitive architecture can also be considered as a more graded associated network that holds Bayesian priors of the mappings of sensory cues, objects, and further potentially, even affective appraisals and semantic concepts (e.g., Baier, Kleinschmidt, & Müller, 2006). Learning throughout the lifespan can result in the strengthening and weakening of associative nodes between everything from features to concepts. Presented with a triangle then, under the influence of attention, feature analysis can take place, the shape can be recognized, and both these processes may, in turn, activate and propagate through a putative associative network (Parise, 2016). This, in turn, results in it being able to affect higher-level responses such as in a direct matching experiment, but may also, in a top-down manner, affect downstream cortical perceptual processing. It may be likely that prototypical object-mediated associations often win out, being the strongest, most easily generated response. But it is also clear from the studies on the perceptual characteristics that can influence colour choices for shapes that are not easily associated with any object, as well as emotional mediation studies, that the answer to the origins of colour-shape correspondences is likely more varied and complex than a simple object memory explanation. Additionally, colour and shape may differ in their role in semantic object recognition depending on the context and type of object that is brought to mind by the shape or colour (cf. Scorolli & Borgi, 2015).

Perceptual learning paradigms that have, on occasion, been used in a crossmodal setting (e.g., Ernst, 2007; Flanagan, Bittner, & Johansson, 2008) would be one way of

testing the way such associative strengths could be learned and the effect they can have. Additionally, colour-shape associations may realistically, like multisensory features, be useful information in our brain's quest to combine sensory cues in an optimal way (e.g., Fetsch, DeAngelis, & Angelaki, 2013; Trommershäuser, Körding, & Landy, 2011). As such, a theory of colour-shape correspondences would also have to consider and be integrated with work being conducted in the field of sensory cue integration.

1.2.3.2.1 Natural biases and structural influences.

It is not beyond the scope of possibility that certain innate perceptual and affective preferences, appraisals, and expectations are pre-wired in the human infants' brain at least in terms of the available neural structures available to, and influencing, such innate effects (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000; Brocke *et al.*, 2006). As such, the realities of how our brains are structured, connected, and code for specific sensory cues, may affect the likelihood of what associations are strengthened or weakened as statistical information is gathered as well as how they are organized into higher-level constructs (e.g., Makram & Perin, 2011; Perin, Berger, & Makram, 2011). Moreover, the associations we do make as a result of learning are likely to result in neurobiological structural changes in connectiveness between neurons and processing modules (see, for example, Rothen *et al.*, 2018; although of course the most hardened of dualists may disagree with this basic premise). Thus, such

neurobiological changes can, in turn, affect future learning processes as well. Exploring such possibilities will be particularly interesting from a developmental perspective, whilst it is, of course, important to remember that differentiating between innate and learned information can be inherently subtle and complex (Spence & Deroy, 2012).

1.2.3.2.2 Meta-cognition.

Especially in direct matching experiments, any feature integration or associative accounts posited have to contend with the conscious cognitions that arise in participants as they are confronted with the task. An open-minded individual may intuitively feel at ease picking a shape based on what they feel are their conscious affective appraisals of the shape-colour combinations. Others, instead, may respond more in line with what they think is the correct answer, perhaps based on how they think the majority of individuals would respond (Koriat, 1975, 2008). However, this deduction may still rely on similar feature congruencies that determine personal confidence ratings of matches (Chen, Y.-C., Huang, Woods, & Spence, 2019). Additionally, whilst studies that have tested this do not find an effect of instructions (e.g., Jacobsen, 2002), there a number of ways one can ask individual to match colours and shapes. Even if no study has tested extensively the effects of all the different instructions used on colour-shape associations, it is may be a worthwhile factor to consider for future researchers. Appendix 6.6 presents a table of examples of how researchers describe the task in the articles themselves and to the participant. Finally,

to test whether colour-shape correspondences are driven by anything beyond meta-cognition, animal models may offer a fruitful next step for future research. In fact, Premack and Premack (2003, pp. 216-218), noted in passing that monkeys matched round objects with soft and pink things, while pairing angular objects with rough and red qualities (for another example of crossmodal correspondences being documented in animals, see Ludwig, Adachi, & Matzuzawa, 2011; Ravignani & Sonnweber, 2017).

1.2.3.2.3 Conceptual coherence.

Finally, a consideration pointed out by Parise (2016) requires additional reflection – if various components of crossmodal correspondences can be dissociated, it calls into question, or at least requires additional theory building legwork to uphold the notion that a specific correspondence is a unitary phenomenon. If implicit versus explicit paradigms can find dissociable effects, can a specific correspondence, or even intramodal and crossmodal correspondences overall, really be considered a unitary phenomenon or phenomena, respectively. For example, if the plethora of easily generated cognitive associations between sensory dimensions do not show perceptual effects (Parise, 2016), or different perceptual components of a correspondence can be dissociated (e.g., Flanagan *et al.*, 2008), what does this mean for how we conceive of such correspondences? It will take further studies to truly examine the coherence of colour-shape correspondences across levels of processing. However, it is an issue that may very well loom for the field: N. Chen, Matsuyoshi, and Watanabe's (submitted)

study described above, for example, found no implicit effects indicating an association between blue and the square, and yet, as Chapter 2 will show, this is the most consistent and strongest one-to-one association found in the experiments presented in this thesis that use the Kandinsky shapes and colours.

1.2.4 Issues and key considerations for future researchers.

Above, the most pertinent empirical findings and trends in the colour-shape correspondence field over the past century were distilled out, and the beginnings of an integrative theory of how associations between colours and shape can arise and be activated was posited. In this section, the focus will be on critically engaging with the fundamental problems that colour-shape research faces and what the key take-away messages are for future colour-shape researchers.

1.2.4.1 Statistical issues.

Much of the direct-matching research on colour-shape correspondences, including the effect sizes and power analyses calculated above, run into a fundamental statistical issue. It is a statistical issue that the vast majority of direct matching experiments run into as well, since they predominately use Chi-square analyses and log-linear analyses to determine whether there are colour-shape correspondences (exceptions include, e.g., Albertazzi, Da Pos, *et al.*, 2013, for the component analysis; Chen, N., 2015, Experiment 1; Malfatti, 2014, Experiments 4 and 5).

The attentive reader may have already noticed that due to the design of the experiments, each participant contributes not one data point – as statistical tests based on the Chi-square statistic require – but rather as many observations as there are shapes presented to them. Therefore, the assumption of independence of observations is violated for both Chi-square and log linear analyses (McHugh, 2013).

To be clear, as Scheepers (2018) point out in their chapter on log-linear analyses:

> Certain conditions have to be met for log-linear models to be reasonably applied to one's data. First, all considered variables need to be measured at nominal-scale level where each variable has to come in two or more discrete observational categories. Second, all observations should be independent of one another, meaning that each participant or sampling unit should contribute one and only one observation to the data set. This is an important requirement, which also holds for classical Chi-square tests. If your research design involves repeated measurements from the same subjects (such that each participant contributes more than one observation to the data), cross-tabulation tests and log-linear models should not be used. (p .2)

Some researchers, in the form of post-hoc tests performed after these assumption-violated statistical tests, do report Chi-square analyses for each shape separately (e.g., Chen, N., Tanaka, Matsuyoshi, & Watanabe, 2015), which strictly-speaking do not violate the independence assumption since each participant now only contributes to one cell. However, it is not clear whether ignoring the experimental design in this way accounts for the fact that observations may well be correlated within participants.

Additionally, it should be noted that this procedure tests a very different type of distribution of expected observations of colours across the shapes than a test of the full contingency table that may be used to determine an overall association between

colour and shape. When the full contingency table is analysed using a Chi-square or log-linear analysis, the expected values are based on the total number of times each colour was chosen in total, which is then divided evenly across the number of shapes as the expected value to compare the observed value against. If yellow is chosen more commonly across all shapes, and brown rarely is, this affects what the 'chance' expected yellow observations are.

By conducting separate analyses for each shape, one arguably avoids violating the independence assumption. However, one also assumes *prima facie*, that the expectation is that each colour is chosen an equal number of times across all shapes. For example, in the Kandinsky questionnaire context, red, blue, and yellow would be expected to be chosen one third of the time for each shape at chance level. As such, the initial test and post hoc analyses are testing fundamentally different distributions of expected values (for further discussion of this issue in practice, see, Section 3.1.5). At any rate, it would be prudent to be clear about the assumptions one is making under the statistical test one is using, the coherence of the assumption with other statistical analyses that have been conducted, and finally to consider the influence this could have on the study's broader conclusions.

One way to move past this statistical impasse is to turn to continuous measures of either colour, shape, or both, to allow for the wider range of statistical tests developed for continuous data to fall within the arsenal of colour-shape correspondence

researchers (see Chapter 3; Dreksler & Spence, 2019; Malfatti, 2014, Experiments 4 and 5, for examples of this). Additionally, this would avoid researchers having to make the somewhat arbitrary groupings of colours that is necessitated by Chi-square analyses since otherwise too many expected cell counts fall below 5 when a large number of colours is used. This switch to continuous outcomes by no means solves all problems for the colour-shape researcher, as will be discussed below with regard to the complexities of how shape and colour can be classified in continuous ways.

1.2.4.2 The complexities of colour and shape.

1.2.4.2.1 Colour precision.

Whilst efforts have been made in most studies to keep lighting conditions constant (see Appendix 6.4 for instances of the control conditions discussed here on in) it is, of course, crucial to take into consideration aberrations in hue and luminance that can occur within a testing environment. Testing for the exact colour that was seen by participants under the conditions is not usually completed but some also reanalyse their data according to the subjective unique hue categorization of each participant (e.g., Malfatti, 2014; also see Kuehni, 2004). However, neither kind of control is the norm in the field. If such instruments and checks are available to the researchers, it would be prudent to make wider use of them to allow better comparison of stimuli between research groups and experiments. In the author's own studies (see Dreksler & Spence, 2019, and the experiments presented in this thesis), experiments were

conducted using online platforms that introduce uncontrollable colour differences between participants that are unlikely to be fully addressed by strict participant instructions to set up the individual's room in a particular way. It should be noted, though, that online studies have been used to study colour-related synaesthesia (Rothen, Seth, Witzel, & Ward, 2013; Witthoft *et al.*, 2015) and can be especially helpful for future researchers hoping to conduct larger-scale cross-cultural studies of colour-shape correspondences.

Moreover, not all studies use actual tests of colour vision and synaesthesia, but it would probably be advisable, especially now that relatively simple versions are available online ('A new web-based colour vision test', n.d., Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). Whilst failures to fully control for such variables described above may well be one of the sources of the inter-individual variation between participants and samples, it is your author's opinion that they are no reason to not allow comparisons between studies and their results to be made. It is, of course, true that a participant does not see the exact same instance of the specific red chosen in different studies, but we are, arguably, more interested in more graded measures of redness, greenness, blueness, yellowness, and lightness as we move to continuous measures of colour and shape. These allow us to pick out trends in perceptual predictors of colour-shape correspondences, rather than remain singularly focused on one-to-one associations. Additionally, despite this lacking precision of exact colours, certain trends are still found across studies and rise above the minutiae of colour

aberrations (e.g., triangle-yellow[7]). Indeed, colour and shape related crossmodal research has found remarkably consistent mappings despite facing the same confounding problems and using both verbal labels and sensory stimuli across experiments. Naturally, every effort should be made to reduce the variation and uncertainty in what colours are presented to participants, but it is not necessary to throw out the baby with the bathwater at this point in time for colour-shape correspondences. Rather, it is necessary to acknowledge these issues as a potential source of variation and endeavour to reduce their influence in the future.

The research to date is limited on the neural encoding of categorical colour. Nevertheless, it is likely that humans' categorisation of colour into discrete categories occurs at the level of attention and conceptual processing in the frontal lobes, instead of in the visual cortical regions (see Bird, Berens, Horner, & Franklin, 2014). Since colour-shape correspondences are likely to be top-down influences, rather than being sensory effects, as discussed above in Section 1.2.3.1, variations in colour caused by different monitors and lighting conditions, may well have minimal effects providing they do not alter the colour categories individuals would categorize the colour stimuli into. This, of course, would be something that future researchers may want to verify experimentally, especially within the context of varying cultures and languages

[7] Note that, focusing on dimensions of colours allows for the investigation of whether an association between triangle and yellow is driven by an association of yellowness with the triangle (or some other shape), or perhaps, that the lightness of yellow comparison to blue and red, is in fact what is driving the association.

between experimental samples and participants potentially having an effect on colour categorization (Regier & Kay, 2009; Roberson, 2005).

1.2.4.2.2 Dimensions of colour and shape.

Colour-shape correspondence research is made more complex by the many ways colour and shape can be categorized and analysed. In many ways, this is different to some dimensions that have been used more commonly in crossmodal correspondences research (e.g., taste, simple tones, 2D visual position). Colour, for example, could be analysed subjectively and continuously (e.g., have individuals rate colours on various colour dimensions such as hue, lightness, and saturation). That being said, simple tones, can also be analysed on loudness, duration, pitch, or frequency. The properties and polar dimensions of such rating scales are not immediately obvious, however, in the case of colour: For example, some researchers have chosen to have individuals rate colours on an opponent colour rating scale (red-green, e.g., Malfatti, 2014), whilst others have suggested that separating out each colour as a separate scale should also be considered (Dreksler & Spence, 2019). Colour could also be measured subjectively as a categorical variable, where all presented hues are subjectively categorized into unique colour labels by participants before analysis (e.g., Albertazzi, Da Pos, *et al.*, 2013, Experiment 2), which could also take into account individual differences in colour labelling and perception between cultures (Regier, Kay, & Khetarpal, 2007). Another way of measuring colour is in a more objective manner: by classifying them according

to the continuous dimensions of formal colour systems (e.g., CMYK, CIELAB, RGB). In turn, such (mostly) continuous object data could further be turned into categories of colour using cluster analysis (Dreksler & Spence, 2019) or simply, as is done usually now, presented as single hues which are, relatively arbitrarily combined into groups for the sake of statistical analysis.

Shape too can be objectively classified into categorical data by researchers based on how they generated the stimuli and their objective properties (symmetrical vs. asymmetrical) or rated subjectively and phenomenologically (see Albertazzi, 2018) by participants on shape dimensions researchers might posit to be important (e.g., symmetry, complexity, angularity, harmony, and balance). Malfatti (2014) is the only researcher to have published research using both of these types of 'perceptual' and 'geometric' shape models, and differences in the colour-shape associations found when using either type of shape dimensions does differ to some extent. So, for example, Malfatti (2014) found variance in lightness in closed shapes was predicted by geometrically determined symmetry axes (8%), pointedness (11%), and concavities (12%) but was associated only with complexity (23%) when taking into account perceptual measures. Additionally, there may be objective ways to continuously measure shape properties using computer-algorithms, allowing for colour-shape associations to potentially be analysed in the vein of research on the influence of natural scene statistic research (e.g., Parise, Knorre, & Ernst, 2014; also see Spence, 2011 for discussion of how this relates to Bayesian coupling priors). It should be noted

that the size and orientation of shapes have generally not been found to have significant effects on colour-shape associations (e.g., Albertazzi, Da Pos, *et al.*, 2013, Experiment 2). In contrast, in a different stream of research discussed above regarding the semantic-coding hypothesis and indirect experiments, size and brightness have been found to be associated (small-brighter, e.g., Walker, P., & Walker, L., 2012; Walker, P., Walker, L., & Francis, 2015). Additionally, if rotating a shape changes its valence (e.g., rotating a V from upward- to downward-pointing), one might expect that an effect could be found for a particular shape (see Salgado-Montejo, 2018, and discussion of the downward- and upward-pointing V in Section 3.1.3.1).

The breadth of analysable features alongside the indeterminacy on what contradictions between results using different methods would mean for colour-shape associations (e.g., Dreksler & Spence, 2019; Malfatti, 2014) complicates the choice of stimuli and analysis methods for colour-shape correspondence research and is something future researchers need to grapple with. To echo Wassily Kandinsky: "Since the number of forms and colors is infinite, the number of possible combinations is likewise infinite as well as their effects. This material is inexhaustible." (Kandinsky, 1912/1994, p. 163).

1.2.4.3 On the nature of intramodal correspondences.

Whilst the crossmodal correspondences research field has been expanding rapidly, with increased reports of replicable and meaningful effects for various crossmodal associations (Parise & Spence, 2013), it is surprising that there have seemingly been

far fewer reports of intramodal correspondences. In this sense, the correspondences arising from the Kandinsky shapes and colours represent an example of a putatively robust intramodal correspondence, even if closer analysis of the data reveals some individual differences that have yet to be taken into account by potential modulating variables. Closer analysis of recent studies where larger stimuli sets are used (Chapter 3; Dreksler & Spence, 2019; Malfatti, 2014) highlights the questionable nature of intramodal correspondences as a phenomenon that manifests as strongly as crossmodal associations. This difference between intramodal and crossmodal correspondences in terms of inter-individual variation and association strength needs to be tested further and verified. With so few researchers looking for, or exploring, intramodal associations (or at least not publishing their results on them), it will take other intramodal correspondences aside from colour-shape correspondences to be examined in order to make more theoretical and empirical headway on the matter.

Once such additional research has been conducted on intramodal correspondences, it will make it easier to consider why there may be differences in aetiology and nature of intramodal and crossmodal correspondences. However, there are some preliminary reasons as to why differences may exist between intramodal and crossmodal correspondences. For one, sensory noise is more independent between modalities than within a modality, and this may be important as to why crossmodal correspondences are more common and sizable in terms of effect (Hillis, Ernst, Banks, & Landy, 2002; Spence, 2018). Additionally, the fact that colour and form may form conjunctions at

such early stages of perceptual processing, as discussed above, may also affect the nature of this intramodal correspondence, in comparison to a crossmodal correspondence for which this type of early combined representation does not exist. Finally, the spatial aspect of the crossmodal binding problem and the challenge of aligning cues between different senses, also provides a potential justification for why differences between crossmodal and intramodal correspondences may be found. It may be simply be that they are needed to solve such cognitive tasks at the crossmodal level, and are, therefore, needed less intramodally.

1.2.4.4 Individual differences, regularities, and replications.

The systematic review that has been reported in this chapter has found evidence of both regularities and individual differences (or lack of replication of regularities) for different interpretations of colour-shape correspondences. It will be particularly important to balance the issue of individual differences with the question of what the possible meanings of replicability within the context of colour-shape correspondences could be. So, for example, evidence could be found for an association between the broader variables of shape and colour, more specific one-to-one associations, or the same perceptual, affective and semantic mechanisms driving colour-shape associations. Replication, especially for colour-shape correspondences, is not a straightforward question therefore (for relevant discussion also see Stroebe & Strack, 2014). Aside from theoretical rigour, more sophisticated statistical methods that can account for variation between participants when using continuous outcome measures for colour and shape

data, will be useful in the arsenal of the correspondence researcher attempting to wrestle with this particular issue.

1.2.4.5 Tested or potential causes and mechanisms.

It is common in the field of correspondences research to find potential explanations for origins of particular associations. The actual problem, of course, lies in truly finding out why two things may become associated in such a way, and further, testing this in a verifiable manner. Perceptual learning paradigms, natural image statistics, cognitive and computational neuroscience approaches, and an ever-expanding arsenal of implicit tests will need to be used alongside the explicit matching paradigms that have dominated the field in order to allow us to probe the architecture of our mind's potential colour-shape associations. Neurocomputational approaches, for example, have provided a fruitful way of looking at multisensory integration (e.g., Ursino, Cuppini, & Magosso, 2014). Especially on the question of emotional and semantic mediation, it may be prudent to expand beyond explicit ratings of such dimensions. Using physiological (cf. Salgado-Montejo, 2018) and neuroimaging indicators would offer additional verification that such variables are indeed having a causal effect in the origins of colour-shape correspondences. Indeed, even the related field of aesthetics has found neuroscience to provide a fruitful path for understanding aesthetic appreciation at the levels of sensation, motor systems, emotional appraisal, and high-level semantic knowledge (e.g., Chatterjee & Vartanian, 2014; Jacobsen & Höfel, 2003).

Such multi-paradigm approaches will undoubtedly also be helpful in deepening our insight of how colour-shape correspondences may form and be enacted within our cognitive architecture. If colour-shape research expands its use of implicit tests, many of which have been the bread and butter of cognitive neuroscience research, and combines them with neurophysiological data, more progress can be made beyond the explanations currently posited for why intramodal and crossmodal correspondences exist. It is only with such implicit and mixed-model paradigms that proper hypothesis testing of any theoretical and empirical suppositions can be completed to a satisfactory level that allows for falsification (Popper, 1963). Moreover, they allow us to go beyond difficult to test just-so explanations that posit object and culturally mediated influences that are unlikely to offer any certainty on the causal origins of colour-shape correspondences or their instantiations in our cognitive architecture.

1.2.4.6 Colour-shape conjunctions.

As mentioned previously, form and colour are processed as conjunctions and interactively from an early stage of information processing (e.g., Seymour *et al.*, 2009). Most studies present form or colour separately, with few asking, for example, for 'fitness' ratings for coloured shapes. It may be interesting to see what effects different types of colour-form conjunctions (e.g., those which are made up of colours and shapes which are usually found to be more strongly associated) have in both explicit and implicit experiments. Are congruent shapes really always found to have higher fitness ratings as Sakuta and Gyoba (2006) reported for shapes and colours congruent in

semantic evaluations? Could they be found more beautiful? In turn, are different colour-form conjunctions processed more rapidly, and with more ease due to perceptual, affective, and semantic congruence between their features, and could this increase in processing fluency affect liking and aesthetics ratings (Reber, Schwarz, & Winkielman, 2004; Winkielman, Schwarz, Fazendeiro, & Reber, 2003)? Some of these questions will be addressed in Chapter 4.

1.2.4.7 Task order.

Indeed, explicit experimental paradigms can be expanded upon in a variety of ways to offer novel ways of looking at colour-shape correspondences. For example, few (Campbell, 1942; Lindauer, 1973), if any, modern direct matching studies that use up-to-date statistical analyses, have looked at colour-shape correspondences using paradigms that present a colour and require individuals to choose a shape. Proverbio, Burco, del Zotto, and Zani (2004) reported that whilst colour was selected faster than shape, as measured by event-related potentials, colour selection depended on the shape of the object, whilst the reverse effect was not found. This support for object-based attention highlights that paradigms that switch around the task requirements between shape and colour, may result in different results to the current set of experiments explored above. Nevertheless, it should be noted that in the case of the yellow-triangle association, N. Chen, Matsuyoshi, and Watanabe (submitted) found that yellow improved recognition for the triangle, whilst the reverse effect was not found, so it may not always be clear-cut that shape presentation triggers stronger colour-shape

associations. Future experiments using direct paradigms could thus probe whether the stimuli-order task requirements affect what colours and shapes are associated (see Chapter 4, Experiment 4A), whilst indirect experiments could contribute to our understanding of feature and object-based selective attention and recognition in the concurrent processing of colour and shape.

1.2.4.8 Practical recommendations.

A few practical recommendations are offered for researchers based on the findings of the systematic review reported in this chapter:

- Report and interpret effect sizes where possible, alongside statistical significance testing and confidence intervals.
- Where possible, test the actual hue being presented to participants and consider testing for unique subjective hue categorizations of your colour stimuli set. This can take the form of subjective phenomenological ratings from each individual (e.g., for online methodologies), or more stringent spectral analysis in the laboratory setting.
- Consider using well-controlled shape stimuli that go beyond prototypical geometric shapes if testing for the perceptual shape characteristics that could potentially be driving colour-shape associations.

- Test for the power of your studies *a priori* if at all possible, using the average effect sizes found in other studies, such as have been calculated above, or later in this thesis, as a potential guide.
- Consider the assumptions of the statistical tests being used and the implications they make about the distribution of observations that your results are being tested against, as well as the potential correlations within the data (e.g., caused by multiple observations from the same participant).
- Consider the type of language used in the task in terms of how participants should match colours and shapes in order to be able to compare your results to those from other studies.
- Consider that colours, colour categories, subjectively rated colour properties, and objective colour systems all exist and may affect what type of colour-shape correspondences are found to be most common.

1.2.5 Conclusions.

In sum, this systematic review has highlighted the small to moderate effect size of the phenomenon of colour-shape correspondences – there do appear to be associations between colours and shapes at both the explicit and implicit level. Overall, there appear to be sufficient regularities to warrant the study of colour-shape correspondences in the future. However, detailed discussion of specific one-to-one combinations, and perceptual characteristic associations demonstrates that amongst some more replicable associations (e.g., triangle/yellow), there remains much inter-

individual variation that needs to be better understood alongside the more structured regularities that have been documented. Such discussions of individual difference will need to go beyond considering the influence of culture, especially when culture is simplistically conceived of as a monolith, as well as depending on participant reported object-associations. Much work remains to be done in terms of advancing the theoretical foundation of colour-shape correspondences: their causal origins and place in our cognitive architecture. The application of appropriate and more sophisticated statistical methods and the paradigms at both the explicit and implicit level, alongside more nuanced critical reflection on what it means for colours and shapes to be associated, will stand future colour-shape correspondences in good stead for the future challenges in this field of research.

2 Revisiting Kandinsky

2.1 Introduction

Chapter 1 showed that it is difficult to make any strong conclusions on the nature and existence of colour-shape correspondences due to the limited shape stimuli that have been used to date and the often brushed over inconsistencies in what colours and shapes are associated. In this chapter, the historical beginnings of the colour-shape correspondence research field are zeroed in on, by returning to the shapes and colours of Kandinsky's initial questionnaire noted in Chapter 1. They are investigated anew empirically, since even here, the results of previous research have remained variable to some extent and have been hampered by the choice of statistical analyses. The triangle, square, and circle – alongside a vibrant red, yellow, and darker blue – will be the focus of this chapter where the associations between the Kandinsky shapes and Kandinsky colours are revisited.

The three experiments reported in this chapter were designed to elucidate the: 1) nature (*viz.* what shapes and colours are associated); 2) mechanisms underlying; and 3) individual differences in colour-shape matching when the stimuli are limited to the three Kandinsky shapes and three Kandinsky colours. Below the previous research that has been conducted will be explored briefly and the resulting hypotheses for Experiments 2A, 2B, and 2C will be presented. Whilst Experiments 2A and 2B explore

the nature, mechanisms, and individual differences in Kandinsky colour-shape correspondences, Experiment 2C, restricts itself to their nature since it only explores individuals' colour-shape matches.

2.1.1 The nature of Kandinsky colour-shape matches.

First[8], the most common colour-shape matches found in previous research when stimuli are restricted to the three Kandinsky shapes and three Kandinsky colours will be considered. Jacobsen (2002) tested 200 participants, varying the instructions to either be mere matches or to ask participants to choose the colours they would consider to be the most aesthetic match for the shape. A Chi-square test revealed no significant differences in the distributions of assignments under the two types of instructions so Table 2.1 sums the frequency of the colour-shape assignments of both instruction conditions. The most commonly chosen assignments, by far, are the association correspondences (Combination 5, 46.0%). Interestingly, the Kandinsky correspondences were the least commonly chosen (Combination 1, 5.0%), which held true for the re-test of 58 of the participants conducted at a later date.

[8] Since Chapter 1 provided an exhaustive review of the colour-shape correspondence field, the experiments mentioned here have all been discussed previously. They are touched on here mainly to highlight the results in more depth.

Table 2.1 Observed percentage of choices made for each of the six colour-shape combinations in Jacobsen (2002).

Combination		Percentage of choices	Name of correspondence
	1	5.0%	Kandinsky
	2	14.0%	
	3	15.5%	Dissident
	4	7.0%	
	5	46.0%	Association
	6	12.5%	

In a sample of 74 visitors of an art education conference in Germany, participants were asked to assign to a colour to the shapes based on what they found most aesthetically pleasing (Jacobsen & Wolsdorff, 2007). As can be seen in Table 2.2, the most frequently chosen were the dissident correspondences (Combination 3, 50.0%), with the association correspondences (Combination 5, 21.6%), and the Kandinsky correspondences (Combination 1, 14.9%), being the second and third most frequently chosen, respectively.

Table 2.2 Observed percentage of choices made for each of the six colour-shape combinations in Jacobsen and Wolsdorff (2007).

Combination		Percentage of choices	Name of correspondence
	1	14.9%	Kandinsky
	2	2.7%	
	3	50.0%	Dissident
	4	9.5%	
	5	21.6%	Association
	6	1.4%	

N. Chen, Tanaka, and Watanabe (2015) presented Japanese students with an explicit questionnaire that tested the Kandinsky shape and colour associations, after the participants completed an IAT that tested the Kandinsky correspondences (Experiment 1, $N = 38$) and the dissident correspondences (Experiment 2, $N = 24$). Table 2.3 shows the percentage of participants choosing the different colour-shape combinations. When preceded by an IAT that could have primed the Kandinsky correspondences, the Kandinsky (Combination 1, 36.8%) and dissident correspondences (Combination 3, 36.8%) were the most commonly chosen combination. The association correspondences were the least frequently chosen combination in both experiments (Combination 5, 5.3%, and .0%). When the explicit questionnaire was preceded by an IAT testing the dissident correspondences in

Experiment 2, the participants were even more likely to choose the dissident correspondences than in Experiment 1 (Combination 3, 54.2%).

Table 2.3 Observed percentage of choices made for each of the six colour-shape combinations in N. Chen, Tanaka, and Watanabe's (2015) Experiments 1 and 2.

Combination		Experiment 1	Experiment 2	Name of correspondence
	1	36.8%	12.5%	Kandinsky
	2	5.3%	12.5%	
	3	36.8%	54.2%	Dissident
	4	7.9%	16.7%	
	5	5.3%	.0%	Association
	6	7.9%	4.2%	

There are notable differences between the results of Jacobsen (2002), Jacobsen and Wolsdorff (2007), and N. Chen, Tanaka, and Watanabe (2015). The most common combination by far in one experiment, is the least chosen combination in another in more than one instance, across even these very few experiments. Nevertheless, what does seem consistent is that the two most commonly chosen combinations, are always restricted to the Kandinsky, dissident, or association correspondences. As such, it is predicted that:

Hypothesis 2A: Whilst results across the experiments are likely to be mixed, the Kandinsky, association, and dissident correspondences are going to be the most commonly chosen combined colour shape choices across the three experiments[9].

Two further studies examined the Kandinsky shapes and colours but were more limited in terms of the data reported on the combinations that participants chose, and rather reported only the separate colour-shape choices. Dumitrescu (2011) asked participants to rate the appropriateness of different coloured cardboard shapes on a scale of 1 to 5. The percentage of participants choosing '5' is shown in Table 2.4. The blue square stands out as often being rated as the highest level of appropriateness by the participants (40.3%). Red (9.6%) and yellow (9.1%) are rarely chosen as the highest level of appropriateness for the square. For the triangle and circle, the fewest participants rated blue (13.8%, 7.2%) as being a '5' in terms of appropriateness.

[9] It may appear odd to predict variation in results between experiments, yet it is exactly this that the previous research points to that has been reviewed in this thesis. Indeed, the extent of variation in colour-shape correspondences between individuals and samples will be underlined by the findings of Chapter 3.

Table 2.4 Percentage of individuals indicating the highest rating of a '5' in terms of appropriateness of a colour for each of the three shapes in Dumitrescu (2011).

	Colour		
Shape	**Blue**	**Red**	**Yellow**
Circle	7.2%	36.3%	25.7%
Square	40.3%	9.6%	9.1%
Triangle	13.8%	23.9%	17.9%

Kharkhurin (2012) tested 284 students with a modified Kandinsky questionnaire. Since no information is given regarding participants' choices across all three shapes, all that can be determined are the percentage of individuals choosing a colour for each shape separately. The results are shown in Table 2.5. Kharkhurin (2012) states that the only significant preference found was for the blue square based on a Chi-square analysis, although the residuals are not reported. In a second experiment, a further 60 participants were tested but the colours participants could choose from were not limited to the three Kandinsky colours. As such, it is difficult to evaluate the available data in terms of colour-shape preferences for the Kandinsky colours and shapes. However, the author reports that no one indicated a preference for all three shapes that matched the Kandinsky correspondences, nor was there any significant preference for any particular colour-shape combination.

Table 2.5 Percentage of individuals choosing each colour for each shape in Kharkhurin (2012).

	Chosen Colour		
Shape	**Blue**	**Red**	**Yellow**
Circle	26.1%	31.6%	45.2%
Square	42.8%	37.6%	15.7%
Triangle	31.1%	30.8%	39.1%

When taking into account the similarities between the Kandinsky, association, and dissident correspondences in comparison to the less commonly chosen combinations, as well the data from the separate colour-shape associations from Dumitrescu (2011) and Kharkhurin (2012), an additional prediction can be made that:

> **Hypothesis 1b**: Colour-shape matches involving blue triangles and/or yellow squares will be chosen least frequently, whilst colour-shape matches including blue squares will be chosen more frequently.

In terms of the blue square, the prediction also appears to be in line with the results of the experiments conducted by N. Chen and their colleagues (Chen, N. *et al.*, 2014; Chen, N., Tanaka, Matsuyoshi, & Watanabe, 2015a, 2015b) and Albertazzi, Da Pos *et al.* (2013) that extended the stimuli sets beyond the Kandinsky shapes and colours, but still included them (see Appendix 6.4). Squares were positively associated with blue or blue/green in three of these four experiments.

2.1.2 The underlying mechanisms of Kandinsky-colour shape matches.

Colour-shape correspondences are, of course, an example of an intramodal correspondence. Yet it does not seem amiss to look at the mechanisms explored for crossmodal correspondences when evaluating potential explanatory mechanisms for the existence of intramodal correspondences. For one, as discussed in Chapter 1, *a priori*, there is no immediate reason as to why intramodal correspondences should have different potential mechanisms underlying them than crossmodal correspondences, although it may well be the case that differences are eventually found. Colour-shape correspondences are the only intramodal correspondence that have been explored in any great detail (except research relating lightness to intramodal features such as size, lightness, and location; Sunaga, Park, & Spence, 2016; Walker, P., 2012a; Walker, P. & Walker, L., 2012, Walker, P., *et al.*, 2015). Moreover, only Albertazzi, Malfatti, *et al.* (2015) and Malfatti (2014) have explored the underlying mechanisms of colour-shape correspondences. As such, there is little other research to lean on. As was explored in Chapter 1, four main, non-mutually exclusive, explanations have been suggested that could potentially underlie the acquisition and specific associations of crossmodal correspondences: affective, semantic, statistical, and structural (Parise & Spence, 2013; Spence, 2011, 2018).

The first two – affective and semantic – are mechanisms that can be investigated directly in the case of colour-shape correspondences by asking participants to rate the shapes and colours on a range of affective and semantic polar dimensions (e.g., liking,

arousal, threat, harmfulness) using Osgood's semantic differential technique (Osgood *et al.*, 1957). This has become a common way in which to evaluate the semantic and affective mechanisms that could underlie intramodal and crossmodal correspondences (e.g., Palmer, Schloss, & Sammartino, 2013). It should be noted that a linguistic or semantic hypothesis could also claim something more specific: namely, that the stimuli are represented using these semantic labels in our cognitive architecture, as discussed in Chapter 1 (Martino & Marks, 2001; Walker, P., 2012a). The semantic differential technique here probes the association of these stimuli with these polar adjectives but cannot make strong claims on the cognitive representations of the stimuli without further experimentation, for example, using indirect experiments as discussed in Chapter 1.

Malfatti (2014) found, for a more varied set of shape and colour stimuli, that both emotional (e.g., harmfulness, strength, anger) and 'non-emotional' conceptual dimensions (e.g., pleasantness, preference)[10] associated with a shape and the three most consistently chosen and the three most inconsistently chosen colours exhibited large statistically significant correlations (e.g., for closed line shapes, anger, $r = .62$, harmfulness, $r = .68$, activity, $r = .46$, liking, $r = .57$, pleasantness, $r = .57$). Overall, Malfatti (2014) found that individuals tended to choose colours they liked more for

[10] Arguably, though, there is no strict differentiation between these emotional and non-emotional categories that Malfatti (2014) uses, and indeed, preference is considered elsewhere as a variable that falls under emotional mediation (Palmer, Schloss, Xu, & Prado-León, 2013).

shapes they liked more. Aside from liking, individuals matched colours more emotionally congruent in their affective and semantic associations with shapes that also aligned with these emotional and semantic associations. These particular correlations regarding the dimension of liking (or preference), alongside emotional arousal, have been found consistently across crossmodal correspondences involving a variety of senses (e.g., Lau, Schloss, Eagleman, & Palmer, 2011; Palmer, Schloss, Xu, & Prado-León, 2013; Schifferstein & Tanudjaja, 2004; Simner *et al.*, 2005; Velasco, Woods, Deroy, & Spence, 2015; Wang *et al.*, 2016). In line with previous research on crossmodal correspondences and the work of Malfatti (2014) it is predicted that:

> **Hypothesis 2A**: Participants will choose colours they like more for shapes that they like more and colours they find more emotionally arousing for shapes they find more emotionally arousing.

Finally, if, as suggested by Parise (2016, p. 15), correspondences are driven by a "putative associative network of interconnected sensory cues", and, additionally, if one wanted to test whether perceptual characteristics of shapes drive colour-shape matches, it may also make sense to additionally test 'perceptual' polar dimensions (e.g., complexity[11], symmetry, sharpness, warmth, and hardness) in addition to more affective and semantic characteristics. For example, both N. Chen (2015) and Albertazzi, Da Pos, *et al.* (2013) found that correlations between shape and colour

[11] Defining complexity can be exceedingly complex, as noted in Chapter 3, Section 3.1.3.1.2.

warmth ratings were a significant driver of colour-shape matches. As such, it is predicted that:

Hypothesis 2B: Chosen colour and shape warmth ratings will correlate positively.

In sum, then, on the question of underlying mechanisms and associations that drive colour-shape matches, it is predicted more generally that:

Hypothesis 2C: Participants' colour choices will be driven, at least in part, by similarities in ratings on perceptual, emotional, and semantic polar dimensions between the shapes and chosen colours.

The latter two mechanisms – statistical and structural – are more difficult to evaluate. Structural mechanisms would, arguably, have to be evaluated through methods that lie outside of the scope of this behavioural thesis (i.e., neuroimaging techniques would be required). However, implicit paradigms, as those reviewed in Chapter 1, may also give relevant insight here. With regard to statistical explanations for colour-shape correspondences, the ideal method would probably involve using natural scene statistics in order to evaluate what sensory correlations we are exposed to in our natural daily environment. It would be challenging to construct an exhaustive sample of all forms, shapes, and objects individuals are exposed to. It would have to capture the natural scene statistics of how colours and shapes covary across the many types of environment humans are exposed to around the world. Although, it should be noted

that Parise *et al.* (2014) successfully used natural auditory scene statistics to verify the association between elevation and pitch. There is no immediate physical reason (e.g., one dictated by physics, chemistry, or biology) why certain shapes should be associated more with certain colours. Nevertheless, future researchers may well want to test what dimensions of natural scene statistics are correlated with colour characteristics, and, in turn, attempt to relate such factors back to characteristics relevant to shape processing. Of course, the affective and semantic influences on colour-shape correspondences, which have been shown to be crucial both to our preferences of certain stimuli, and how these preferences relate to our crossmodal correspondences, are difficult to capture in this way and would require other methodologies (see Palmer & Schloss, 2010; Saluja & Stevenson, 2018).

The experiments in this chapter probe whether participants associate certain real-world objects with the Kandinsky shapes. In turn, whether these associations align with colour-shape matches and if participants report this as driving their decisions is explored. In Experiment 2A, the participants were directly asked about their real-world associations for the three shapes and if these affected their choices. In both Experiments 2A and 2B, the explanations (including real-world, object-based associations) individuals give for their choices are examined to explore the (conscious) drivers of their colour-shape matches.

Jacobsen (2002, p. 908) reported that 56% of participants who chose the association correspondences, mentioned "*both* the traffic sign/warning triangle and the sun in their rationale", and that when instructions included choosing colour-shape matches that were aesthetically pleasing, that this rationale was less likely amongst those choosing association correspondences (even though total counts for the association correspondences were identical across the two instruction conditions). After being tested 1-12 months later, 59% of those who chose the association correspondences mentioned both warning signals and the sun in their rationale. Unfortunately, no further information is given on the rationale individuals gave for their choices, such as information from those participants who did not choose the association correspondences. In general, the author states that a large percentage of individuals mentioned object knowledge in their rationale, and in a later paper, notes that: "The second half of the participants, who did not pick the most frequently chosen colour-form assignment [the association correspondences], showed considerable individual differences." (Jacobsen & Wolsdorff, 2007, p. 22).

As noted previously, in Kharkhurin's (2012) study, 90.2% of the participants noted in their explanation for their choices, what the authors describe as, a pragmatic association (such as the yellow being chosen for the circle because it looks like the sun), whilst a much smaller percentage noted something about the visual or felt properties of the stimuli (such as a circle 'feeling' yellow to them, 9.8%). With a much wider stimuli set of abstract open line shapes, Malfatti (2014) found that 31% of colour

choices were reported by participants to have been influenced by shape-object associations. In line with these studies, especially those that looked at the Kandinsky shapes, it is expected that:

> **Hypothesis 3**: References to real-world object colour-shape associations will be the most frequent type of explanation given by participants for their colour-shape matches.

One further factor explored in this chapter is whether the mode of presentation of the shapes affects colour choices. Generally, where tested, it appears that shape size and orientation have no effect on colour choices (e.g., Albertazzi, Da Pos, *et al.*, 2013), and, as such, the focus will instead be on the unexplored effect of the location and configuration of the presented shapes in Experiment 2B. In the original Kandinsky questionnaire, the shapes were arranged in a triangular arrangement, with the circle being presented centrally below the triangle to its top left and the square to its top right. Could the location of the shapes and the configuration in which they are presented affect what colour-shape matches are made by participants?

Whilst no study has previously investigated this question with regards to colour-shape correspondences, there is some research that indicates that height or perceptual elevation could be associated with lightness. First, humans have been shown to possess a 'light-from-above' prior, that, whether learned or hardwired, highlights the fact that our perceptual system generally expects light to come from above (although it can be

adapted based on recent experience with a changing, interactive environment, see Adams, Graf & Ernst, 2004). Second, there is an association between lower locations and heaviness, and in turn, darker colours (Deng & Kahn, 2009; Sunaga *et al.*, 2016; Walker, P., 2012a; Walker, P., Francis, & Walker, L., 2010; Van Rompay, Fransen, & Borgelink, 2014). As such, it is predicted that such associations could transfer to colour-shape matches such that:

Hypothesis 4: For shapes presented in the lower centre position in Experiment 2B, darker colours and colours rated as heavier on the light-heavy continuum will be chosen.

2.1.3 The individual differences in Kandinsky-colour shape matches.

As Parise (2016) notes, little work has been conducted in the field of individual differences and how they relate to crossmodal correspondences. Most of the existing research is limited to age, gender, training, and culture in crossmodal work or the differences in responses that participants make (e.g., Bremner *et al.*, 2013; Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2006; Marks, 1989; Walker, R., 1987; also see Wang, 2017 for work on how supertaster status may affect taste-related correspondences).

If personality and non-neurotypical factors are considered, however, little research has been conducted in the field of crossmodal correspondences: Occelli, Esposito, Venuti, Arduino, & Zampini (2013) documented a reduction in the Bouba/Kiki

(Takete/Maluma) crossmodal correspondence association strength in those individuals with autistic traits (cf. Oberman & Ramachandran, 2008). Blazhenkova and Kumar (2018) found that increased emotional processing ability, particularly performance on an emotion recognition test, was associated with making shape correspondence choices that were more like the prevalent trend amongst the sample.

Looking at what would technically be crossmodal correspondences and instances of actual synaesthesia in a large undergraduate sample, Rader and Tellegen (1987) found that absorption (a measure of imaginative involvement from the Multidimensional Personality Questionnaire; Tellegen, 1982) was associated with the degree to which participants reported seeing, thinking of, and feeling colours in response to vowels, tones and musical selections, as well as spontaneous visual-auditory synaesthetic experience. Synaesthesia and synaesthetic experiences were not related to intelligence nor to psychopathology.

Although it is inaccurate to call crossmodal correspondences a weak form of synaesthesia (for a full discussion of this issue, see Deroy & Spence, 2013; cf. Martino & Marks, 2001), synaesthesia is, at the very least, the most related multisensory field concerned with the association between sensory features which has examined personality-related individual differences. Furthermore, as discussed in Chapter 1, synaesthesia for pairings of colours with shapes or graphemes is one of the most common variants (Wagner & Dobkins, 2009; Witthoft *et al.*, 2015). As such, with the

possibility of adding to the literature that looks at how best to delineate synaesthesia and crossmodal correspondences from one another (Parise, 2016), synaesthesia-related individual differences are another starting point for the individual differences research regarding colour-shape correspondences.

The relationship between creativity and colour-shape correspondences were explored in Experiments 2A and 2B. This is in line with both the creative origins of colour-shape correspondences research in Kandinsky's work which popularised the notion of associations between colour and form as well as the various work linking synaesthesia with art and certain aspects of creativity (e.g., Mulvenna, 2012; Mulvenna, Hubbard, Ramachandran, & Pollick, n.d.; Rothen & Meier, 2010; Ward, Thompson-Lake, Ely, & Kaminsky, 2008). Rothen and Meier (2010), for example, found that there was a high prevalence of synaesthesia in art students. Although the relationship between synaesthesia and creativity may be more complex, a number of neurocognitive differences (such as higher cognitive control) may, provided the right environment, lead to enhanced creative thought in synaesthetes (Domino, 1989; Mulvenna, 2012). This chapter aims to find out whether those exhibiting higher creativity may find making colour-shape correspondences more intuitive. In later chapters, the effect of other individual differences, such as differences in interest in the arts, openness or mental imagery, on how participants engage with colour-shape matching tasks is tested. It is predicted that:

Hypothesis 5: Participants who exhibit higher creativity and greater engagement with artistic activities will rate their matches as more intuitive.

Whilst being a purely speculative prediction, with no previous research looking at this relationship, it derives from a number of existing relationships between synaesthesia, creativity, and related concepts. To a certain extent, it rests on the questionable assumption that crossmodal and intramodal correspondences are at least in some ways related to synaesthetic experiences, even if they are distinct phenomena. That is not to say it requires equating the phenomena: as concepts, neurobiologically, or phenomenologically. Rather, it means leaving open the possibility that the crossmodal phenomenon of synaesthesia can be a starting point from which other crossmodal and intramodal associative mechanisms can be explored. One such example is the individual differences perspective in the light of the lack of personality and individual difference research in the crossmodal correspondences field (consider, in comparison, fruitful approaches that look at synaesthesia-correspondences relationships: Simner *et al.*, 2005; Ward, Moore, Thompson-Lake, Salih, & Beck, 2008).

Synaesthesia is associated with engaging more in artistic activities (Ward *et al.*, 2008), higher absorption in terms of imaginative involvement (Rader & Tellegen, 1987) and the neurocognitive capacities needed for creative thought (Mulvenna, 2012). Absorption, for example, in turn, has been found to be associated with openness to

experience, participating in artistic activities, being affected by art emotionally, and valuing art in one's daily life (Wild, Kuiken, & Schopflocher, 1995).

Creativity is associated with openness to experience (Batey, Furnham, & Safiullina, 2010; Furnham, Batey, Anand, & Manfield, 2008), which may predispose people to being more open to engaging with a task that can seem arbitrary to others. Furthermore, Raidl and Lubart (2001) found that creativity when measured by a creative production task involving drawing and a Torrance's Unusual Uses Test was positively associated with how much participants were likely to depend on intuition in hypothetical scenarios as measured by the Intuitive Behaviour Questionnaire (IBQ; Raidl and Lubart, 2001).

Taken together, these intercorrelations between synaesthesia, creativity, artistic pursuits, absorption, openness to experience, and emotional engagement with art, point to a possible relationship between how individuals experience intramodal and crossmodal correspondences – for example, as feeling matches to be more intuitive and 'right' – and their level of creativity. Note, though, that here a different claim is being made to Koriat's (1975, 2008) idea, mentioned in Chapter 1, that choices may be affected by what individuals believe others would choose. Naturally, this may well have an influence on choices and whether a match feels 'right' to an individual, but it is not what is specifically being probed here.

2.1.4 An overview of Experiments 2A, 2B, and 2C.

Three experiments were conducted in order to investigate the hypotheses presented above. Experiment 2A was conducted in the laboratory and was a close replication of the historical Kandinsky questionnaire that requires participants to colour in the three Kandinsky shapes (square, triangle, and circle) with the three Kandinsky colours (red, blue, and yellow). Participants additionally rated the intuitiveness of their matches and filled out rating scales for the shapes and colours on a variety of perceptual, emotional, and semantic dimensions and three creativity measures. Experiment 2B was conducted online, presenting the shapes either in a line or, as in the original questionnaire and in Experiment 2A, a triangular configuration when asking participants to choose the colour that they felt best matched the shape as well as how intuitive they found their match. It similarly involved participants rating shapes and colours and filling out three creativity measures. Experiment 2C was a short, online survey where participants were presented with one of the three shapes at a time when choosing the colour that they felt best matched the shape.

2.2 Method

2.2.1 Experiment 2A.

2.2.1.1 Participants.

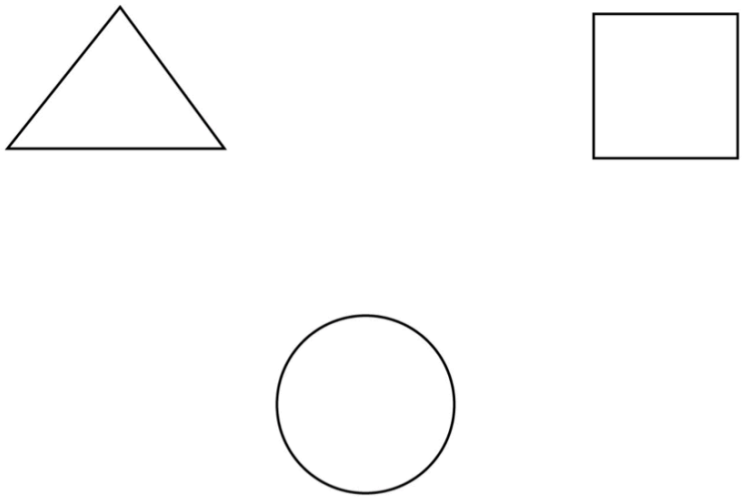
A sample of 31 participants (mean age = 20.58 years; SD = 4.62 years, 11 identified as male, 18 identified as female, 2 participants declined to answer; 23 European, 2 North Americans, 5 South East Asian, 1 Middle Eastern participant(s)) was recruited using the University of Oxford Experimental Psychology Research Participation Scheme (RPS, 25 participants) and Oxford Psychology Research Recruitment Scheme (OPR, 6 participants) and were reimbursed for their time in credits or financial compensation. The experiment took between 15-20 minutes to complete. To be eligible to be recruited both recruitment schemes noted "Normal vision (including colour vision)" as a requirement. This experiment, and all other experiments contained in this thesis, were given ethical clearance from the Medical Sciences Inter-divisional Research Ethics Committee (R44977/RE001).

2.2.1.2 Design and procedure.

Participants were presented with a pen-and-paper questionnaire and told that there were not any right or wrong answers. They were provided with three coloured felt-tip pens (red, blue, and yellow) and a black biro. The felt-tips pens were placed on the table in a random order for each participant and closely corresponded to the colours used in Experiments 2B and 2C (see, for example, Figure 2.4 below).

The first page of the questionnaire was designed to closely resemble the original Kandinsky questionnaire (see Appendix 6.1 for a translation of the original questionnaire; Figure 2.1 shows the first page of the questionnaire used in Experiment 2A which was made to closely resemble the original 1923 questionnaire, filled out versions of which exist at the Bauhaus-Archiv Berlin[12]). The shapes were traced as closely as possible using Adobe Photoshop from the original Kandinsky questionnaire, to mimic the look and scale of the original questionnaire.

[12] One such filled out questionnaire can be found here: http://www.jitter-magazin.de/wp/wp-content/uploads/2014/06/9_Fragebogen_Wandmalerei_1923_Bildnachweis-Bauhaus-Archiv-Berlin_600.jpg (Retrieved 23rd September 2019).



Specialisation (Occupation):……

Gender:……..

Nationality:……

The Crossmodal Research Laboratory invites you for research purposes to answer the following questions.

1. *Fill the 3 drawn shapes with 3 colours – yellow, red, and blue – and such that each shape is completely filled by one of the colours.*

2. *If possible give an explanation for these choices.*

Explanation:

Figure 2.1 Depiction of the first page of the pen-and-paper questionnaire presented to participants in Experiment 2A that was designed to closely resemble Kandinsky's original 1923 questionnaire.

The participants were presented with a circle, square, and triangle at the top of the page. After filling in their occupation, gender, and nationality, as in the original Kandinsky questionnaire, the questionnaire asked participants to fill in "the 3 drawn shapes with 3 colours – yellow, red, and blue – and such that each shape is completely filled by one of the colours" and "If possible give an explanation for these choices." Below these statements, there was space to write an explanation for the colour-shape matches that were made.

Participants were then asked to rate their colour choice for the circle, square and triangle on "how intuitive it felt" on a 1 to 5 Likert scale that ranged from "I chose completely randomly" to "This match feels very right". Participants rated the three colours of the pens (red, blue, and yellow) and the three shapes (triangle, square, and circle) on 1 to 5 Likert scales on five perceptual dimensions - warmth (cold/warm), complexity (simple/complex), roughness (smooth/rough), pointedness (rounded/pointed), hardness (soft/hard) - and seven semantic and emotional dimensions - valence (negative/positive), happiness (sad/happy), liking (not at all/very much), emotional arousal (calming/emotionally arousing), salience (not at all attention grabbing/very attention grabbing), harmfulness (safe/harmful), threat (not at all threatening/very threatening). The participants also indicated what their favourite colour was in a text entry box. After completing the above tasks, the participants were asked to note down what object(s) first came to mind for the three

investigated shapes, what colour(s) they associated with these objects, and, finally, whether these associations affected their choices (Yes/No/Not Sure).

The participants completed three creativity measures: A self-designed measure of trait creativity (see Appendix 6.7) was used that included statements about trait tendencies towards creativity (e.g., 'I have many wild ideas', 'Little can emotionally move me more than music', 'I often feel like associations between ideas, concepts or images form easily in my mind'). Alongside trait creativity, a measure of biographical creativity, or creative achievement, the Biographical Inventory of Creative Behaviours (BICB; Batey, 2007) was administered. The BICB lists 34 creative activities and asks participants to indicate which they have engaged in over the last 12 months. Activities include things such as writing a short story, composing a piece of music, and having choreographed a dance. The BICB correlates positively with divergent thinking (DT; $r = .21$ (rated DT), Batey *et al.*, 2010; $r = .33$ (DT fluency), Furnham *et al.*, 2008) and with openness to experience ($r = .38$, Furnham *et al.*, 2008), two common markers of creativity.

Additionally, participants rated how regularly they engaged in five creative pursuits and activities to give a measure of regularity of creative activity (producing art, visiting museums and art galleries, playing an instrument, making things look more aesthetically pleasant, going to concerts and live music events) on a scale of 1 to 5 (Never/Very Regularly). Additionally, participants also answered Yes/No questions

on whether they had ever heard of Kandinsky or of Kandinsky's colour correspondence theory. If participants had heard of Kandinsky's colour correspondence theory, they were invited to best assign colours to the shapes in the manner of Kandinsky's correspondence theory.

The participants were presented with a description of synaesthesia created based on The Synaesthesia Battery pre-test found online on https://www.synaesthete.org/:

> Synaesthesia is a rare perceptual phenomenon. It can involve numbers, letters, weekdays, or months being visually experienced to have specific colours or locations, perceiving a colour when hearing a sound, experiencing a taste in your mouth when hearing a specific word, feeling like you are touching a certain surface when smelling something, and many other blendings of the senses.

Participants were asked to indicate whether they might have any form of synaesthesia based on this description, and if they answered 'yes' to describe their experience. Finally, participants completed basic demographic questions including their age, nationality, gender, and where they spent the majority of their life growing up.

2.2.1.3 Data restructuring and analysis.

2.2.1.3.1 Explanations given for colour-shape matches.

All explanations were read and six general categories of types of explanation were extracted that participants reported affected their choices: 1) Reference made to real-world objects or instantiations of the shapes or colours (e.g., "Yellow - like the sun, red - like road signs"), 2) Reference made to the emotional or semantic associations of the

shapes or colours (e.g., “Squares are hard and strong, therefore red; circles lithe and calm, therefore blue; triangles quirky and lively”, 3) Reference that stated that participants chose randomly or without reason (e.g., “Completely arbitrary”), 4) Reference made to choices ‘feeling right’ or some analogous expression of the choices being instinctive (e.g., “I felt each shape corresponded somehow to the colours. It was very intuitive.”), 5) Reference made to memories (e.g., “Memories from primary school”, and 6) Reference to following some sort of rule (e.g., “I did it in the order written down, moving from right to left”).

Participants sometimes referenced more than one of the six categories of explanation, all of which were coded and included in the analysis. So, for example, the explanation “I was going to colour the circle yellow for the sun, but felt the triangle would look odd in red or blue so coloured it yellow. Of he [sic] two remaining colours I felt the angrier emotive red should go with the cornered angular square and calmer watery blue with the smooth, droplet-like circle. I also wondered if I was remembering the colours of shapes kids play with as toys.” was coded as explanation 1, 2, 4, and 5.

2.2.1.3.2 Creativity measures and intuitiveness.

Trait creativity was calculated by subtracting the sum total of negative items from the sum total of positive items. The BICB biographical creativity score is calculated by summing all instances of activities a participant marked as having engaged in over the last 12 months. The regularity of creative activities was summed as a total of the

answers on the five 1-5 Likert scale responses. The intuitiveness rating for each shape was averaged to give a summary average intuitiveness score.

2.2.2 Experiment 2B.

2.2.2.1 Participants.

A cross-cultural sample of 103 participants was recruited online on Prolific (https://prolific.ac) with the requirement that participants be fluent in English, having an above 98% acceptance rates on the platform in order to exclude fraudulent users and bots, and not having participated in any of previously conducted experiments related to colour or shape conducted in the context of the current thesis (the experiments are presented in the thesis in the chronological order in which they were conducted except that Experiment 2C was conducted before Experiment 2B). Nine participants were excluded due to reporting synaesthesia related to either colour or shape, having non-corrected vision problems, or responding in a biased manner on rating scale questions (e.g., only answering 100 to numerous questions in a row) giving a final sample of 94 participants (mean age = 32.23 years; SD = 10.91 years; 46 identified as male, 47 identified as female, 1 participant indicated 'other'; 66 European, 10 North American, 11 South East Asian, 3 South or Central American, 2 African, 2 North Eurasian participant(s)). Participants were reimbursed at a standard rate of 5 pounds Sterling per hour with the questionnaire taking 15 minutes to complete (1.25 pounds reimbursement).

2.2.2.2 Design and procedure.

Experiment 2B was conducted using an online Qualtrics questionnaire that participants accessed through the participant recruitment platform Prolific. On the landing page of the study, participants were requested to sit in front of their computer, set so that the stimuli could be viewed easily, in a normally lit room that was quiet and free from distractions. Participants were also reminded that there were no right or wrong answers and that to take part they had to have normal or corrected-to-normal vision, including colour vision. After reading the welcome page, participants proceeded to give their informed consent to take part in the study and then provided their Prolific ID.

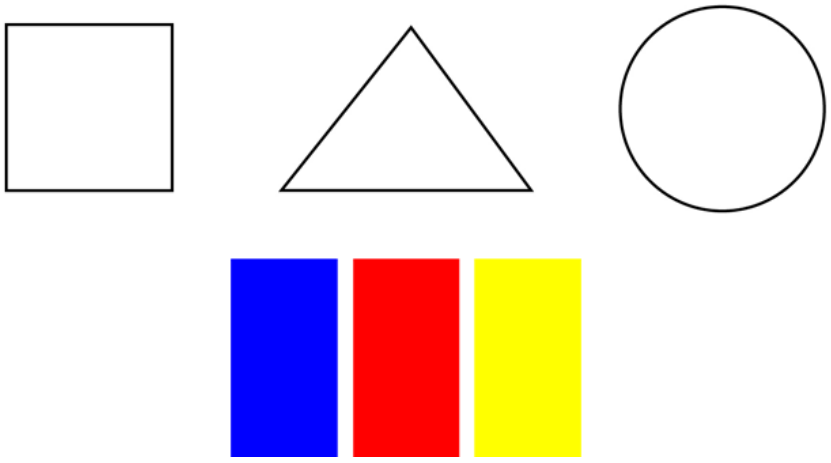


Figure 2.2 Depiction of one order of the line configuration in Experiment 2B. Note that the CIELAB colour values for all colours presented in the experiments of this thesis can be found in Appendix 6.8.

Participants were then randomly allocated to one of two groups. One group was presented with the shapes in a line (see Figure 2.2) whilst the other group was presented with the shapes in a triangle configuration (see Figure 2.3) akin to the original Kandinsky questionnaire and the arrangement in Experiment 2A (see Figure 2.1). Within each group, the order in which the shapes were presented within each of these two configurations was randomised. The order of the colour swatches (blue, red, and yellow) was also randomised.

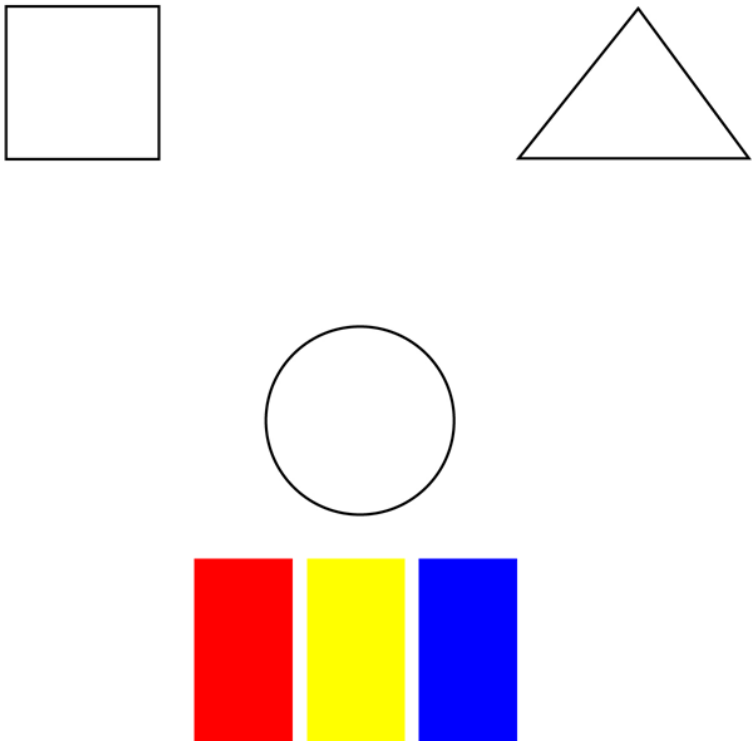


Figure 2.3 Depiction of one order of the triangle configuration in Experiment 2B.

Participants were instructed as follows:

> Looking at the above three shapes and three colours, pick what colour best matches each shape. Please try to answer as intuitively as possible. Try not to base your answer on past experiences of the world, but rather what feels right to you. There are no right or wrong answers but please avoid answering randomly.

They were thus not restricted in which colour they chose for each shape and could choose to pick a colour for more than one shape. Then, as in Experiment 2A, participants were asked to rate the intuitiveness of each of their three colour-shape matches.

Participants then completed the following seven blocks in a randomised order:

2.2.2.2.1 Shape and colour preferences.

Participants indicated their liking for the three shapes (triangle, circle, and square) and three colours (red, blue, and yellow) on a 1-5 Likert scale that ranged from 'Not at all' to 'Very much'. They also indicated their favourite colour.

2.2.2.2.2 Creativity.

All three creativity measures were the same as in Experiment 2A.

2.2.2.2.3 Kandinsky knowledge and regularity of creative activities.

Participants were asked whether they had heard of Kandinsky and his colour correspondence theory. If participants had heard of Kandinsky's correspondence

theory, they were asked to judge whether it affected their responses and to assign the colours to the three shapes in accordance with Kandinsky.

2.2.2.2.4 Synaesthesia check.

Participants were presented with the same description of synaesthesia as in Experiment 2A and were asked to indicate whether they believed if they had synaesthesia (Yes/No/Not sure), and if so or if they were not sure, to provide a description.

2.2.2.2.5 Perceptual, semantic, and emotion shape ratings.

The participants were instructed to respond as follows: "Please rate the SHAPES presented in each row on the scale shown above each of the three sliders. Answer as intuitively as possible. There are no right or wrong answers. Please avoid answering randomly since this invalidates our findings."

Sliders were anchored by the polar dimensions being tested and did not indicate a number to the participant. The location was encoded by Qualtrics on a 0 to 100 scale. The same five perceptual semantic dimensions were tested as in Experiment 2A. An additional four dimensions were added to the seven semantic and emotional dimensions tested in Experiment 2A - morality (bad/good), activity (passive/active), beauty (ugly/beautiful), and strength (weak/strong).

2.2.2.2.6 Perceptual, semantic, and emotion colour ratings.

Participants were instructed to respond as follows:

> Please rate the COLOUR presented in each row on the scale shown above each of the three sliders. Answer as intuitively as possible. There are no right or wrong answers. Please note that the questions pertain to the colour shown, not the shape the colour is shown in (a circle). Please avoid answering randomly since this invalidates our findings.

Sliders were anchored by the polar dimensions being tested and did not indicate a number to the participant. The location was encoded by Qualtrics on a 0 to 100 scale. The same perceptual, emotional, and semantic dimensions participants rated the shapes on were also used for the colours to allow the investigation of perceptual, emotional, and semantic mediation.

Participants then finished by completing some simple demographic questions about their age, gender, nationality, and where they spent the majority of their lives growing up.

2.2.3 Experiment 2C.

2.2.3.1 Participants.

A cross-cultural sample of 213 participants was recruited online on Prolific (https://prolific.ac) with the same requirements set out in Experiment 2A and 2B. Thirteen participants were excluded due to reporting synaesthesia related to either colour or shape, giving rise to a final sample of 200 participants (mean age = 32.92

years; SD = 10.64 years; 114 identified as male, 85 identified as female, 1 participant indicated that they would 'rather not say'; 135 European, 46 North American, 12 South East Asian, 3 South or Central American, 1 African, 1 North Eurasian, 1 Middle Eastern, and 1 Oceanian participant(s)). Participants were reimbursed at a standard rate of 5 pounds Sterling per hour with the questionnaire taking 2-3 minutes to complete.

2.2.3.2 Design and procedure.

The experiment was conducted using an online Google Forms questionnaire that participants access through the participant recruitment platform Prolific. Participants read a short information slide about the experiment before agreeing to the consent form. The information slide highlighted that there were "no right or wrong answers" and that "to take part you must have normal or corrected-to-normal vision (this includes colour vision)". After agreeing to take part in the study, participants provided their Prolific ID and were presented with the following information:

> In this study you will be shown shapes and asked to match them with colours. Your answers should be based on your gut instincts - try to answer as intuitively as possible. Try to avoid basing your answer on past experiences, rather go with what simply feels right to you. There are no right or wrong answers. Avoid answering randomly.
>
> Please make sure your screen is well lit, that you are not experiencing any glare on the screen, and that you are in a quiet space where you can do the study free from distractions.

By clicking on a random number generator website (random.org), participants were given an integer from 1 to 6 which they were asked to choose from a dropdown menu. The chosen integer determined which of the six shape order conditions participants were presented with. Each participant saw a triangle, square, and circle in the order determined randomly by the random number generator on a different page, with the colour options presented in different orders for each shape. On each page, before seeing the shape and colour, participants were instructed with the following: "Please try to answer as intuitively as possible. Try not to base your answer on past experiences of the world, but rather what feels right to you. There are no right or wrong answers but please avoid answering randomly."

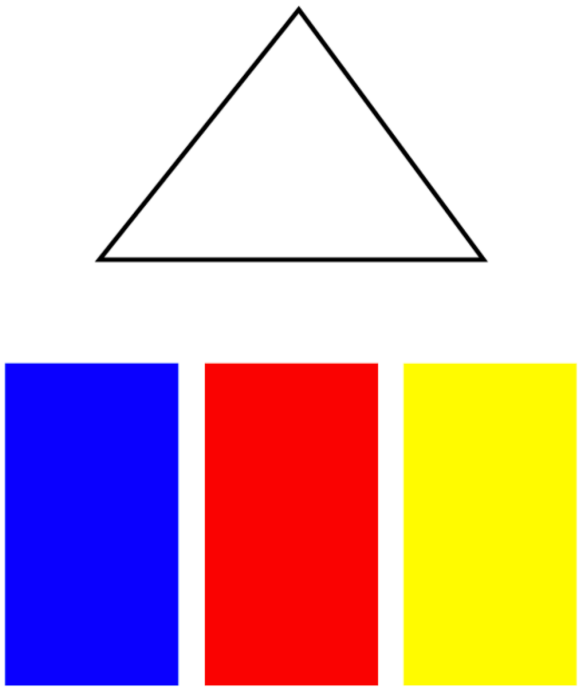


Figure 2.4 A figure showing an example presentation of how the shape and colour choices were presented in Experiment 2C.

After seeing the shape and three colours presented as shown in Figure 2.4, participants were asked "Which of the three colours best matches the shape shown?" After choosing a colour for each of the three shapes, participants answered a few individual difference and knowledge questions concerning: 1) whether they had heard of the Kandinsky correspondences and if that affected their answers; 2) whether they experienced any type of synaesthesia based on the description of synaesthesia presented in Experiments 2A and 2B above as well; 3) their nationality and where they spent the majority of their life growing up; 4) their age; and 5) their gender (male, female, rather not say, other).

2.2.3.3 Data restructuring and analysis.

Due to an error in the Google Forms survey, individuals presented with shape order 6 were presented with a triangle, circle, and then triangle again. When looking at the case-by-case data, the first two responses were included but no square ratings were made for these individuals, so this was treated as missing data in the analysis. When looking at the combined colour choices in the participant-by-participant data, 6 individuals were excluded from the analysis since there was data only for two of the three Kandinsky shapes. All further online experiments were conducted using the Qualtrics platform to avoid such future mistakes and to offer more flexibility in terms of study design.

All analyses were conducted using IBM SPSS Statistics version 24 and 25 and RSpace for Experiments 2A, 2B, and 2C.

2.3 Results

2.3.1 Colour-shape matches: Combined colour choices.

2.3.1.1 Experiment 2A.

The first way colour-shape correspondences can be analysed is by looking at the combined associations that were chosen across the three shapes and three colours, rather than evaluating shape-colour matches separately. To do this, a Chi-square analysis was conducted on the combined colour choices to see what combined shape-colour combinations were chosen most frequently. The Chi-square statistic was significant (χ^2 (5, $N = 31$) = 14.48, $p = .013$, Cramér's $V = .68$), indicating that some combinations were chosen more or less frequently than if the six combined colour-shape choices were chosen equally frequently.

Table 2.6 shows how often each colour-shape combination was chosen. The most frequent choice (35.5%, residual = 2.6), and the only combination with a standardised residual above or below +2/-2, was Combination 5 which corresponds to the association correspondences discussed in Jacobsen (2002). The second most frequent

choice was Combination 1 (29.0%, residual = 1.7), which corresponds to Kandinsky's correspondences.

Table 2.6 Percentage showing how many participants chose each combination (1 d.p.) and standardised residuals of combined colour-shape choices in Experiment 2A. The residual for each observed count is used as an indicator of whether the count can be considered to be significantly above or below the expected count. Standardised residuals of 2 or above indicate that this colour combination was chosen significantly more frequently than the expected frequency. Standardised residuals of -2 or below indicate that this colour combination was chosen significantly less frequently than the expected frequency. Significant adjusted residuals of 2 or above are shown in ***bold****, those which are -2 or below are* <u>*underlined*</u>*. All other tables containing standardised residuals can be interpreted in the same way.*

Combination		Percentage of choices	Standardised residual
	1	29.0%	1.7
	2	9.7%	-1.0
	3	12.9%	-.5
	4	6.5%	-1.4
	5	35.5%	**2.6**
	6	6.5%	-1.4

Combination 3, the dissident correspondences or "Japanese colour-shape associations" (Chen, N., Tanaka, & Watanabe, 2015, p. 2), were chosen 12.9% of the time but the residual of -.5 indicates that this was not chosen significantly less than expected from an even frequency distribution. The remaining three combinations (2, 4, and 6), were

chosen the least but did not differ significantly in choice from what would have been expected from a chance distribution. Indeed, as will be seen below in the analysis of singular shape-colour associations, considering that these three combinations involve instances of blue triangles or yellow squares (i.e., squares that are not blue or red) or both, it is unsurprising that these combinations are also chosen least frequently.

2.3.1.2 Experiment 2B.

Of the total 94 participants in Experiment 2B, 12 chose a colour more than once when matching a colour to the three shapes. Most experiments that look at only the Kandinsky stimuli require the matching of one colour to each shape, with it only being possible to choose each colour once. In order to evaluate which colour-shape combinations were most common as a set across the three shapes, these 12 participants were excluded from the following analysis to allow for the same six combinations that were evaluated for Experiment 2A above. The Chi-square test for the colour-shape combinations frequencies was significant ($\chi 2$ (5, $N = 82$) = 18.24, $p = .003$, Cramér's $V = .47$) indicating that the different combinations were chosen to a significantly different degree by participants.

The two most frequently chosen colour combinations were Combination 3 (dissident correspondences, 26.8%, residual = 2.3) and Combination 5 (association correspondences, 26.8%, residual = 2.3), which were both chosen significantly more frequently than expected by chance. Interestingly, the Kandinsky correspondences, the

second most frequent combination chosen in Experiment 2A, were chosen less frequently than would have been expected from an even frequency spread (Combination 1, 9.8%, residual = -1.5), although not to a significant extent as indicated by the standardised residual above -2. Combination 4, which was the least chosen in Experiment 2A as well, was chosen significantly less frequently than would be expected by chance (6.1%, residual = -2.3).

Table 2.7 Percentage showing how many participants chose each combination (1 d.p.) and standardised residuals of combined colour-shape choices in Experiment 2B. Significant adjusted residuals of 2 or above are shown in ***bold****, those which are -2 or below are underlined.*

Combination		Percentage of choices	Standardised residual
	1	9.8%	-1.5
	2	15.9%	-.2
	3	26.8%	**2.3**
	4	6.1%	-2.3
	5	26.8%	**2.3**
	6	14.6%	-.5

2.3.1.3 Experiment 2C.

Of the total 200 participants in Experiment 2C, 167 responded with a colour choice to each shape, and 70 chose a colour more than once when matching a colour to the three

shapes. In order to evaluate which colour-shape combinations were most common as a set across the three shapes, these 70 participants were excluded (leaving 97 participants) from the following analysis to allow for the same six combinations that were evaluated for Experiments 2A and 2B above, in line with the rest of the literature. It should be noted, though, that because one shape was presented at a time in Experiment 2C, a much larger number chose repeat colours than in Experiment 2B. Indeed, some repeat colour choice combinations were chosen more frequently than the usual six combinations (a different colour chosen for each of the three shapes) that are evaluated in the literature, although no repeated colour combinations were chosen anywhere as frequently as the Kandinsky, dissident, and association correspondences.

The adjusted residuals for the six combinations described in Table 1.1 only increase during an analysis of the data that includes all possible colour combinations. This indicates that individuals are more likely overall to choose a different colour for each shape, even when not expressly asked to do so, at least in comparison to what would be expected from an equal spread of choices across all possible unconstrained 27 combinations. Whether this is in virtue of these associations between shapes and chosen colours being stronger, or as a function of the task demands, or a mixture of both, cannot be determined from this experiment.

The Chi-square test for the six colour-shape combinations' frequencies was significant (χ^2 (5, N = 97) = 12.42, p = .029, Cramér's V = .36) indicating that the different combinations were chosen to a significantly different degree by participants.

*Table 2.8 Percentage showing how many participants chose each combination (1 d.p.) and standardised residuals of combined colour-shape choices in Experiment 2C. Significant adjusted residuals of 2 or above are shown in **bold**, those which are -2 or below are underlined.*

Combination		Percentage of choices	Standardised residual
	1	18.6%	.5
	2	8.2%	-2.0
	3	24.7%	1.9
	4	9.3%	-1.8
	5	18.6%	.5
	6	20.6%	1.0

As can be seen in Table 2.8, the most frequently chosen colour combination was Combination 3 (dissident correspondences, 24.7% residual = 1.9), as in Experiment 2B, although the residual remained just below the 2 mark. Combination 6 (20.6%, residual = 1.0), surprisingly, and in contrast to Hypothesis 2A, a combination including a blue triangle, was chosen second most frequently, but did not have a residual above 2. Combinations 1 (Kandinsky correspondences, 18.6%, residual = .5) and 5

(association correspondences, 18.6%, residual = .5) follow on close behind but were not chosen significantly more or less than would be expected from an even distribution of frequencies. Combination 2 (8.2%, residual = -2.0) and Combination 4 (9.3%, residual = -1.8) were chosen least frequently. However, only Combination 2 was chosen significantly less frequently than would be expected by chance.

2.3.1.4 Colour-shape matches – Combined colour choices: Summary.

Hypothesis 2A predicted that although the results would be mixed, the Kandinsky, association, and dissident correspondences would be the most frequently chosen colour-shape combinations. Overall, Hypothesis 2A was part confirmed. Across the three experiments, at least two of the Kandinsky, association, and dissident correspondences were in the top three combined colour choices. In Experiment 2A, that most closely followed the original Kandinsky questionnaire, they were indeed the top three choices. Mixed results were found in Experiment 2B, where the association and dissident correspondences were the two most frequently chosen combinations, but the Kandinsky correspondences were only chosen 9.8% of the time (second least frequent out of the six possible combinations). Combination 2 was the third most frequently chosen colour-shape combination. In Experiment 2C, Combination 6 was chosen second most frequently, but the Kandinsky, dissident, and association correspondences made up the first and third most frequent choices. The association and dissident correspondences were each chosen most frequently in two of the three experiments.

The results in regard to the Kandinsky correspondences were more mixed – varying between making up between one tenth to one third of the chosen colour-shape combinations, but never being the most frequently chosen combination. Statistically, both Experiment 2A and 2B supported the strength of the association correspondences with standardised residuals above 2. The dissident correspondences only showed this type of significant frequency of choice in Experiment 2B. In Experiment 2C, neither the association nor the dissident correspondences were chosen significantly more often than would have been expected by chance. In fact, no combination at all was. It was only Combination 2 that was chosen significantly less often than would be expected by chance.

2.3.2 Colour-shape matches: Shape-colour associations.

In order to address the statistical issues associated with using Chi-square and log-linear analyses for the type of data where each participant contributes more than one observation, highlighted in Chapter 1, Section 1.2.4.1, the shape-colour associations for each experiment will be analysed using multinomial logistic regression models run with the mblogit command in R (Elff, 2018; R Core Team, 2013) with participant entered as a random effect, shape as fixed effect, and colour choice as the dependent variable (mblogit(Colour Choice ~ Shape, random = ~1|Participant). This statistical test does not require independence of observations and can take into account the random effect of participant (this will be discussed in more detail in Chapter 3, Section 3.1.5). The

data always has to be interpreted in comparison to a reference category, which makes the way association is described slightly different, as will be seen below.

2.3.2.1 Experiment 2A.

In comparison to a triangle, a square is more likely to be associated with blue rather than yellow (b = 2.28, SE = .77, p = .003). A circle (b = 1.95, SE = .76, p = .010) as well as a square (b = 1.56, SE = .69, p = .024) are more likely to be associated with blue than with red. In comparison to a circle, a square is less likely to be associated with yellow than red (b = -1.56, SE = .73, p = .033) and more likely to be associated with blue than yellow (b = 2.28, SE = .77, p = .003). In comparison to a circle, a triangle is less likely to be associated with blue than red (b = -1.95, SE = .76, p = .010).

In comparison to a square, a triangle is less likely to be associated with blue than red (b = -1.56, SE = .69, p = .024) or yellow (b = -2.28, SE = .77, p = .003). Additionally, in comparison to a square, a circle is more likely to be associated with yellow than red (b = 1.56, SE = .73, p = .033). Looking at the intercepts, in particular, highlights that triangles are less likely to be associated with blue, in comparison to both yellow (b = -1.18, SE = .54, p = .029) and red (b = -1.25, SE = .54, p = .019).

2.3.2.2 Experiment 2B.

In comparison to a triangle, a square is less likely to be associated with red than blue (b = -1.33, SE = .35, $p < .001$), more likely to be associated with blue than red (b = 1.33, SE = .36, $p < .001$), and less likely to be associated with yellow than blue (b = -1.39, SE = .38, $p < .001$). In comparison to a circle, a square is less likely to be associated with red (b = -1.00, SE = .36, $p = .006$) and yellow (b = -1.38, SE = .37, $p < .001$) than with blue, and more likely to be associated with blue than with red (b = 1.00, SE = .36, $p = .006$).

In comparison to a square, a circle is more likely to be associated with red (b = 1.00, SE = .36, $p = .006$) and yellow (b = 1.38, SE = .37, $p < .001$) than blue, and less likely to be associated with blue than red (b = -1.00, SE = .36, p = .006). In comparison to a square, a triangle is more likely to be associated with red (b = 1.33, SE = .36, $p < .001$) as well as yellow (b = 1.39, SE = .38, $p < .001$) than blue, and less likely to be associated with blue than with red (b = -1.33, SE = .36, $p < .001$).

2.3.2.3 Experiment 2C.

In comparison to a triangle, a square is more likely to be associated with red (b = 1.14, SE = .28, $p < .001$) and blue (b = 1.43, SE = .28, $p < .001$) than yellow, and less likely to be associated with yellow than with red (b = -1.14, SE = .28, $p < .001$). In comparison to a circle, a square is more likely to be associated with red and blue (b =

1.17, SE = .28, $p < .001$) than with yellow (b = .84, SE = .28, p =.003), and less likely to be associated with yellow than with red (b = -.84, SE = .28, p = .003).

In comparison to a square, a triangle is less likely to be associated with red (b = -1.14, SE = .28, $p < .001$) and blue (b = -1.43, SE = .28, $p < .001$) than with yellow, and more likely to be associated with yellow than with red (b = 1.14, SE = .28, $p < .001$). In comparison to a square, a circle is less likely to be associated with red (b = -.85, SE = .28, p = .003) and blue (b = -1.17, SE = .28, $p < .001$) than with yellow, and more likely to be associated with yellow than with red (b = .84, SE = .28, p = .003).

2.3.2.4 Colour-shape matches – Shape-colour associations: Summary.

The multinomial logistic approach reveals remarkable consistencies between the three experiments that would have been obscured by a Chi-square analysis conducted shape for shape[13]. In particular, it highlights what associative strengths are the driving forces in colour-shape correspondences for the Kandinsky shapes and colours. The strong association of blue with the square and incongruency between blue and the triangle, are consistently apparent throughout the three experiments. This, therefore, reduces the likelihood of Combinations 4 and 6 being chosen most frequently, and increases the likelihood of Combinations 3 (dissident correspondences) and 5 (association correspondences) being the most common outcome, as was found when analysing the

[13] In fact, as can be seen in Table 6.2 in Appendix 6.4, the Chi-square results for the same data presented in these experiments results in far more inconsistent results, especially when each shape is analysed separately.

combined choices. Additionally, there is some evidence that the square is more likely to be associated with red than with yellow, in comparison to the triangle and circle, which would, in turn, speak in favour of Combination 1 (Kandinsky correspondences) being chosen at a reasonable frequency since it contains no blue triangle and a red square. The attentive reader will note that this closely mirrors the findings of the combined shape-colour associations discussed above. What is markedly absent from the analysis are any indications of significant differences between the triangle and circle in terms of the colours red and yellow.

It is, of course, possible that this could be swayed by an individual's strong object-associations for one of these shapes (e.g., having a strong imprint of the Japanese flag in one's mind, or associating circles with emojis or the sun) as well as emotional or semantic appraisals induced by these shapes. However, it appears that the association of squares with blue (to a lesser degree red), and not yellow; and the strong disassociation of triangles with the colour blue, are crucial driving forces of what combinations are found to be the most frequent, and what colours individuals choose on a shape-for-shape basis as well.

2.3.3 Non-matching colour choices on a case-by-case level.

Participants also chose which colour they would most disagree with for each shape in Experiments 2A and 2B. In Experiment 2A, no significant associations were found when multinomial logistic regression models were run, as for the shape-colour

associations above (just with disagreed colour instead of chosen colour as the dependent variable). For Experiment 2B, however, the disagreed results mirrored those found for the best match shape-colour associations, only with the reverse results found. So, for example, in comparison to a triangle, squares were strongly associated with the colour yellow being the most disagreed rather than the colour blue (b = 1.15, SE = .38, p = .002). Similarly, in comparison to a square, yellow was far less likely to be the most disagreed colour compared to blue, for both circles (b = -1.66, SE = .39, $p <$ .001) and triangles (b = -1.15, SE = .38, p = .002).

2.3.4 The effect of shape configuration and location on colour choices in Experiment 2B.

The effect of shape location (left, middle, or right) was tested for both configurations (straight and triangular) using the /GENLINMIXED command in SPSS with participant entered as a random effect (intercept only model). Shape location had no significant effect on colour choices (F(4, 276) = 1.80 p = .29). The same was found to hold true for when shapes were presented in a triangle, showing that the lower middle position had no effect on colour choices, counter to Hypothesis 4, which predicted a darker colour might be chosen for this position. An LMM run using the SPSS /MIXED command, however, showed that the location of the shape when shapes were presented in a triangle did have a significant effect on the heavy/light rating of the associated chosen colour (F(2,132) = 3.08, p = .049). The middle lower shape indeed resulted in colour choices with an average heavier rating (mean = 45.13, SE = 4.87) than both

the left (mean = 60.93, SE = 4.87) and right locations (mean = 47.40, SE = 4.87), as was predicted by Hypothesis 4. However, it appears that this is most strongly driven by the lighter nature of the colours chosen for the left position versus middle position (mean difference = 15.80, SE = 6.89, p = .023, 95% CI (2.19, 20.41), rather than the darker nature of the middle shape in comparison to the right shape (mean difference = -2.27, SE = 6.89, p = .742, 95% CI (-15.88, 11.35)). So, whilst the heaviest rated colour, red, was chosen most frequently for the middle lower position, statistically, Hypothesis 4 did not find strong support for the prediction that heavier rated, darker colours would be chosen for the lower centre position.

2.3.5 Explanations for colour choices.

2.3.5.1 Experiment 2A.

Of the 31 participants in Experiment 2A, 25 (80.6%) gave some type of explanation for their colour choices. Table 2.9 shows that the most frequent explanation made reference to some sort of object (32.3%) that determined, at least in part, what colour-shape choices the participant had made. References to the emotional and semantic associations of colours and shapes (25.8%) and the choices simply feeling right (29.0%) were also commonly made. Only four people reported choosing randomly (12.9%) and only two said they chose according to some sort of rule (6.5%), such as the order that colours were presented in.

Table 2.9 Observed percentage (1 d.p.) of participants making reference to the six types of explanations for their colour-shape matches in Experiment 2A.

What explanation references	Percentage of participants
Objects	32.3%
Emotional or semantic associations	25.8%
Choosing randomly	12.9%
Choices feeling right	29.0%
Memories	9.7%
Following some sort of rule	6.5%

In Experiment 2A, all of the participants were also asked to note down what objects shapes reminded them of, and what colour they associated with these objects. Since object references were the most commonly chosen explanation, some of the more frequent object-colour associations reported by participants are examined with a focus on those objects which were mentioned four times or more by participants. Participants' responses concerning whether they felt the reported object-colour associations affected their colour-shape matches are reported for the circle in Table 2.10, the square in Table 2.11, and the triangle in Table 2.12.

Table 2.10 Observed percentage (1 d.p.) of participants responses for whether the object-colour association they had to a circle affected their colour-shape matches in Experiment 2A.

Response: Did the object associations with the circle affect your colour choices?	Percentage of sample
No	41.9%
Not sure	16.1%
Yes	38.7%
No response	3.2%

Across participants, 57 objects were reported for the circle, thirteen of these objects were some type of ball, although colour associations with ball were not consistent. Thirteen participants also mentioned the sun which was consistently associated with yellow by twelve of these thirteen participants.

Table 2.11 Observed percentage (1 d.p.) of participants' responses for whether the object-colour association they had to a square affected their colour-shape matches in Experiment 2A.

Response: Did the object associations with the square affect your colour choices?	Percentage of sample
No	71.0%
Not sure	12.9%
Yes	12.9%
No response	3.2%

For the square, 41 objects were reported. Six people mentioned boxes that were associated with darker and more reddish hues such as black or brown. Four individuals mentioned houses that were not consistently associated with any colour. Four participants mentioned windows which were associated with blue and 'clear' equally.

Table 2.12 Observed percentage (1 d.p.) of participants' responses for whether the object-colour association they had to a triangle affected their colour-shape matches in Experiment 2A.

Response: Did the object associations with the triangle affect your colour choices?	Percentage of sample
No	54.8%
Not sure	25.8%
Yes	16.1%
No response	3.2%

For the triangle, 40 objects were noted down by the participants. Seven participants associated triangles with some type of weapon or non-natural dangerous item, these were often associated with grey or silver (e.g., an arrow, blade, or knife). Six individuals associated triangles with signs (e.g., road, warning, hazard signs) which were associated with red for five of the participants. Four of the participants associated triangles with pyramids which were consistently related to yellow. Four participants also associated triangles with roofs which were associated with reddish and brown hues.

Overall, the majority of individuals felt that they were not affected by the object-colour associations that first came to their mind. However, this was so to a lesser degree for the circle than the square and triangle, whereby 38.7% felt that the object associations they had with a circle affected their colour choice. A portion of individuals were unsure about whether these object-colour associations had affected them, especially in the case of the triangle (25.8%).

2.3.5.2 Experiment 2B.

Of the 94 participants in Experiment 2B, 64 (68.1%) gave some type of explanation for their colour choices. This lower percentage is likely due to the fact that in Experiment 2A, the Kandinsky questionnaire layout is used, which makes the explanation task more prominent than the online Qualtrics experiment. As one can see in Table 2.13, references to objects (30.9%), choices feeling right (27.7%), and the emotional and semantic associations of shapes and colours (21.3%) were, like in Experiment 2A, the most common explanations given for colour-shape matches. References to objects were still the most common despite participants being asked to disregard past experiences of the world in their colour choices. Similarly, few reported choosing randomly (2.1%) or following some sort of rule (3.2%), although those individuals who did not report any type of explanation may well be more likely to have chosen colours arbitrarily or according to some rule as well, not responding since they

felt they had nothing to report on in terms of why they chose certain colours for certain shapes.

Table 2.13 Observed percentage (1 d.p.) of participants that made reference to the six types of explanations for their colour-shape matches in Experiment 2B.

What explanation references	Percentage of participants
Objects	30.9%
Emotional or semantic associations	21.3%
Choosing randomly	2.1%
Choices feeling right	27.7%
Memories	0.0%
Following some sort of rule	3.2%

2.3.5.3 Explanations for colour choices: Summary.

References to real-world object colour-shape associations were the most frequent type of explanation given by participants for their colour-shape matches, confirming the predictions made by Hypothesis 3. This is of particular note since in Experiment 2B participants were specifically asked to answer intuitively rather than base their answers on past experiences of the world. Nevertheless, participants referenced emotional or semantic associations of shapes and colours, as well as that choices simply 'felt right', almost as frequently as object-based association in both Experiments 2A and 2B.

When object associations were specifically prompted in Experiment 2A, this did not always result in consistent colour associations. Balls and the sun were the two most frequent associations for a circle, for example, but only the sun had a consistent colour association (yellow). Participants felt most strongly compared to the other shapes that object associations with the circle may have affected their colour choices. Significant associations between shape and colour choices were found across all three experiments. Squares were matched to a variety of items, which generally were associated with darker, bluish, or reddish hues. This is line with finding that squares were associated with blue, and to a far lesser degree red, but the variety of other coloured associations make it difficult to see how the strength of the square-blue association is driven predominantly by object-associations. Additionally, it was also the shape where the most individuals (almost three quarters) felt that object associations did not drive their colour choice. Triangles were most often matched to types of weapon or dangerous items (which were associated with grey or silver) or warning signals (which were associated with red warning signs most commonly).

Overall, it is difficult to determine on a case-by-case basis whether someone's explanation for their colour-shape choices in fact is the reason why or the only reason why that particular colour was chosen. Rather they only give us an insight into meta-cognitive processes and phenomenological experiences an individual may have whilst completing the task. Object-associations undoubtedly play a part in the associative learning over a lifetime and, as such, are likely to affect colour-shape correspondences.

However, as will be seen below, there is evidence that backs up the participants' responses that indicate that emotional and semantic associations do play a part in determining colour-shape correspondences as well.

2.3.6 Perceptual mediation.

2.3.6.1 Experiment 2A.

A bivariate correlation analysis was conducted on the five perceptual characteristics tested to evaluate whether similarities in ratings on these dimensions for colours and shapes mediated colour choices. All correlations reported in this chapter are Pearson's correlations. To reiterate, of course these are semantically/linguistically, as well as, in another sense, phenomenologically (Albertazzi, 2018), probed perceptual dimensions. Of the five characteristics that were compared, three were not significant – there was no significant association between warmth (cold/warm), complexity (simple/complex), and roughness (smooth/rough) ratings for shape and the associated chosen colour, indicating that similarities in these three characteristics are unlikely to have driven, or perceptually mediated, colour choices. Pointedness (rounded/pointed; $r(88) = .45$, $p < .001$) showed a significant correlation under a strict Bonferroni correction ($\alpha = .001$), indicating that similarities in perceptual appraisals of pointedness may mediate colour choices for the three shapes. Hardness (soft/hard; $r(91) = -.29$, $p = .005$) exhibited a significant negative correlation between shape and chosen colour appraisals, such that, on average, harder rated colours were chosen for softer rated shapes.

2.3.6.2 Experiment 2B.

A bivariate correlation analysis was conducted on the six perceptual characteristics tested to evaluate whether similarities in ratings on these dimensions for colours and shapes mediated colour choices. The same five perceptual characteristics were tested as in Experiment 2A, alongside the additional dimension of weight. Of the six characteristics that were compared, two were not significant – that is, there was no significant association between complexity (simple/complex) and weight (heavy/light) ratings for shape and the associated chosen colour, indicating that similarities in these two characteristics are unlikely to have driven or perceptually mediated colour choices. Pointedness (rounded/pointed; $r(280) = .25$, $p < .001$), hardness (soft/hard; $r(280) = .21$, $p < .001$), and warmth (cold/warm; $r(280) = .23$, $p < .001$) showed significant correlations under a strict Bonferroni correction ($\alpha = .008$), indicating that similarities in perceptual appraisals of these dimensions may mediate colour choices for the three shapes. Correlations between shape and chosen colour roughness (smooth/rough; $r(280) = .13$, $p = .027$) would not have survived a strict Bonferroni correction but remained significant at the .05 significance level.

2.3.6.3 Perceptual mediation: Summary.

Hypothesis 2B predicted that chosen colour and shape warmth ratings would correlate, since this had been a commonly suggested and tested dimension in previous research. The relationship between chosen colour and shape warmth was only significant in

Experiment 2B and was significantly smaller than many of the emotional, semantic, and perceptual correlations reported by Malfatti (2014). Indeed, this is the case across the perceptual dimensions tested in Malfatti's (2014) Experiments 4 and 5. Pointedness of shape and chosen colour was significantly correlated in Experiments 2A and 2B. However, no other perceptual characteristic was found to consistently mediate colour choices across the two experiments. Indeed, the direction of the relationship was in fact opposite for hardness across the two experiments. As such, it seems that the predictions of Hypothesis 2C are only confirmed to a limited degree for perceptual characteristics overall. Additionally, in line with the direct test of Hypothesis 4, weight did not appear to drive colour-shape matches in Experiment 2B.

2.3.7 Emotional and semantic mediation.

2.3.7.1 Experiment 2A.

A bivariate correlation analysis was conducted on the case-by-case data to determine whether the emotional and semantic characteristics of the shapes and the colours participants chose for them were associated. Of the seven characteristics that were compared, two were not significant – there was no significant association between valence (negative/positive) and happiness (sad/happy) ratings for shape and the associated chosen colour, indicating that similarities in these two characteristics are unlikely to have driven or affectively mediated colour choices.

Ratings of shapes and the associated chosen colour's liking (not at all/very much; $r(91) = .46$, $p < .001$) and emotional arousal (calming/emotionally arousing; $r(90) = .48$, $p < .001$) revealed significant correlations under a strict Bonferroni correction ($\alpha = .007$). This indicates that similarities in these emotional and semantic appraisals may mediate colour choices for the three shapes. Harmfulness (safe/harmful; $r(88) = -.39$, $p = .013$) ratings exhibited a significant negative correlation, such that colours rated more harmful were, on average, chosen for those shapes that were rated as safer. Correlations between shape and chosen colour threat (not at all threatening/very threatening; $r(88) = .21$, $p = .045$) and salience (not at all attention grabbing/very attention grabbing; $r(91) = .46$, $p = .038$) would not have survived a strict Bonferroni correction but remained significant at the .05 significance level.

2.3.7.2 Experiment 2B.

A bivariate correlation analysis was conducted on the case-by-case data to determine whether the emotional and semantic characteristics of the shapes and the colours participants chose for them were associated. In Experiment 2B, an additional four characteristics were tested (beauty, morality, activity, and strength) in comparison to Experiment 2A. Of the eleven characteristics that were compared, three were not significant. That is, there was no significant association between threat (not at all threatening/very threatening), activity (passive/active), and strength (weak/strong) ratings for shape and the associated chosen colour. This indicates that similarities in

these three characteristics are unlikely to have driven or affectively mediated colour choices.

Ratings of shapes and the associated chosen colour's liking (not at all/very much; $r(280) = .35$, $p < .001$), emotional arousal (calming/emotionally arousing; $r(280) = .24$, $p < .001$), happiness (sad/happy; $r(280) = .32$, $p < .001$), beauty (ugly/beautiful; $r(280) = .34$, $p < .001$), and morality (bad/good; $r(280) = .17$, $p = .004$) highlighted significant correlations under a strict Bonferroni correction ($\alpha = .005$), indicating that similarities in these emotional and semantic appraisals may mediate colour choices for the three shapes. Correlations between shape and chosen colour valence (negative/positive; $r(280) = .17$, $p = .005$), salience (not at all attention grabbing/very attention grabbing; $r(280) = .12$, $p = .038$), and harmfulness (safe/harmful; $r(280) = .15$, $p = .013$) would not have survived a strict Bonferroni correction. However, they remained significant at the .05 significance level.

2.3.7.3 Emotional and semantic mediation: Summary.

Whilst not all emotional and semantic characteristics mediated colour-shape matches across both experiments, it certainly appears that the common emotional and semantic associations of colours and shapes contribute to the colour-shape matches of individuals, thus confirming at least part of Hypothesis 2C. In particular, the characteristics of shape and colour liking and emotional arousal were consistently, significantly, and positively associated across Experiments 2A and 2B, thus confirming

Hypothesis 2A. Additionally, beauty and morality, only tested in Experiment 2B, were found to be significantly correlated between shape and chosen colour.

2.3.8 Individual differences.

2.3.8.1 Effect of Kandinsky knowledge on colour choices.

2.3.8.1.1 Experiment 2A.

In Experiment 2A, two cross-tabulations and Chi-square analyses explored whether the combined colour choices differed between individuals that reported having heard of Kandinsky or his Kandinsky's correspondence theory and those who had not. Combined colour choices were considered to evaluate whether the Kandinsky correspondences were more likely to be chosen by those who had heard of Kandinsky and his colour-shape correspondences. Both analyses revealed no significant Chi-square test statistics. It should be noted that no participant had heard of Kandinsky's correspondence theory so no Chi-square analysis could be completed in regard to this variable. As such, in Experiment 2A, knowledge of Kandinsky and his correspondence theory did not affect the combined colour choices.

2.3.8.1.2 Experiment 2B.

The same analyses were conducted on the data from Experiment 2B. The Chi-square test statistics for both knowledge of Kandinsky and his correspondence theory were non-significant, like in Experiment 2A, indicating that knowledge of Kandinsky and

his correspondence theory did not affect combined colour choices in Experiment 2B either.

2.3.8.2 Relationship of creativity with intuitiveness of choices.

2.3.8.2.1 Experiment 2A.

Bivariate correlations between the three creativity measures were conducted. In Experiment 2A, the BICB, a measure of biographical creativity, only correlated with the regularity of creative activities measure ($r(29) = .44$, $p = .013$) at the strict Bonferroni correction α level of .017. This is perhaps unsurprising since they both tap into creative activities. The Pearson correlation between regularity of creative activities and trait creativity would not have survived a strict Bonferroni correction ($r(29) = .36$, $p = .045$). The Pearson correlation between biographical creativity and trait creativity was non-significant, indicating that the two psychometrics are not tapping into a coherent psychological characteristic or trait.

Bivariate correlations between average intuitiveness of ratings and the three creativity measures were conducted. In Experiment 2A, the Pearson correlation between average intuitiveness and trait creativity ($r(29) = .43$, $p = .015$) was found to be significant after a strict Bonferroni correction ($\alpha = .017$). The Pearson correlation between regularity of creative activities and average intuitiveness was only marginally significant ($r(29) = .43$, $p = .017$). Biographical creativity was not correlated with the average intuitiveness of participants' colour-shape matches.

2.3.8.2.2 Experiment 2B.

The same correlation analyses were conducted for Experiment 2B. Biographical creativity correlated strongly with trait creativity in Experiment 2B ($r(92) = .50$, $p < .010$), which is at odds with the results of Experiment 2A. The regularity of creative activity was not correlated with either trait creativity or the more validated BICB in Experiment 2B, again, a result that is at odds with the findings of Experiment 2A. In Experiment 2B, the Pearson correlations between creativity measures and average intuitiveness were not found to be significant, although the correlation between average intuitiveness and trait creativity approached significance at the $\alpha = .025$ level ($r(92) = .23$, $p = .028$), which a strict Bonferroni correction would require.

2.3.8.2.3 Individual differences: Summary.

In sum, neither having heard of Kandinsky nor his correspondence theory appears to have resulted in more frequent choices of the Kandinsky correspondences in both Experiments 2A and 2B. Overall, knowledge of Kandinsky had no effect on combined colour choices in Experiments 2A and 2B. It should, though, be noted that very few had heard of Kandinsky's correspondence theory, as such not providing a good spread of this difference in knowledge between individuals.

The relationship of creativity to intuitiveness of matches was mixed between the two experiments. It appears that the creative activities that individuals engage in, as

measured by the BICB and the regularity of creative activities measure, does not correlate with the intuitiveness of colour-shape matches. If the significant results in Experiment 2A and the approaching significant results in Experiment 2B for the relationship between average intuitiveness and trait creativity are taken into account, there is some indication that higher trait creativity is related to rating the colour-shape matches made as being more intuitive. Overall, then, Hypothesis 5, which predicted that participants exhibiting higher creativity and greater engagement with artistic activities would rate their matches as more intuitive, was, at best, only part confirmed, and from a more critical perspective, does not show much promise as a replicable individual difference effect.

2.4 Discussion

2.4.1 Overview of the results of Experiments 2A, 2B, and 2C.

The association and dissident correspondences were the two most frequently chosen colour-shape combinations across the three experiments, with the Kandinsky correspondences being less consistently chosen across the three experiments, part confirming Hypothesis 2A. Additionally, confirming Hypothesis 1B, there appears to be a positive relationship between blue and squares, and a negative association between blue and triangles. Squares also seem to a have a less strong association with the colour red, and a negative association with the colour yellow. For circles and triangles, the

associations to reds and yellows were not shown to be determined by anything other than the significant relationships between squares and the colour blue, and triangles and the lack of association with the colour blue.

Whilst the results do not indicate that there is a definitive colour-shape combination that is consistently most frequent in more culturally diverse samples than some of the previous research has used (e.g., Chen, N., 2015; Jacobsen, 2002), it does appear that especially the association and dissident correspondences stand out as the most common choices. When looking at one-to-one matches of colours and shapes, a clearer and more consistent statistical relationship emerges, in particular, for the square and the triangle with regard to the colour blue. This is perhaps surprising since, as Jacobsen and Wolsdorff (2007) point out, colour-shape correspondences are likely to be culturally relative and historically influenced – many environmental changes, for example, existing between countries and time periods. Indeed, cultural effects do affect other more replicated crossmodal correspondences such as the Bouba/Kiki effect and taste-related associations between colour and shape, but cross-cultural trends do still exist (Bremner *et al.*, 2013; Chen, Y.-C., *et al.*, 2016; Cuskley, Simner, & Kirby, 2017; Ngo *et al.*, 2013; Piqueras-Fiszman, Velasco, & Spence, 2012; Wan *et al.*, 2014; Wan, Woods, Seoul, Butcher, & Spence, 2015). Although, interestingly, it should be noted that cultural influences appear to be far less influential in the music/tones-colour sphere (see Spence, 2019a, for discussion and references therein). What is it about shape, in particular, and its association with colour that is driving an increase in

expected cultural variation? Indeed, the experiments that will be described in Chapter 3 suggest, in contrast, that cultural variation may play a comparably small role. Rather, large amounts of inter-participant variation regardless of culture come to bear on colour-shape correspondences, especially when larger numbers of colours and shapes are presented.

Nevertheless, with such surprisingly consistent results for this limited set of stimuli using this method of analysis[14], the question arises what mechanisms and associations drive colour-shape matches for this set of colours and shapes. Liking and emotional arousal were found to be plausible emotional dimensions of appraisal underlying colour-shape correspondences in confirmation of Hypothesis 2A and previous research in the crossmodal correspondence field (Palmer, Schloss, Xu, & Prado-León, 2013; Velasco *et al.*, 2015; Velasco, Woods, Petit, Cheok, & Spence, 2016; Wang, Wang, & Spence, 2016). Warmth, counter to Hypothesis 2B and previous colour-shape correspondence research and theorising (e.g., Albertazzi, Malfatti, *et al.,* 2015; Chen, N., 2015), was not found to be a driving factor in colour-shape matches. Overall, similarities in emotional and semantic dimensions, and to a lesser degree perceptual dimensions, did, at least in part, drive participants' colour choices, confirming Hypothesis 2C. It would

[14] As highlighted by Dreksler and Spence (2019), the importance of method of analysis, and how it can alter colour-shape correspondence results can also be seen when the data of Experiments 2A, 2B, and 2C is analysed using two types of Chi-square analyses: one shape at a time versus the full contingency table. As noted previously, the results can be compared to one another and the mulitnomial logistic results in Appendix 6.4. The stark differences between them highlight how different conclusions can be reached based on the choice of analysis.

be amiss though to make strong statements about a single causal mechanism most definitely having driven a particular choice or effect, since such emotional, semantic, and perceptual associations are often intercorrelated and would form part of an arguable associative network (see Parise, 2016) that makes certain colour-shape matches more or less likely. The fact that liking and arousal showed consistent effects in relatively culturally diverse samples, does speak to their utility in evaluating the affective mechanisms underlying intramodal and crossmodal correspondences.

Real world object-based associations, such as the Japanese flag's red circle affecting Japanese participants, as suggested by N. Chen, Tanaka, & Watanabe (2015), are another potential driver of colour-shape correspondences. These could, for example, also be inadvertently heightened by experimental confounds such as background colour (e.g., a red circle on a white background is probably more likely to remind a participant of the Japanese flag than a red circle on a grey background). In support of Hypothesis 3, real-world object colour-shape associations were indeed the most commonly made reference in participants' explanations. Nevertheless, references to emotional and semantic associations and choices simply 'feeling right' were almost as common. As such, the pre-conceived notion of object-based explanations may have caused previous researchers (e.g., Jacobsen, 2002; Jacobsen & Wolsdorff, 2007) to code explanations with not enough sensitivity to other possible explanations, making object associations seem more central than is the case. Furthermore, no clear link existed between the colours of objects that people associated with shapes, and the prevalent colour-shape

matches in the three samples. This points to the fact that, at least consciously available, object associations are unlikely to be the full causal story for the existence of colour-shape correspondences. Ultimately, a more extensive and systematic analysis of object associations, akin to the methodology used by Palmer and Schloss (2010) to test their model for colour preferences (see 3.1.3.2 for further discussion), will need to be conducted on a wider set of shape stimuli in order to quantify how object-colour associations may contribute to colour-shape matches.

Arguably, an associative network (cf. Parise, 2016; Proctor & Cho, 2006; Walker, L., Walker, P., & Francis, 2012) formed across the lifespan would include the statistical information and weights of environmental object-based, emotional, semantic, and perceptual associations. The cross-activation over this network of nodes would determine colour-shape correspondences. In light of the fact that even in often replicated and more robust crossmodal correspondences, the effect of other associations can vary across individuals, it would be expected that such putative networks could differ significantly between individuals. Marks (1989), for example, found that participants consistently differed in how pitch and loudness contributed to the crossmodal similarity between pitch, loudness, and brightness. Whilst, for all participants pitch and loudness were contributing factors to crossmodal similarity with brightness, for some participants pitch played a more important role. Therefore, perceptual associations (such as those related to heaviness) or even more consistently found emotional drivers such as liking or arousal, are unlikely to consistently contribute

to colour-shape choices across a sample, especially when cultural influences and other individual differences act as further diversifying influences.

Hypothesis 4, predicting heavier rated colours to be chosen for the lower centre position in Experiment 2B, was not confirmed. Neither location, configuration of shapes, nor rated heaviness had an effect on colour choices overall. Nevertheless, the heaviest rated colour, red, was indeed the most common choice for the lower centre positioned shape. It should be noted that whilst size-brightness associations exist (Walker, P., & Walker, L., 2012; also see Warden & Flynn, 1926), previous colour-shape research highlights, as mentioned above, that size of shapes does not affect colour choices when moderate changes in the dimensions of the shapes are made (e.g., Albertazzi, Da Pos, *et al.*, 2013; Chen, N., Tanaka, Matsuyoshi, & Watanabe, 2015a).

For example, N. Chen, Tanaka, Matsuyoshi, & Watanabe (2015a) found some indication that size interacted with colour, though not with shape and colour. It may be that such shape presentation associations do not transfer to colour-shape correspondences and, as such, do not greatly affect choices. Additionally, it may also be that the relative sizes of the shapes did not differ enough to trigger size-brightness associations. In a small sample experiment with 22 participants conducted by N. Chen (2015), colours in the categories of red and red/blue were rated as heavier, similar to in Experiments 2A and 2B. However, only colour heaviness (not shape heaviness) correlated significantly with the second correspondence analysis factor they derived

from their data, which overall, though, was not well explained by heaviness (or weight) and sharpness rating colour-shape correlations, and, contributed far less to colour-shape choices than the first factor. In the experiments of Chapter 2, weight was also not found to significantly correlate between shape and chosen colour. In sum, then, heaviness alongside other perceptual factors such as size, spatial orientation (see, for example, Chen, N., Tanaka, Matsuyoshi, & Watanabe, 2015a), location, and configuration, do not appear to have a strong effect on colour-shape matches (at least not under the experimental conditions they have been tested in to date).

Finally, with no strong or consistent relationships between creativity and intuitiveness having been found, with the exception of a potential link between trait creativity and intuitiveness, Hypothesis 5 did not receive much support. Since the prediction was speculative and based on a series of intercorrelations between synaesthesia, creativity, artistic pursuits, absorption, openness to experience, and emotional engagement with art, it may simply indicate that these effects do not transfer to the type of creativity measures chosen here or the correspondence phenomenon.

In sum, on the first question of the nature of colour-shape correspondences within the constraints of the Kandinsky colours and shapes, there do appear to be consistent colour-shape associations that can be found in three culturally diverse samples that were tested using three subtly different presentations of the experimental task. The association and dissident correspondences stand out as the most commonly chosen

combinations when the task from the original Kandinsky's (1923) questionnaire is revisited. On the second question of mechanisms, similarities in sharpness, liking, and emotional arousal of chosen colour and shape stood out as the perceptual and emotional dimensions that most consistently predicted colour-shape matches. In regard to the third and final question concerning individual differences, it appears that creativity, at least, does not seem to be a strong predictor of how intuitive individuals experience their colour-shape matches to be.

2.4.2 Takeaways for future experiments of the thesis.

2.4.2.1 Emotional and semantic mediation.

Liking and emotional arousal were the two characteristics which consistently emotionally mediated colour-shape matches in Experiments 2A and 2B. Indeed, this speaks to a verification of their centrality in understanding the range of emotions relevant to affective appraisals of stimuli, as suggested by Osgood's evaluation-activity-potency semantic differential model and other models of emotion, such as the Circumplex Model (Barrett & Russell, 1999; Osgood *et al.*, 1957). They are also the most commonly investigated emotional mediation dimensions in other crossmodal correspondence research (Palmer, Schloss, Xu, & Prado-León, 2013; Velasco *et al.*, 2015; Velasco, Woods, *et al.*, 2016; Wang *et al.*, 2016). As such, it is these two dimensions of affective appraisal that will be the focus in the experiments reported in Chapter 3. The experiments otherwise would have been inappropriately long in

duration if a large number of shapes and colours had to be rated on a full battery of emotional and semantic concepts as was required in Experiment 2B, for example.

2.4.2.2 Individual differences: Creativity.

Due to the decidedly contrasting results between Experiment 2A and 2B in terms of the relationships between the three measures of creativity, it is difficult to determine how the three measures relate to one another. As such, going forward, different individual differences will be explored that side-step the conceptual and measurement issues that the field of creativity has to battle with (for a review, see Batey & Furnham, 2006). Moreover, since the only measure validated by other creativity research, the BICB, showed no convincing or consistent relationship with average intuitiveness of colour-shape matches, and as such does not appear to be a good predictor of how intuitive individuals will find engaging in a colour-shape correspondence task, it seems prudent to expand the exploration of individual differences to other measures.

2.4.2.3 Task demands.

It should be noted that presenting stimuli one by one, creates fewer task demands and constraints on individuals' colour-shape choices. Thus, if the aim is to truly find out what shapes and colours are associated, it makes sense to continue with an experimental design that is less constrained than the Kandinsky questionnaire and presents shapes one at a time to participants. The experiments reported in Chapter 3, take this on board, and present a wider range of shape and colour stimuli, one at a

time. In addition, the sheer number of shapes makes it harder to track colour choices, thus reducing the likelihood that individuals may constrain their colour choices based on the stimuli set presented. Furthermore, to truly test whether perceptual characteristics of the shapes have an effect on colour choices, having a larger sample of shapes and colours that differs across a variety of perceptual characteristics is necessary.

3 Examining the Replicability of Colour-Shape Associations

3.1 Aims and Objectives of the Chapter

With the findings of the previous two chapters, there are still quite a few open questions concerning colour-shape correspondences. For one, there were some consistent findings with regard to colour-shape associations in Chapters 1 and 2, when the presented stimuli are restricted to the Kandinsky shapes and colours. However, the evidence is by no means unequivocal for one set of shape-colour matches that is consistently chosen across experiments for this very limited set of stimuli. Additionally, when sets of shape stimuli are expanded, analysis of what shape characteristics map on to certain hues has been restricted to the analysis of prototypical geometric and polygon shapes. Within such stimuli, it is often found that acute angles and shapes based on them map onto yellower hues. Round shapes are associated with warmer colours, in particular red, whilst obtuse angles and shapes based on them are associated with colder colours (Albertazzi, Da Pos, *et al.*, 2013; Albertazzi, Malfatti, *et al.*, 2015; Chen, N., 2015; Chen, N., Tanaka, Matsuyoshi, & Watanabe, 2015a).

Often statistical methods are used that are less than ideal, as has been discussed previously and will be explored in more depth below. Moreover, and more importantly, in these cases where shapes are analysed, shapes are not explicitly designed to vary along certain shape characteristics. This means research stays close to examining one-

to-one mappings of shapes to hues. This makes it difficult to generalise conclusions to a broader set of shapes or make generalisable statements about what shape characteristics may predict what colour properties.

Malfatti (2014) conducted two experiments that attempted to address this by systematically varying geometric closed shapes and open line shapes along dimensions such as number of concavities, pointedness, and number of axes of symmetry. Additionally, shapes were also rated for their perceptual characteristics. It was found that for closed shapes, pointedness, complexity, and symmetry were important characteristics that explained variance in individuals' colour choices. However, as discussed in Chapter 1, it should be noted that the results revealed differences in the associations that were found between shape characteristics and chosen colour properties for line shapes and closed shapes as well.

3.1.1 Do consistent associations of shape characteristics and colour properties exist?

This brings us to the main question of the present chapter – are there consistent colour-shape correspondences across different types of shape stimuli, experiments, and individual differences such as nationality and gender? Here, colour-shape associations are not conceptualised as one-to-one mappings of certain colours to certain shapes. Rather, the aim is determining whether specific shape characteristics consistently predict chosen colour properties across a range of stimuli sets. To do this, Malfatti's

(2014) lead was followed and shape stimuli that specifically vary along the dimensions of angularity, symmetry, and complexity were created. This path was chosen to avoid relying on post-hoc classification of these shapes based on the eyeballing of and restricted analysis possible with contingency table data. Additionally, this one set of characteristics is used for all sets of shapes and conceived of both as categories determined objectively and continuous dimensions rated by participants' perceptions of the shapes.

Four experiments are presented in this chapter. The first three each tested one type of stimuli set (3A – geometric shapes, 3B – mandala shapes, 3C – RF pattern shapes). A fourth experiment (3D) was conducted with a large global sample where all three of the stimuli sets were tested again. This allowed for the testing of consistency across stimuli sets and experiments. Thus, it could be determined if specific colour-shape correspondences and associations between shape characteristics and colour properties could be replicated. Additionally, the large sample size and ample groups from different nationalities of Experiment 3D allowed testing of whether the individual difference factors of nationality and gender interacted with shape characteristics in predicting chosen colour characteristics. Finally, the use of linear mixed models (LMMs), allowed consideration of these questions with an eye to how much variance is actually accounted for in colour-shape matches when data are considered at the case-by-case level, instead of averaging across several items (see Section 3.1.5 below).

3.1.2 Affective mechanisms: Emotional mediation.

As shown in the experiments reported in Chapter 2, as well as the review presented in Chapter 1, affective and semantic mediation of colour-shape correspondences are fertile explanatory mechanisms for the colour choices individuals make for each shape. This chapter's experimental focus is on liking and arousal, since these stood out in Chapter 2 as dimensions of emotional mediation. Moreover, they are well evidenced dimensions in most models of how affective states and appraisals are structured (e.g., Barrett & Russell, 1999). As such, the emotional mediation hypothesis (Palmer, Schloss, Xu, & Prado-León, 2013) will be tested here again for how it fares when colour and shape stimuli are expanded extensively in number, and a variety of shape stimuli are used. Malfatti's (2014) experiments on colour-shape correspondences too found liking and arousal to affect colour-shape matches. In addition, a variety of other crossmodal correspondence research related to shape and colour have found liking and arousal to mediate associations (e.g., Deliza & MacFie, 2001; Risso, Maggioni, Olivero, & Gallace, 2015; Salgado-Montejo *et al.*, 2015; Velasco *et al.*, 2015; Velasco, Michel, *et al.*, 2016; Velasco, Salgado-Montejo, Marmolejo-Ramos, & Spence, 2014; Zhou, Wan, Mu, Du, & Spence, 2015). Therefore, it is predicted that individuals will be more likely to choose colours that they like more for shapes that they like more and choose colours that they find more arousing for those shapes that they find more arousing.

3.1.3 Affective appraisals of shapes and colours.

The affective associations and appraisal of colour and shape stimuli has a long history in psychology and aesthetics that has followed through to the current day (e.g., Adams & Osgood, 1973; Fechner, 1865, 1871, 1876; Gordon, 1909; Hevner, 1935; Lyman, 1979; Palmer, Schloss, & Sammartino, 2013; Shimamura, 2013; Valdez & Mehrabian, 1994). Specific features of interest in the literature have been the valence and arousal associated with complexity (Eisenman, 1967; Madan, Bayer, Gamer, Lonsdorf, & Sommer, 2018; Nadal, Munar, Marty, & Cela-Conde, 2010; Tinio & Leder, 2009), the strong appraisal and social signalling effect of the colour red (Elliot & Mayer, 2012; Elliot & Niesta, 2008, Feltman & Elliot, 2011; Guéguen *et al.*, 2012; see for a meta-analysis, Lehman, Elliot, & Calin-Jageman, 2018;), our preference for curvature and association of pointedness with threat (Bar & Neta, 2006, 2007; Bertamini *et al.*, 2016; Larson, Aronoff, Sarinopoulos, & Zhu, 2009; Larson, Aronoff, & Stearns, 2007; Leder, Tinio, & Bar, 2011; Lundqvist, Esteves, & Öhman, 2004; Silvia & Barona, 2009), and our fundamental affinity for symmetry (Cárdenas & Harris, 2006; Enquist & Arak, 1994; Jacobsen & Höfel, 2003; Makin, Pecchinenda, & Bertamini, 2012).

3.1.3.1 Affective responses to shape.

3.1.3.1.1 Symmetry.

The experiments in this chapter will focus on the three shape characteristics of symmetry, complexity, and angularity. Whether in the aesthetic sciences (Höfel &

Jacobsen, 2007b; Jacobsen & Höfel, 2002; Jacobsen, Schubotz, Höfel, & Cramon, 2006), judgement of faces (Cárdenas & Harris, 2006; Gangestad, Thornhill, & Yeo, 1994; Koehler, Rhodes, & Simmons, 2002; Little, Apicella, & Marlow, 2007; Little, Burt, Penton-Voak & Perrett, 2001; Perrett *et al.*, 1999; Rhodes, Proffitt, Grady, & Sumich, 1998, though see Zaidel, Aarde, & Baig, 2005), or art across the world and eras (Arnheim, 1974; Boas, 1955; Brain, 1979; Gombrich, 1984; Hodgson, 2011; Washburn & Crowe, 1988, though see McManus, 2005), symmetry has been strongly and fundamentally linked with beauty and the aesthetic experience. The relationship between symmetry and beauty, individuals' preference for symmetrical displays, and the ubiquity of symmetry in nature, mathematics, and art has been picked up on by academics, artists, philosophers, and scientists for millennia (e.g., Darwin, 1882; Haeckel, 1904/2004; Lockwood & Macmillan, 1978; Sartwell, 2017[15]; Stewart, 2007; Weyl, 1952).

Symmetry preference has even been found in non-human animals and insects (Clara, Regolin, & Vallortigara, 2007; Møller, 1992; Møller & Sorci, 1998; Rensch, 1957, 1958; Swaddle & Cuthill, 1994; Wignall, Heiling, Cheng & Herberstein, 2006). Indeed, our enjoyment of, attraction to, and sensitivity to bilateral symmetry is often argued to have evolutionary origins in terms of health signalling for sexual selection (Andersson, 1994; Bradbury & Vehrencamp, 1998; Darwin, 1882; Gangestad *et al.*, 1994; Jones *et*

[15] See discussion and references therein for how the classical conception of symmetry, such as that referred to by Aristotle, differs from the simple notion of bilateral symmetry.

al., 2001; Møller & Swaddle, 1997; Møller & Thornhill, 1998; Thornhill & Gangestad, 1999; though see Henderson, Holzleitner, Talamas, & Perrett, 2016; Kalick, Zebrowitz, Langlois, & Johnson, 1998). Although there are alternative accounts of how the preference and salience of symmetry could have arisen as an adaptation to recognise visual signals across positions and orientations in the visual field (see Enquist & Arak, 1994; Enquist, Ghirlanda, Lundqvist, & Wachtmeister, 2002; Enquist & Johnstone, 1997). Studies have even found that symmetry can facilitate memory of spatial configurations in individuals who are congenitally blind (Cattaneo *et al.*, 2010), highlighting its salience in perceptual processing beyond the visual realm.

Symmetry, considered a contributing factor to 'goodness' for Gestalt psychologists (Wertheimer, 1923; Marković, 2002; Palmer, 1991; though see Garner & Clement, 1963), has often been analysed under the guise of ease of perceptual processing (Koffka, 1935). This construct has most recently been incarnated as the concept of 'processing fluency' (Reber, Schwarz, & Winkielman, 2004; Reber, Wurtz, & Zimmerman, 2004, Winkielman, Schwarz, Fazendeiro, & Reber, 2003; Winkielman, Ziembowicz, & Nowak, 2015). The sub-types of perceptual and conceptual fluency relate to the ease of processing perceptual or conceptual information (Reber, 2012). Arguably, both could apply to colour-shape correspondences, if the line of argument that perceptual, affective, and semantic mechanisms could drive shape-colour matching behaviour is followed. In relation to aesthetic preferences, fluency theory holds that if something is processed more easily, it results in positive affect and pleasure (Reber, Schwarz, &

Winkielman, 2004; Winkielman & Cacioppo, 2001). This type of perceptual fluency has been suggested to be evoked by symmetry (Barlow & Reeves, 1979; Pecchinenda, Bertamini, Makin, & Ruta, 2014; Tyler, 1995; Wagemans, 1995), figure-ground contrast (Checkosky & Whitlock, 1973; Reber, Wurtz, & Zimmermann, 2004), prototypicality (Posner & Keele, 1968; Winkielman, Halberstadt, Fazendeiro, & Catty, 2006), repeated exposure (Bornstein & D'Agostino, 1994; Jacoby & Dallas, 1981), as well as, potentially, curvature (Bertamini, Palumbo, & Redies, 2019; Treisman & Gelade, 1980; though see Bar & Neta, 2006, 2007).

The salience and ease and speed of processing of symmetry, and our putatively related preference for it, has been highlighted by implicit studies, using measures such as the IAT or preferential looking paradigms in infants, behavioural studies, and by neuroscientific methodologies that point to a dedicated perceptual system for detecting symmetry in humans, and potentially animals (Bertamini, Silvanto, Norcia, Makin, & Wagemans, 2018; Bertamini & Makin, 2014; Bornstein, Ferdinandsen & Gross, 1981; Barlow & Reeves, 1979; Corballis & Roldan, 1975; Evans, Wenderoth, & Cheng, 2000; Höfel & Jacobsen, 2007a, 2007b; Humphrey & Humphrey, 1989; Jacobsen & Höfel, 2001, 2003; Jacobsen *et al.*, 2006; Julesz, 1971; Makin, Pecchinenda, & Bertamini, 2012; Oka, Victor, Conte, & Yanagida, 2007; Pecchinenda *et al.*, 2014; Royer, 1981; Sasaki, Vanduffel, Knutsen, Tyler, & Tootell, 2005; Treder, 2010; Tyler *et al.*, 2005; Vetter, Poggio, & Bülthoff, 1994; Wagemans, 1997; Wagemans, Vangool, & Dydewalle, 1991; Weichselbaum, Leder, & Ansorge, 2018; though see Tjan & Liu, 2005). These

implicit and explicit studies have highlighted the association of symmetry with positive valence and high arousal (Bertamini, Makin, & Pecchinenda, 2013; Bertamini, Makin, & Rampone, 2013; Eisenman, 1967; Eysenck, 1941b; Jacobsen & Höfel, 2002, 2003; Makin, Pecchinenda, & Bertamini, 2012; Makin, Wilton, Pecchinenda, & Bertamini, 2012). However, there have been mixed findings on how automatic such evaluations are (see Höfel & Jacobsen, 2007a; Makin, Pecchinenda, & Bertamini, 2012; Pecchinenda *et al.*, 2014; Treder, 2010).

As such, it may be expected that if perceptual shape characteristics affect the nature of colour-shape correspondences, symmetry may be amongst those characteristics being both readily perceived, salient, and evocative in terms of affective responses. Second, across the shape stimuli tested the expectation would be that when explicitly probed, symmetrical shapes are rated as more pleasurable and arousing than asymmetrical shapes. Additionally, due to higher perceptual fluency, it is predicted that they symmetrical shapes result in faster responses in Experiment 3D, where RTs were collected. Symmetry will be parameterised as a binary variable (asymmetrical vs. symmetrical) and a continuously rated dimension. It should be acknowledged that analysis of symmetry can also be fruitful by differentiating between kinds of symmetry (Palmer & Hemenway, 1978; Turoman *et al.*, 2018; Van der Helm & Leeuwenberg, 1996; Weyl, 1952). However, since the stimuli in Experiments 3A-3D were not systematically designed to represent different kinds of symmetry, this was not a factor that was tested.

3.1.3.1.2 Complexity.

Berlyne (1960, p. 38) defined complexity as the "amount of variety or diversity in a stimulus pattern". Complexity has been suggested to depend on and be measurable by factors such as number of elements, heterogeneity, amount of similarity between elements, order, the regularity of the arrangement, amount of detail, and ambiguity, edge density, perimeters, and compression errors (Berlyne, 1960; Birkhoff, 1932: Forsythe, Mulhern, and Sawey, 2008; Jakesch & Leder, 2015; Machado *et al.*, 2015; Pieters, Wedel, & Batra, 2010; Tinio & Leder, 2009). As Nadal *et al.* (2010) have demonstrated, it is not a straightforward task to capture what is meant by complexity, or whether it performs as a unitary construct in perceptual and aesthetic studies. Indeed, Spence and Wang (2018), highlight that the notion of complexity in the chemical senses (e.g., flavour, aroma) runs into similar issues. For example, the phenomenological experiences and physical/chemical conceptions of complexity can often diverge. For this reason, when comparing between stimuli sets in the experiments below where objective comparison become more difficult due to subtle changes and interplays between new and different features between the kinds of shapes, complexity is conceived of as a rated continuous and subjective measure of complexity, instead of an objectively determined one.

Early theories of complexity often proposed and found an inverted U-shaped function between complexity and preference ratings (Berlyne, 1960, 1971; Berlyne & Peckham,

1966; Birkhoff, 1932; Eysenck, 1942; Friedenberg & Liby, 2016; Roberts, 2007; Saklofske, 1975). Berlyne (1960) described stimulus complexity as having arousal potential and argued that our reward and aversion systems interacted thus making moderately complex stimuli the most preferable by balancing our desire for comfort and lack of monotony (Berlyne, 1970, 1971). Studies have shown that arousal increases with complexity across a variety of stimuli (Berlyne, 1961, 1963; Berlyne, Craw, Salapatek, & Lewis, 1963; Bryson & Driver, 1969; Day, 1967; Eisenman, 1966; Jang, Baek, Yoon, & Choo, 2018; Marin & Leder, 2013; Van Paasschen, Zamboni, Bacci, & Melcher, 2014). Thus, some theorists suggest that because organisms prefer medium levels of arousal (Hebb, 1955; Hunt, 1963), moderately complex stimuli are considered the most pleasant. Overall, much research suggests that complexity is preferred over simpler objects and scenes (Berlyne, 1970; Friedenberg & Bertamini, 2015; Marin & Leder, 2013, 2016; Osborne & Farley, 1970).

However, the relationship of complexity with valence and aesthetic appraisals is not a simple issue to disentangle: Mixed results have been found across several types of stimuli, experiments, and conceptualisations of complexity. U-shaped and increasing and decreasing linear trends have been found too (Gauvrit, Soler-Toscano, & Guida, 2017; Nicki & Moss, 1975; Phillips, Norman, & Beer, 2010; see Nadal *et al.*, 2010, for an overview, and Van Geert & Wagemans, 2019, for a critical review). In fact, a decreasing linear trend would be more in line with the predictions of fluency theory, than the prevailing wisdom that moderate complexity is preferred to simplicity

(Güçlütürk, Jacobs, & Van Lier, 2016; Reber, 2012; Reber, Schwarz, & Winkielman, 2004). Results may also differ starkly by domain and function – research on web or store design, for example, finds that naïve observers prefer visually less complex scenes (Jang *et al.*, 2018; Michailidou, Harper, & Bechhofer, 2008; Tuch, Presslaber, Stöcklin, Opwis, & Bargas-Avila, 2012).

Additionally, other confounding factors may influence subjective perceptions of complexity (Attneave, 1957; Chipman, 1977; Ichikawa, 1985; Nadal *et al.*, 2010) and affective appraisals of complexity. The interplay between complexity and symmetry has, for example, been found to be crucial for affective appraisals of complexity, with complex symmetrical shapes being preferred over simple symmetrical shapes (Day, 1968; Eisenman & Gellens, 1968). Bies, Blanc-Goldhammer, Boydston, Taylor, and Sereno (2016) found that for exact fractals, symmetry could increase preference ratings at lower levels of recursion and complexity, than was possible without symmetry. Additionally, increased complexity combined with increased internal repetition within fractal patterns, was also found to improve experienced ease of solving puzzles after presentation.

This positively reinforcing relationship of symmetry (or other regularities) and complexity may exist, in part, since symmetrical displays have been found to help with disregarding redundant information processing, allowing for faster scene processing (Apthorp & Bell, 2015). This increases processing fluency (Reber, Schwarz, &

Winkielman, 2004) and reduces informational load, perceived complexity, ambiguity, and offers a higher-order structure to detect regularity (Garner, 1962, 1974; Gartus & Leder, 2017; Nicki, Lee, & Moss, 1981; Palmer & Hemenway, 1978; Tinio & Leder, 2009; Wagemans, Van Gool, Swinnen & Van Horebeek, 1993). Additionally, previous exposure to simple or complex shapes, as well as repeated exposure to reduce novelty, can affect complexity preferences. This may occur by potentially affecting both liking and arousal reactions to the stimuli (see Tinio & Leder, 2009, for excellent discussion of these issues as well as exploration of how complexity and symmetry interact).

Moreover, Güçlütürk *et al.* (2016) found large individual differences in complexity preference ratings between participants and review the evidence for the fact that this finding has been documented by other studies. They find evidence for two clusters of individuals – one cluster preferring simplicity, and another preferring complexity. Spehar *et al.* (2015) found that even individual differences in sensitivity to simple visual patterns affects aesthetic preferences. Those participants that showed high sensitivity to sine-wave gratings, also preferred simple visual patterns, speaking to a potential processing fluency account of how individual differences may affect preferences.

To address this call to investigate the effect of individual differences on visual preferences, the effect of several psychometric constructs on the effect of complexity, symmetry, and angularity on shape liking were examined in Experiments 3A, 3B, and

3C. It should be noted, though, that such analyses can lead to certain ambiguities of interpretation: Street, Forsythe, Reilly, Taylor, and Helmy (2016) found that mid-range fractal images were preferred, thus corroborating both early research findings such as those by Berlyne (1970), but also those of studies conducted with fractal dimensions (Taylor, Spehar, Hagerhall, & Van Donkelaar 2011). However, both culture and gender were found to significantly affect whether this mid-range fractal preference was instantiated. Indeed, this ambiguity of universality called into question by individual differences is one that needs to be conceptually wrestled with not only within the field of empirical aesthetics as Street *et al.* (2016) suggest, but also within the intramodal and crossmodal correspondence fields.[16]

In addition to individual differences, it appears that there may be stimuli differences that can affect complexity preferences. Adkins (2016, data published as well in Adkins & Norman, 2016) found that for solid, filled-out snowflake shapes, the simplest and most complex shapes were most preferred, whilst moderately complex shapes were rarely chosen. The snowflake stimuli, however, showed an increase in aesthetic ratings with increased complexity, with the least complex snowflakes rarely being chosen over the most complex ones. This may be particularly relevant to the mandala stimuli used in Experiment 3B and 3D, which have structural similarities to snowflakes.

[16] See Chapter 5, Section 5.2.2.2, for further discussion on this tension between universality and inter-individual variation.

In the light of the mixed findings discussed above, it is difficult to predict what the effect of complexity will be on preference ratings. For mandala shapes the expectation may be a linear increase in preference with increased complexity. For the more typical polygons used in the geometric stimuli set of Experiment 3A and 3D, it may be more likely that the inverted U-shape is found as in previous experiments, although this is generally not in line with what would be expected from processing fluency accounts of aesthetic and affective experiences. Finally, previous research suggests that there may be interactions between complexity and symmetry in predicting shape liking, such that increased symmetry improves liking for highly complex shapes. In regard to shape arousal, the evidence would appear to point to a more straightforward increase in arousal with increased complexity.

3.1.3.1.3 Angularity and curvature.

The idea that lines can express emotions is by no means novel (Gordon, 1909; Kandinsky, 1914; Lundholm, 1921; Poffenberger & Barrows, 1924), and how liking and arousal can be affected by complexity and symmetry when lines coalesce into collative forms has already been discussed above. The beauty and aesthetics of curvature has fascinated philosophers, psychologists, mathematicians, and other thinkers for hundreds of years (e.g., Allen, 1877; Hogarth, 1753; Lockwood, 1961; Spencer, 1873; for reviews of the history of curvature and aesthetics, see Bertamini & Palumbo, 2015; Gómez-Puerto, Munar, & Nadal, 2016). Hogarth (1753) even named a particular S-

shaped curve the *line of beauty*, and a serpentine line, that similarly balanced tapering and bulging, the *line of grace*. Indeed, the use of curves, rounded features, spiralling lines, gaping concavities, bulging convexities, and undulating features has been found in art from prehistoric times, throughout artistic movements, to the present day (Bertamini *et al.*, 2016; Bertamini & Palumbo, 2015; Clottes, 2003; Collins, 2005; McDermott, 1996; McRobie, 2017).

The evidence for our liking of curvature being driven by perceptual fluency explanations is mixed: We do have dedicated cortical cells and streams dedicated to perceiving curvature and angularity (Bar & Neta, 2007; Hubel & Wiesel, 1968; Pasupathy & Connor, 2002; Vuilleumier, Armony, Driver, & Dolan, 2003). Additionally, humans find curved features easier to detect than non-curved ones (Ruta, Palumbo, & Bertamini, 2014; Treisman & Gelade, 1980). However, this does not appear to transfer to the time taken to rate the preferred curved stimuli (Bar & Neta, 2006, 2007).

In the aesthetic sciences, explicit and implicit appraisal-based studies of curvature have been consistent in demonstrating our preference for curves over angularity. Bertamini *et al.* (2016), for example, found that curved lines were preferred to both straight and angular lines. Curved abstract shapes were also more liked than angular shapes, regardless of perceived complexity (though see Palumbo & Bertamini, 2016, who found subtle effects of complexity). This preference for curvature phenomenon is a robust

effect and has been replicated by both implicit and explicit paradigms using a variety of shapes, objects, and even photos on Instagram (Bar & Neta, 2006; Corradi *et al.* 2019; Cotter, Silvia, Bertamini, Palumbo, & Vartanian, 2017; Dazkir & Read, 2012; Jadva, Hines, & Golombok, 2010; Leder & Carbon, 2005; Leder *et al.*, 2011, Silvia & Barona, 2009; Thömmes & Hübner, 2018; Vartanian *et al.*, 2013). This preference may even be found in great apes (Munar, Gómez-Puerto, Call, & Nadal, 2015; Munar, Gómez-Puerto, López-Navarro, & Nadal, 2014), as well as infants as young as 1-week of age (Fantz & Miranda, 1975).

Studies using manikin tasks[17] have shown that these preferences are likely due to an approach stance towards curvature, rather than the avoidance of angularity (Bertamini *et al.*, 2016; Palumbo *et al.*, 2015). Additionally, this effect may not hold true for objects having a negative emotional valence, rather than a positive or neutral one (Leder *et al.*, 2011). Consider, for example, the serpentine curves of a snake, which are less likely to trigger an approach stance in most individuals. Generally, though, curved shapes are associated with positive valence, safety, female gender, and emotions of relief. Angular shapes have been found to be associated with threat, negative valence,

[17] Manikin tasks involve a stick figure that the participant has to move through a visual field towards and away from a shape in way that mimics walking. In this way approach/avoidance tendencies are measured by measuring how fast individuals move the stick figure towards a shape (approach) versus away from it (avoidance; see, Palumbo *et al.*, 2015).

excitement or surprise, and male gender (Blazhenkova & Kumar, 2018; Hevner, 1935; Palumbo *et al.*, 2015; Poffenberger & Barrows, 1924).

Lines and simple geometric shapes that reflect facial expression have been found, in particular, to convey emotions (e.g., Lundqvist, Esteves, & Öhman, 1999; Salgado-Montejo *et al.*, 2017). The universality of how emotions are expressed using facial musculature and displays (Darwin, 1872/1998; Ekman 1973, 2003; Ekman, Friesen, & Hager, 2002), and the potential for innate facial expression feature detectors (Ekman 1982, 2003), suggests that these mechanisms could contribute to affective evaluations of line and shape cross-culturally. Angular shapes, in particular those instantiating a downward pointing 'V', reminiscent of the angled eyebrows and facial features of someone who is angry, have been associated to threat, attentional capture, and anger. Rounded shapes, on the contrary, replicating the contours of a happy face, are associated with positive valences, happy meaning, and do not show the same rapid response and attentional capture (Aronoff, 2006; Aronoff, Barclay, & Stevenson, 1988; Aronoff, Woike, & Hyman, 1992; Larson *et al.*, 2007; Larson, Aronoff, Steuer, 2012; LoBue & Larson, 2010; Watson, D.G., *et al.*, 2012; Watson, D.G., Blagrove, & Selwood, 2011). Neuroimaging studies have found that the amygdala, crucial in threat and arousal processing, is more activated when angular, sharp objects are presented in comparison to curved ones. This also holds true when a downward pointing 'V' is shown instead of an upwards-facing version of the grapheme (Bar & Neta, 2007; Larson *et al.*, 2009; though see Vartanian *et al.*, 2013).

Whilst much is written about the positive valence and beauty of curves, and association of angularity with threat (and as such, low-valence and high-arousal), the literature is far less extensive on the question of arousal appraisals of curvature. Collier (1996) finds that curved shapes are associated with the notions of peace, calm, relaxation, and soothing in the positive and low-activity category, but with positive high-activity words such as merry, love, pleased, and proud too. Blazhenkova and Kumar (2018), found that curved shapes were associated with relieved emotions (positive valence, low arousal). As such, it is predicted that participants will exhibit a preference for curvature across Experiments 3A, 3B, and 3C, and are more likely to rate angular shapes as more arousing, due to the strong evidence linking angularity to threat detection and processing.

3.1.3.2 Colour preferences.

Colour preference theories and research similarly has a long history (e.g., Ball, 1965), that generally points to replicable and consistent effects in colour preferences (for reviews, see Palmer, Schloss, & Sammartino, 2013; Eysenck, 1941a; Granger, 1955; Guilford & Smith, 1959). Cross-cultural differences in preference do still appear to exist (Choungourian, 1968; Hurlbert & Ling, 2007; McManus, Jones, & Cottrell, 1981; Ou, Luo, Woodcock, & Wright, 2004a, 2004c; Palmer & Schloss, 2010; Saito, 1996; Taylor, Clifford, & Franklin, 2013; Taylor & Franklin, 2012; Yokosawa, Schloss, Asano, & Palmer, 2016), as well as gender differences (e.g., Chiu *et al.*, 2006; Hurlbert

& Ling, 2007; Lobue & DeLoache, 2011; Taylor & Franklin, 2012). Much like shape, a plethora of studies have shown that colours have affective and semantic associations (Albertazzi, Canal, Malfatti, & Micciolo, 2013; Albertazzi, Koenderink, & Van Doorn, 2015; Collier, 1996; D'Andrade & Egan, 1974; Da Pos & Green-Armytage, 2007; Feng, Lesot, & Detyniecki, 2010; Hevner, 1935; Nijdam, 2009; Norman & Scott, 1952; Ou *et al.*, 2004a, 2004b, 2004c; Pressey, 1921, Wright & Rainwater, 1962). Colours may even affect psychological functioning, although, as Elliot (2015) points out in his review, the field is a "nascent stage of development" (p. 1). Whilst less space and analysis are dedicated to the affective appraisals of colours, the aim is to replicate the results of Palmer and Schloss's (2010) influential ecological valence theory (EVT) of human colour preference. The theory posits that colour preferences are strongly determined by the average affective responses individuals have to objects of a specific colour. It aligns itself with evolutionary and functional theories of colour preferences that suggest that colour preferences are in essence adaptive to navigating the world in a successful way (Humphrey, 1976; Hurlbert & Ling, 2007). EVT combines this with the well-evidenced notion that ontogenetic and individual-level affective and semantic learning that occurs about colour-related outcomes during a person's lifetime affect colour preferences (Schloss & Palmer, 2014; Schloss, Poggesi, & Palmer, 2011; Strauss, Schloss, & Palmer, 2013; Taylor, Schloss, Palmer, & Franklin, 2013).

So, for example, Palmer and Schloss (2010) suggest that blues are often preferred due to their association with clean water and blue skies (both having a positive valence),

whilst browns would be strongly disliked due to their association with negatively valenced objects such as faecal matter and rotten food. Here, crucially, object associations are measured by those generated first and most commonly, since of course, any colour is likely to be associated with a number of both positively and negatively valenced objects (e.g., brown and a deliciously crispy roast duck). The EVT model tests such object-colour-emotion associations outright and outperforms models that predict colour preferences solely on colour-emotion associations (Ou *et al.*, 2004a, 2004c) as well as colour appearance models that use dimensions of colour appearance such as red/green or light/dark, as will be made use of in the experiments of this chapter for our perceptual parameterisation of colour (Palmer & Schloss, 2010). As a side note, this use of continuous dimensions avoids, in large part, having to wrestle with the debate concerning whether colour categories are universal or culturally diverse (for discussion on the issue, see Da Pos & Albertazzi, 2010; Jameson, 2005; Roberson, 2005; Roberson, Davies, & Davidoff, 2000). Provided, of course, like in Experiment 3D, each individual rates the colours on these bipolar dimensions for themselves.

Additionally, the same EVT methodology has had success in predicting individual differences in colour preferences by taking into account the particular affective responses of each person to coloured objects (Schloss, Hawthorne-Madell, & Palmer, 2015). Overall, in line with both EVT and previous colour preference research (Crozier, 1999; Palmer & Schloss, 2010; Palmer, Schloss, & Sammartino, 2013), it is expected that blues, greens, and cooler colours, generally rank higher in liking than warmer

colours, in particular, browns. Moreover, the fact that taking into account individual affective associations results in better colour preference predictions, supports the idea of evaluating each individual's colour preferences when investigating the potential effect of emotional mediation on colour-shape correspondences (see also, Palmer, Schloss, & Griscom, 2016; Soriano & Valenzuela, 2009).

The determination of the affective associations of shapes and colours is, of course, an interesting field of study in-and-of-itself. But the research detailed above also shows why the choice of stimuli used in the experiments of this chapter allow the investigation of the emotional mediation hypothesis for colour-shape correspondences across a wider range of liking and arousal appraisals. By varying shapes along dimensions that previous research has shown affects affective appraisals, and offering a breadth of colours with different valences, within in a non-restrictive task (unlike the classic Kandinsky colour-shape matching task where often colours have to be chosen exclusively for one shape), participants were given the opportunity to be led in their choices by wider gamut of nuanced affective, semantic, and perceptual responses to the stimuli for each match.

3.1.4 Shape characteristics, intuitiveness, and individual differences.

Work has also been conducted into the individual differences in aesthetic appreciation (e.g., Jacobsen, 2004a, 2010; Ling & Hurlbert, 2009; McManus, 1980) and preference for specific features such as harmony (Palmer & Griscom, 2013), complexity (Bryson

& Driver, 1972; Eisenman, 1968; Lyssenko, Redies, & Hayn-Leichsenring, 2016), and angularity/roundedness (Jodar, 2015; Silvia & Barona, 2009; Zhang, Feick, & Price, 2006). Although it should be noted that not all necessarily find that individual differences play a large part in aesthetic preferences (e.g., McManus, Cook, & Hunt, 2010; Palmer & Griscom, 2013). However, preliminary experiments conducted for this thesis strongly hinted at a vast amount of variation in individuals' colour-shape association responses to the task used in the following experiments. Assume, as predicted, that affective appraisals do, at least in part, factor into colour-shape correspondences. In that case, considering how individuals may differ in how they process colours and shapes due to potential perceptual differences (e.g., in visual mental imagery), but also in how they react, retrieve, and process threat, novelty, arousal, pleasure, and emotions more broadly, could allow us to better understand colour-shape correspondences. This would improve our overall understanding of what individual differences exist in the affective appraisals of shape characteristics.

Indeed, research has shown that evidence exists that individuals' temperament in terms of the pleasure-arousability-dominance (PAD) model can predict and is related to a variety of personality variables (Mehrabian, 1996a, 1996b; Zhang & Li, 2014). These three traits were suggested by Mehrabian and Russell (1974) to map onto Osgood's (1960) evaluation, activity, and potency factors derived from the semantic differential technique (Osgood *et al.*, 1957). They reflect how individuals react to positive/negative, low/high arousal, and uncontrollable/controlled states (for a review

of this PAD model, see Bakker, Van der Voordt, Vink, & Boon, 2014). Here evaluation and pleasure concepts from the two models are relevant to our measure of liking (unpleasant-pleasant) in the following experiments, and the activity and arousability factors reflect our arousal dimensions (not at all arousing-very arousing).

Furthermore, early laboratory study debriefings revealed that individuals had different responses to the long and repetitive task of matching numerous shapes to colours. Whilst the majority did not give any feedback, some felt the task was unintuitive and required almost random choices to be made. Others felt deeply connected to making such connections between colours and shapes and even invigorated by the experience of delving deeper into their intuitions about such associations. The role individual differences may play in intuitiveness ratings will thus be explored.

Additionally, of course it may be that certain matches feel more intuitive and 'right' to individuals than others. Therefore, the aim was to explore how shape characteristics at the match-by-match level may be influencing intuitiveness ratings of each shape-colour match. The question is one that is related to the fluency theory discussed above but rather requires a meta-cognitive response from the participant on how congruent the match felt[18]. If certain shape characteristics are processed more readily (e.g., symmetry), and certain matches are made for more positively valenced shapes (e.g.,

[18] It should be noted that this is slightly different to the meta-cognitive measure probed by Y.-C. Chen *et al.* (2019).

curvature), and some matches are more affectively congruent to their chosen colour match, it might be expected that these matches feel more 'right' and intuitive to the individual. Additionally, as for affective shape appraisals, how individual differences may be contributing to intuitiveness ratings will be explored.

The individual difference measures that were chosen to be explored in regard to these two questions – the effect of shape characteristics on affective appraisals and how individuals may differ in their intuitiveness ratings of their matches – were openness, visual mental imagery, autistic traits, alexithymia, and extraversion. This type of individual differences work is largely exploratory, in particular in regard to how individual experience the intuitiveness of the colour-shape matching task. Nevertheless, why these constructs were chosen is detailed below, alongside some predictions on how they will moderate effects.

3.1.4.1 Openness.

Due to the lack of consistent results found for creativity in Chapter 2, the conceptual and practical difficulties arising out of analysing and evaluating creativity measures, and the fact that "creativity remains an academic backwater" (Batey & Furnham, 2006, p. 361), it was decided that the studies of Chapter 3 would explore the different yet related measure of 'Openness to Experience'. Openness has been found to be associated with creativity and synaesthesia. Rader and Tellegen (1987), for example, found that absorption (a measure of openness to imagination and responsiveness to

stimuli) was associated with the emotional, cognitive, and visual experiences of colour-auditory synaesthetes. Banissy *et al.* (2013) found that synaesthetes exhibited higher 'Fantasizing' (Interpersonal Reactivity Index; Davis, 1980), lower 'Agreeableness', and stronger 'Openness'. This latter Big Five personality measure is often found to be associated with creativity, artistic preferences and attainment, imagination, unconventionality, sensitivity to emotions, and absorption (Batey & Furnham, 2006; Chamorro-Premuzic, Reimers, Hsu, & Ahmetoglu, 2009; Cleridou & Furnham, 2014; Costa & McCrae, 1992; Feist, 1998; Feist & Brady, 2004; Furnham, 1999, Furnham & Chamorro-Premuzic, 2004; Glisky, Tataryn, Tobias, Kihlstrom, & McConkey, 1991; Kaufman, 2013; McCrae, 1996; McCrae & Sutin, 2009; Oleynick *et al.*, 2017; Saucier, 1992; Silvia, 2007). Despite the separateness of synaesthesia and crossmodal correspondences, it may similarly be the case that individuals who are higher in openness experience the shape-colour matches they make as more intuitive, by simply being more motivated to engage with and be absorbed by this new kind of task that involves imagination and, potentially, creativity.

In regard to the effect of openness as a moderating variable on the effect of shape characteristics on shape liking, research that has considered openness, but also associated concepts such as creativity and dogmatism, is taken into account. Previous research has suggested that creative individuals prefer complexity and asymmetry (Barron, 1963; Eisenman & Robins, 1967; Taylor & Eisenman, 1964), whilst more dogmatic and less open-minded individuals dislike complexity (Rouff, 1975).

Additionally, research using the PAD model has highlighted that individuals high in openness show high arousability (Mehrabian, 1995, 1996a, 1996b). As such, it would be expected that individuals higher in openness potentially react positively to shapes exhibiting higher arousal. Cotter *et al.* (2017) used multilevel models to explore whether shape characteristics and individual differences interacted to affect preference for curvature. Whilst for irregular polygons, those higher in openness and artistic expertise, showed an increased preference for curvature (vs. angularity), this was not found to another set of stimuli made up of circles and hexagons. Therefore, individual's openness may be predicted to positively moderate the effect of curvature on shape liking. However, it should be noted that results with a related construct – expertise in the arts – have shown mixed results on whether experts are more or less affected by the lower level stimulus features of angularity and curvature in terms of aesthetic preferences (Silvia & Barona, 2009)

3.1.4.2 Visual mental imagery.

Vivid visual mental imagery is associated with synaesthesia, including grapheme-colour synaesthesia (Barnett & Newell, 2008; Meier & Rothen, 2013, Simner, 2013; Spiller, Jonas, Simner, & Jansari, 2015). Grapheme-colour synaesthesia has even been suggested to be a conditioned type of mental imagery (Witthoft *et al.*, 2015). Whilst synaesthesia and crossmodal correspondences are separate phenomena (Deroy & Spence, 2013), mental imagery has been suggested as a possible influence on crossmodal

correspondences that needs to be explored (Deroy & Spence, 2016; Spence & Deroy, 2013b). As such, what the effect of visual mental imagery is on how intuitive individuals experience the task to be will be explored. It may be helpful, for example, to be able to visually imagine the shape in a specific colour to make a match that feels particularly 'right'. Similarly, by being able to hold shapes in the mind's eye more vividly, individuals may have different affective appraisals of shape characteristics. Generally, they may be expected to be more reactive to the affective associations of shapes.

3.1.4.3 Alexithymia and autistic traits.

With an eye towards the affective mechanisms that have been suggested to underlie colour-shape correspondences, and the evidence in Chapter 1 that these do indeed play a role, individual measures tapping into differences in emotion retrieval and expression, threat processing, and affective states seemed pertinent to include. Alexithymia and autistic traits were thus chosen as individual differences to be examined in regard to both affective responses to shape and the intuitiveness with which individuals experience completing the shape-colour matching task.

The subclinical construct and trait of alexithymia represents a reduced ability to identify and verbalise feelings, interocept and introspect experienced emotions and bodily sensations such as arousal, reduced imagination, and an externally-oriented cognitive style (Berenbaum & Irvin, 1996; Brewer, Cook, & Bird, 2016; Herbert,

Herbert, & Pollatos, 2011; Murphy, Brewer, Hobson, Catmur, & Bird, 2018; Sifneos, 1972; Taylor, 1994; though see Bausch *et al.*, 2011, for evidence that imaginative abilities are not reduced). Individuals high in alexithymic traits have been found to have a differential modulation of valence and arousal in comparison individual who are low-alexithymic (Heinzel *et al.*, 2010; Peasley-Miklus, Panayiotou, & Vrana, 2016; Van der Velde *et al.*, 2013). High alexithymic individuals show particular high autonomic arousal at the onset of affective or perceptual stimulation, as well as increased ease of excitation and a lower sensory threshold (Bogdanov *et al.*, 2013; Deng, Ma, & Tang, 2013; Liss, Mailloux, & Erchull, 2008; Nyklíček & Vingerhoets, 2000; Sivik, 1993). However, those higher in alexithymic traits are less responsive to their feelings and levels of arousal, especially those elicited by negatively valenced stimuli (Constantinou, Panayiotou, & Theodorou, 2014; Meltzer & Nielson, 2010; Papciak, Feuerstein, & Spiegel, 1985; Pollatos, Schubö, Herbert, Matthias, & Schandry, 2008). This suggests that whilst alexithymic individuals may show higher autonomic arousal to high arousal shape stimuli, this may go unnoticed, be difficult to process consciously, and exhibit in explicit behaviour (Vermeulen, Luminet, & Corneille, 2006). Thus, it was predicted that high-alexithymic individuals have lower effects of arousal on their affective appraisals.

Whilst individuals with autism, or those higher in autistic traits in the general population (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), can be more sensitive to perceptual stimuli, this is often paired with reduced sensitivity to the

emotional and interpersonal subtleties of the associated information (Celani, Battachi, & Arcidiacono, 1999; Liss, Saulnier, Fein, & Kinsbourne, 2006; Sasson, Dichter, & Bodfish, 2012; Watling, Deitz, & White, 2001). The Autism Spectrum Quotient (AQ, Baron-Cohen *et al.*, 2001) captures the increased attention to details yet reduced interpersonal skills associated with increased autistic traits in the general population (Austin, 2005; Hurst, Mitchell, Kimbrel, Kwapil, & Nelson-Gray, 2007; Ruzich *et al.*, 2015). In the general population, this autism-related trait of attention to detail was related to aesthetic sensitivity (Liss *et al.*, 2008), indicating that those higher in autistic traits may find the repetitive, detail-oriented task of making shape-colour matches more intuitive. Indeed, research shows that individuals with higher autistic traits show far higher levels of abilities to imagine emotion-related words and theoretical concepts, which Esposito, Dellantonio, Mulatti, and Job (2016, p. 1) suggest "would allow people with marked autistic traits to make use of perceptual, possibly visuo-spatial, information for 'higher' cognitive processing". As such, it is predicted that higher autistic traits result in higher intuitiveness of the abstract shape-colour matching task that can also be solved using perceptual, semantic, and emotional mental imagery. Since the task is intramodal and subclinical levels of autism were probed, the findings of reduced crossmodal correspondences in individuals with clinical levels of autism, are not deemed applicable in reducing the intuitiveness of the task (e.g., Occelli *et al.*, 2013).

The evidence for the relationship between affective responses and autism is far more mixed in terms of valence and arousal, as well as limited in terms of non-social affective cues (see for a review, Lydon *et al.*, 2014; Bölte, Feineis-Matthews, & Poustka, 2008; Rogers & Ozonoff, 2005; Sasson *et al.*, 2012). However, the increased attention to detail those higher in autistic traits exhibit, may make them more sensitive to perceptual features that are commonly associated with positive valences (e.g., curvature, symmetry). This may be much like the reverse of the suggestion that higher expertise makes you potentially more likely to take into account more global, top-level domain knowledge when making affective judgments (Silvia & Barona, 2009). Additionally, the potential co-morbidity with obsessive-compulsive phenomena (Fischer-Terworth & Probst, 2009; Neil & Sturmey, 2013), and the associated need for symmetry (see for an overview, Summerfeldt, Gilbert, & Reynolds, 2015), may further suggest that individuals with higher autistic traits have a stronger preference for symmetry and dislike for asymmetry than those who score lower on the AQ.

Finally, it should be noted that a recent line of research has highlighted the co-morbidity of alexithymia with autistic traits in diagnosis (Gaigg, Cornell, & Bird, 2018), with the possibility of some traits commonly associated with autism, such as low empathy and reduced interoceptive abilities, in fact being driven by alexithymic traits (Bird *et al.*, 2010; Shah, Hall, Catmur, & Bird, 2016). As such, lower emotional awareness and interoceptive abilities that have also been found in those higher in

autistic traits (Silani *et al.*, 2008), may make them less sensitive to emotional stimuli high in arousal, similar to high-alexithymic individuals

3.1.4.4 Extraversion.

Several researchers have found that introverts preferred more complex stimuli, and extraverts preferred more simple stimuli (Burt, 1937; Eysenck, 1947; Lynn & Butler, 1962). Bryson and Driver (1972) found that preferences for complexity varied along the introversion-extraversion dimensions too, although results depended on cognitive complexity-simplicity of the individual. The explanation that has been offered here is that extraverts search for arousal from the external environment that results in behavioural activity, whilst introverts seek internal stimulation to create cognitive activity, which may still be caused by an external stimulus (Jung, 1923; Eysenck, 1947). This seems, though, like an inadequate explanation to explain why introverts and extraverts react differentially since both could ultimately enjoy an increase in stimulation that is caused by an external stimulus. In the PAD model, extraversion is found to be associated with pleasant, arousable, and dominant temperaments (Mehrabian, 1995, 1996a), which could predict potentially the opposite: that high arousal (vs. low arousal) stimuli are preferred by extraverts (vs. introverts).

3.1.5 Statistical and conceptual issues.

As mentioned in Chapter 1, Section 1.2.4.1, residual analyses that rely on the Chi-square test statistic run fowl of the assumption of independence, unless each shape is

analysed separately. This, previously noted, is also true of log-linear analyses which are a multidimensional extension of a Chi-square crosstabulation (Scheepers, 2018). However, when each shape is analysed separately, this assumes that the best way to know if colour-shape correspondences exist and to determine their nature is by assuming that each colour is equally likely to be chosen *ceteris paribus*. A full cross-tabulation Chi-square analysis takes into account how often a colour is chosen in total across all shapes to determine residuals. Indeed, it is certainly not the case that all colours are chosen at chance level when a large number of choices are made. But researchers may certainly be interested in what the results are under both kinds of expected distributions of colour choices.

In Experiment 3D a total of 6804 colour choices were made. But regardless of whether one tests for equal frequencies between each of the 36 colours 3D ($\chi 2$ (35) = 16367.82, $p < .001$, Cramér's $V = .51$), or the 36 colours divided into 12 hues 3D ($\chi 2$ (11) = 5620.68, $p < .001$, Cramér's $V = .30$), the Chi-square test statistic remains significant, indicating that some colours are chosen more than others overall. For 36 colours, it would be expected at chance level that each colour is chosen 189 times. Table 3.1 presents how often each of the 36 colours is chosen across the entire experiment, alongside the absolute value residual and standardised residual. The saturated red (observed $n = 429$, standardised residual = 17.46), saturated yellow (observed $n = 400$, standardised residual = 15.35), saturated blue (observed $n = 345$, standardised residual = 11.35), white (observed $n = 358$, standardised residual = 12.29), and black

(observed $n = 272$, standardised residual = 6.04) have large and positive standardised residuals, indicating they are chosen significantly more than would be expected under an equal distribution between colours. Meanwhile, colours such as dark brown (observed $n = 79$, standardised residual = -8.00), dark purple (observed $n = 78$, standardised residual = -8.07), and dark orange (observed $n = 57$, standardised residual = -9.60), are notably unpopular.

The fact that the precise colours that Kandinsky also chose as his primary colours for his correspondences – a saturated red, yellow, and blue – is interesting. Indeed, it should be noted that all five colours also feature amongst the most frequently chosen colours for letters in the alphabet in grapheme-colour synaesthesia (Witthoft *et al.*, 2015). This may speak to the prototypicality of these colours in people's colour spaces when making sensory associations. This is in line with research that has attempted to find universal colour categories, where colour terms are found to divide colour space into the colour clusters of black, white, red, blue, yellow, and green (e.g., Cook, Kay, & Regier, 2005; Regier, Kay, & Cook, 2005; though see Roberson *et al.*, 2000). Additionally, it may be grounded at the physiological level by three types of photoreceptors in the human eye (Gegenfurtner, 2003), as well as the colour-opponent cortical processing of colour (Kay & McDaniel, 1978), which is also reflected in early and modern colour vision theories (De Valois. R.L., & De Valois, K.K. 1993; Hering, 1920/1964; Hurvich & Jameson, 1957). Additionally, there is some evidence that

primary colours may, to a certain extent, be more salient than secondary colours even in infancy (Franklin *et al.*, 2008).

In the associated field of grapheme-colour synaesthesia, letters are also more frequently associated with colours that are easier to generate and those that occur earlier in learning (Berlin & Kay, 1969; Root *et al.*, 2018; Simner *et al.*, 2005; Simner & Ward, 2008; Van Leeuwen, Dingemanse, Todil, Agameya, & Majid, 2016). However, the ranking of colours does not always align with the one found here in the case of colour-shape associations. Additionally, two things should be noted: First, the notable absence of green in the most commonly chosen colours. Second, the fact that the three primary colours red, blue, and yellow, are unlikely to be the three colours most likely to be associated with objects in our natural environment is problematic for proponents of the notion that colour-shape correspondences are in the first instance driven by object associations.

Colour preferences alongside perceptual colour salience – that some colours may simply be more attention-grabbing in the colour array presented to individuals – likely influence this distribution of colour choices as well. Of course, it may simply be that, assuming colour-shape associations exist, the specific shapes chosen for this study simply are associated with these colours. In addition, colour-shape correspondences may be more likely to involve colours which are primary in people's colour spaces, and

less likely to involve colours which may be considered less attractive (e.g., certain browns).

If one were to decide, however, to continue to be interested in evaluating each shape separately under an expected equal distribution, it would require in our case 172 separate Chi-square tests in total (86 shapes, each tested twice, in separate experiments). Incidentally, like post-hoc tests conducted on analysis of variance omnibus results, large Chi-square tables, as well as repeated partitioning of a larger Chi-square table, may require corrections for multiple comparisons and potential adjustments of the critical value for standardised residuals (MacDonald & Gardner, 2000; Sharpe, 2015). In practice, this is rarely, if ever, done. Clearly, Chi-square analyses are not an ideal way of evaluating such data. Especially since it is unclear whether by separating out the data into shapes, the fact that the observations within a participant for all shapes may be non-independent and correlated is not simply just ignored instead of taken into account (consider, for example, Hays, 1994). Incidentally, the multinomial logistic regression models used in Chapter 2 become equally unwieldy, considering a multitude of tests would have to be run to allow all shapes to be compared against one another as a reference category, and additionally compare all colours to one another (six tests were required alone to do this for a set of three shapes and three colours for each experiment in Chapter 2).

*Table 3.1 Table showing the frequency of colour choices across all matches made in Experiment 3D. Standardised residuals of 2 or above (**bold**) indicate the colour was chosen significantly more than would be expected chance, whilst standardised residuals of -2 or below (underlined) indicate the colour was chosen significantly less than would be expected by chance.*

Colour	Colour name	Observed N	Expected N	Residual	Standard-ised residual
1	Light red	141	189	-48	-3.49
2	Saturated red	429	189	240	**17.46**
3	Dark red	167	189	-22	-1.60
4	Light orange	135	189	-54	-3.93
5	Saturated orange	215	189	26	1.89
6	Dark orange	57	189	-132	-9.60
7	Light yellow	194	189	5	.36
8	Yellow	400	189	211	**15.35**
9	Dark yellow	151	189	-38	-2.76
10	Light green	149	189	-40	-2.91
11	Saturated green	209	189	20	1.45
12	Dark green	146	189	-43	-3.13
13	Light aquamarine	125	189	-64	-4.66
14	Saturated aquamarine	178	189	-11	-.80
15	Dark aquamarine	203	189	14	1.02
16	Light sky	195	189	6	.44
17	Saturated sky	125	189	-64	-4.66
18	Dark sky	115	189	-74	-5.38
19	Light blue	196	189	7	.51

20	Saturated blue	345	189	156	**11.35**
21	Dark blue	187	189	-2	-.15
22	Light purple	194	189	5	.36
23	Saturated purple	137	189	-52	-3.78
24	Dark purple	78	189	-111	-8.07
25	Light pink	181	189	-8	-.58
26	Saturated pink	222	189	33	**2.40**
27	Dark pink	224	189	35	**2.55**
28	Light brown	195	189	6	.44
29	Saturated brown	167	189	-22	-1.60
30	Dark brown	79	189	-110	-8.00
31	White	358	189	169	**12.29**
32	Light grey	207	189	18	1.31
33	Grey	161	189	-28	-2.04
34	Dark grey	128	189	-61	-4.44
35	Darkest grey	139	189	-50	-3.64
36	Black	272	189	83	**6.04**

Unfortunately, however, the issues of the Chi-square test go beyond potential violations of the assumption of independence and ambiguity over whether cells should be compared against an equal distribution across colour choices or one adjusted by the total number of times each colour was chosen in total. Whilst significant associations were found between specific shapes and colour hues in both Experiments 3A, 3C, and 3D using Chi-square analyses (the interested reader can find the results in Appendix

6.9), it is difficult with this type of analysis to make testable hypotheses for future research that extend beyond the specific stimuli sets used. The reason for this is that each shape has its own set of perceptual characteristics that cannot readily be compared to another shape without further analysis and conceptualisation of each shape. This can either be done, in the case of this particular data, by subjective 'eye-balling' of the data after a residual analysis or further collapsing of shapes into categories. This latter course of action would again trigger the violation of independence assumption even if each category was now tested separately (see Sharpe, 2015, for useful discussion of how to deal with a statistically significant Chi-square test in cases where it is an appropriate method of analysis for one's data).

It is prudent to keep in mind best practice of how many observations should be made per condition to allow well-founded, adequately powered conclusions to be made (Brysbaert & Stevens, 2018; Westfall, Kenny, & Judd, 2014), to avoid contributing further to the replication-crisis the field of psychology is currently faced with (Loken & Gelman, 2017; Open Science Collaboration, 2015; Schönbrodt, Morey, Yao, Gelman, & Wagenmakers, 2017). This is a condition that is not going to be fulfilled by comparing a limited number of shapes, in a post-hoc manner with each condition containing but a handful of examples tested on a relatively low number of participants. Brysbaert and Stevens (2018) provide helpful guidelines of how this may play out depending on your design (between-participants, repeated measures) and expected effect sizes. So, for example, they note: "If you want to play safe and assume an effect

size of $d = .3$, you require 175 participants per condition in a between-participants design, and 89 participants in a repeated measures design" (p. 2) Of course it can be difficult to know what effect size to calculate from, especially in a field where these are rarely reported, but the authors suggest that effect sizes between $d = .3$ and .4 are most common in psychology. For RT experiments that want to interpret 15ms differences this would equate to "1,600 observations per condition in designs with repeated measures" (Brysbaert & Stevens, 2018, p. 16) spread-out over all participants. If one considers the small to moderate effect sizes found using the inappropriate method of analysis of the Chi-square test in the systematic review in Chapter 1, even larger sample sizes and number of stimuli per condition may be required.

Taking into account the pitfalls of Chi-square analyses and the statistical considerations noted above, both colour and shape must be analysed in a way that allows the examination of the effect of perceivable colour and shape features that could potentially generalise across shapes or explain shape-colour matches within each stimuli set. Additionally, it is important to have enough stimuli per condition x participants to make sure experiments are adequately powered for the anticipated effect size. What is crucial for the latter requirement, then, is to create enough stimuli that vary across the conditions that are to be evaluated (e.g., Malfatti, 2014).

For the former aim, the use of continuous data for chosen colours (rated levels lightness or red/greenness), over and beyond frequency data, allows testing for trends in a more

appropriate manner, opening up the possibility of using a host of different statistical tests (e.g., t-tests, ANOVAs, MANOVAs, ANCOVAs, RM ANOVAs). Additionally, it means avoiding having to collapse shapes together into categorical categories within Chi-square analyses, which would mean now that any Chi-square analysis conducted on the new contingency table has to involve each participant contributing an observation to more than one cell (i.e. a violation of the assumption of independence). This is why additional continuous ratings of both shapes and colours were collected so that chosen colours could be re-interpreted as more generalisable properties.

In Dreksler and Spence (2019), the data from Experiments 3A, 3B, and 3C presented in this chapter, were analysed using a variety of statistical between-participants statistical methods to show that no consistent results could be found across the three stimuli sets as to what shape characteristics predict chosen colour characteristics. Use was made both of long format data and analysis at the shape level. The downside of the set of analyses used were that there were no within-participants analyses (due to space considerations) and that long format data was analysed across choices without considering that multiple choices were made by the same participant. This ignoring of the person-level could again lead to spurious conclusions since it does not capture the fact that observations from the same individual are likely not independent. However, ordinary least squares analyses are simply not able to account for such clustering by participant.

RM ANOVAs which are simple to conduct and are often used in the field of crossmodal correspondences, and indeed have been used for colour-shape association too (Malfatti, 2014), are the go-to statistical test for within-participants contrasts. However, RM ANOVAs require the averaging across item choices to create meaningful categories (e.g., angular vs. round), whose averages are then compared in wide format for each participant. This means that potentially valuable information is lost since only averages for each category of stimuli created are ever handled in the data analysis (Carson & Beeson, 2013; Snijders & Bosker, 1999; Woltman, Feldstain, MacKay, & Rocchi, 2012). Additionally, such analyses cannot deal with missing data without completely removing the participant from the analysis, require balanced designs, and would not allow shape characteristics such as angularity, symmetry, and complexity to be conceived of as continuous variables (Grace-Martin, n.d.).

One type of analysis that can be used to address these issues is the linear mixed model (LMM; Bates, 2010; Baayen, Davidson, & Bates, 2008; Brysbaert, 2007; Brysbaert & Stevens, 2018; Carson & Beeson, 2013; Hajduk, 2017; Heck, Thomas, & Tabata, 2013; Pillinger, n.d.; Winter, 2013a, 2013b). LMMs allow the partitioning of data into subjects of analysis, such as the participant, as well as making it possible to let each of these subjects randomly vary with their own intercept, or even slope for an effect. Indeed, in psycholinguistics, the fact that you can account for the random effect of item additionally has revolutionised how data can be analysed (Carson & Beeson, 2013). Adding this random effect of participant addresses the need to cluster data by

participant and accounts for correlations of observations within this unit of analysis. One can then test for the result of fixed effects (such as angularity, symmetry, and complexity) as categorical or continuous variables on continuously rated chosen colour properties (e.g., lightness, red/green, or saturation). The term mixed here refers to the exploration of both fixed effects and random effects on the dependent variable. Data has to be kept in long format, meaning that whilst the data can be partitioned into whatever groups that are desirable (participant, nationality), the variation between participants can be accounted for, and multilevel models can be built that are better able to make use of individual difference data (e.g., Cotter *et al.*, 2017). This latter technique will be made use of when conducting a multi-level analysis to determine the moderating effect of individual differences on shape preferences.

For these reasons, LMMs running using the SPSS /MIXED command with a Maximum Likelihood (ML) estimation were used with participants added as a random intercept and subject unit of analysis to test for shape-colour associations and to explore what the effect of experiment, shape stimuli set, nationality, and gender were on colour choices. Additionally, what will be analysed is: the role of emotional mediation on colour-shape correspondences and the effect of shape characteristics on intuitiveness, processing fluency, and affective appraisals. Furthermore, the moderating role of individual differences on the effect of shape characteristics on affective appraisals and the effect of individual differences on intuitiveness is tested using the same type of models.

3.2 Method

3.2.1 Experiments 3A, 3B, 3C.

3.2.1.1 Participants.

Three experiments were conducted to examine colour-shape correspondences. Participants were excluded if they reported: 1) non-corrected vision impairments that would hinder perceiving the colour and shape stimuli correctly (including making a response to the City University colour blindness test that indicated some sort of colour deficiency); 2) that they experienced synaesthesia related to colours, shapes, and graphemes; 3) exhibited repetitive responding patterns indicative of a failure to read and answer the questions properly (e.g., responding 100 on a large number of rating scales in a row).

A cross-cultural sample of participants was recruited online on Prolific (https://prolific.ac) with the requirements that participants be fluent in English, have an above 98% acceptance rates on the platform in order to exclude fraudulent users and bots, and had not participated in any of the previously conducted experiments related to colour or shape conducted for this thesis. Sixty-four participants took part in Experiment 3A (27 identified as female, mean age = 30.33 years, SD = 9.80 years), sixty-eight participants participated in Experiment 3B (39 identified as female, 1 as agender, mean age = 31.41 years, SD = 9.69), and seventy-five participants participated in Experiment 3C (49 identified as female, mean age = 32.59 years, SD

= 9.95 years). As highlighted by the mean ages of participants, one benefit of conducting this research online is gaining access to a broader sample of individuals than the undergraduate university students that much of psychological research is based on (Henrich, Heine, & Norenzayan, 2010; for a review of the representativeness and use of online samples for perception research, see Woods, Velasco, Levitan, Wan, & Spence, 2015).

3.2.1.2 Materials.

Fifty-eight geometric shapes (see Figure 3.1) were designed for use in Experiment 3A using Adobe Illustrator. They were designed to vary by roundedness (3 levels: angular/rounded/spikey), symmetry (2 levels: symmetrical/asymmetrical), and complexity. Complexity was varied by varying the number of sides (4 levels: 1, 3, 4, 9) and levels of concavities (4 levels: 0, 1, 2, 3) of the shape. These shapes are similar to those used by Malfatti (2014) and are closest to the geometric shapes discussed by Kandinsky (1914) and the shape stimuli used in studies such as N. Chen *et al.* (2014; Chen, N., Tanaka, Matsuyoshi, & Watanabe, 2015a, 2015b).

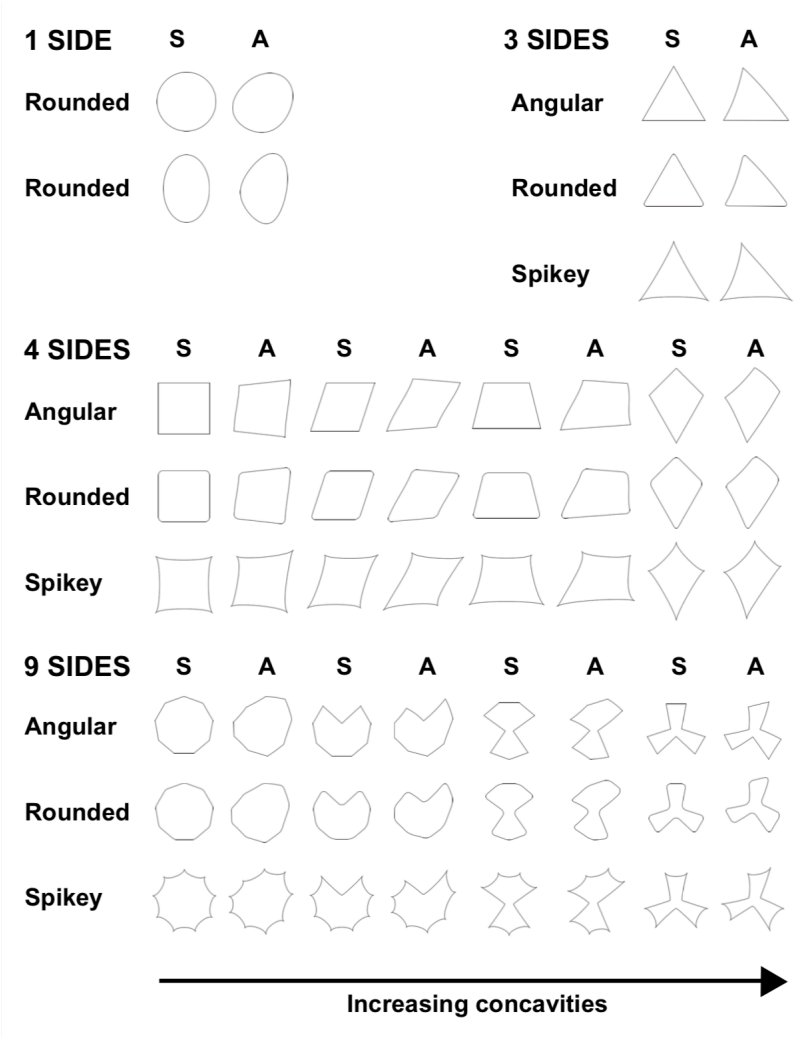


Figure 3.1 The fifty-eight geometric shapes presented in Experiment 3A and 3D. Columns labelled 'S' are symmetrical shapes, columns labelled 'A' are asymmetrical shapes.

Sixteen mandala shapes (see Figure 3.2) were created for use in Experiment 3B using Adobe Illustrator and were designed to vary by roundedness (2 levels: rounded/pointy), symmetry (2 levels: symmetrical/asymmetrical), and complexity (4 levels of increasing complexity created by adding additional repeating elements).

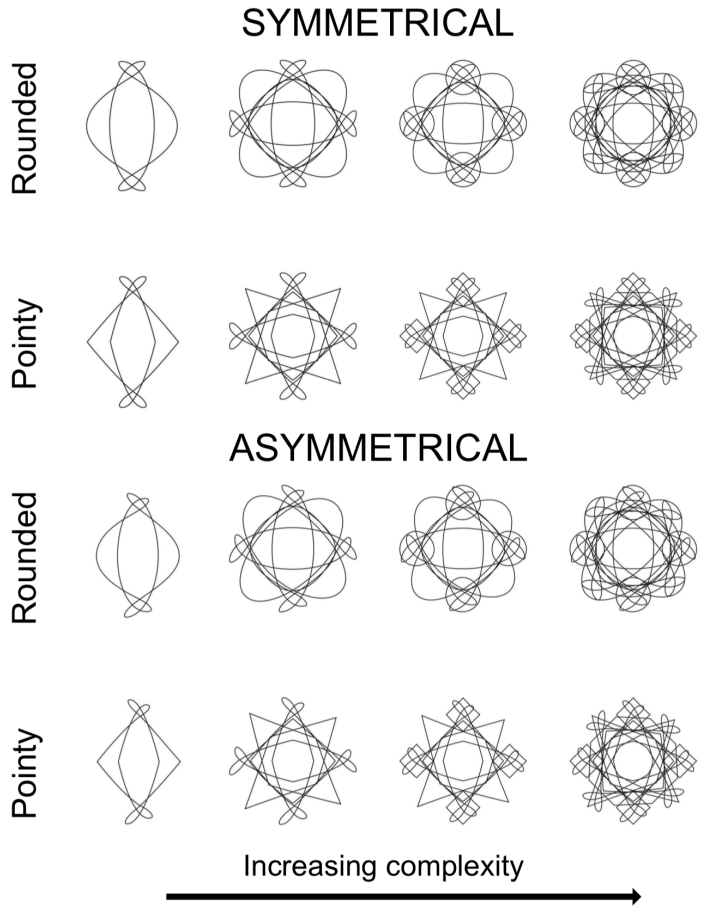


Figure 3.2 The sixteen mandala shapes presented in Experiment 3B and 3D.

Twelve radial frequency 'RF' shapes (see Figure 3.3) were generated using the MATLAB code of Pi-Chun Huang (see online documentation of Turoman *et al.*, 2018) and are most akin to the traditional Bouba/Kiki shapes used in sound symbolism research (Maurer, Pathman, & Mondloch, 2006; see Chen, Y.-C., *et al.*, 2016, for an example of how RF pattern shapes can be used in sound symbolism/crossmodal correspondences research). Furthermore, they tie in with other crossmodal correspondence work that has explored the relationship of shape and taste as well as shape and odour (e.g., Hanson-Vaux, Crisinel, & Spence, 2012; Salgado-Montejo *et al.*,

2015). They were designed to vary by roundedness (2 levels: rounded/pointy), symmetry (2 levels: symmetrical/asymmetrical), and complexity (3 levels of increasing complexity created by adding extra protruding points on each shape).

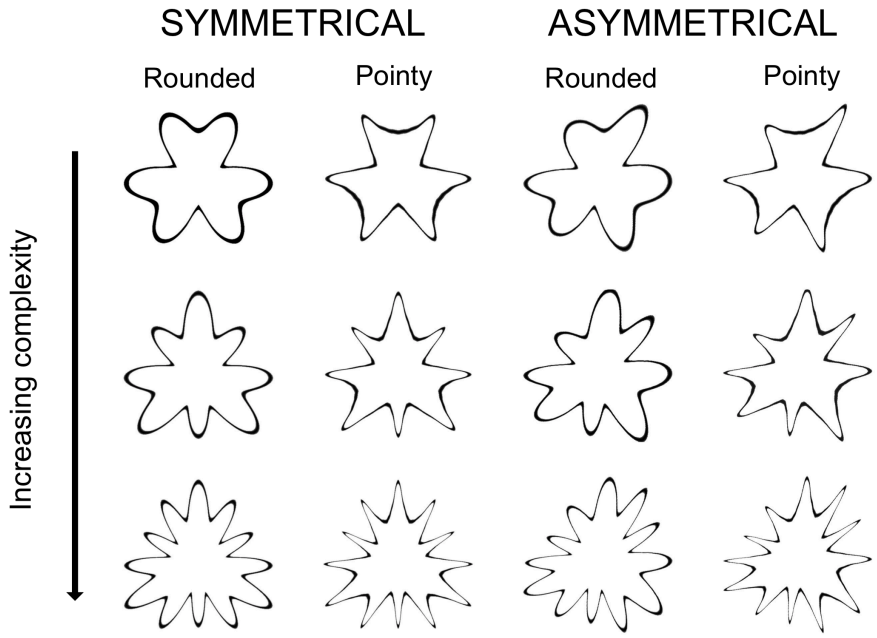


Figure 3.3 The twelve RF shapes presented in Experiment 3C and 3D.

3.2.1.3 Design and procedure.

The same design and procedure were used for Experiments 3A, 3B, and 3C in order to facilitate the examination of replicability across studies of colour-shape correspondence effects. All three experiments were conducted using an online Qualtrics questionnaire that participants accessed through the participant recruitment platform Prolific. Participants provided their Prolific ID and were then requested to sit in front of their computer, set so that the stimuli could be viewed easily, in a normally lit room that

was quiet and free from distractions. They then proceeded to give their informed consent to participate in the study. An outline of the structure and instructions for each section of the study were presented to the participants.

Participants were randomly and evenly allocated to one of two colour-shape matching task blocks where they were presented with the following instructions: "For each shape please choose the colour that you think best matches it. There are no right or wrong answers. Please answer as intuitively as possible." For each shape the participant chose one of the 36 colours and rated how intuitive they found their preceding match on a scale of 'I chose completely randomly' to 'This match feels very right'. This was included in order to explore individual differences in experience of the task and each individual match. In one colour-shape matching block, the colours were presented in the same order (see Figure 3.4) as is common in colour-shape correspondence research, whilst in the other, colours were presented in a randomised fashion. The data was collapsed across these two block conditions for all three experiments due to lack of significant differences in the perceptual colour characteristics chosen in the two blocks.

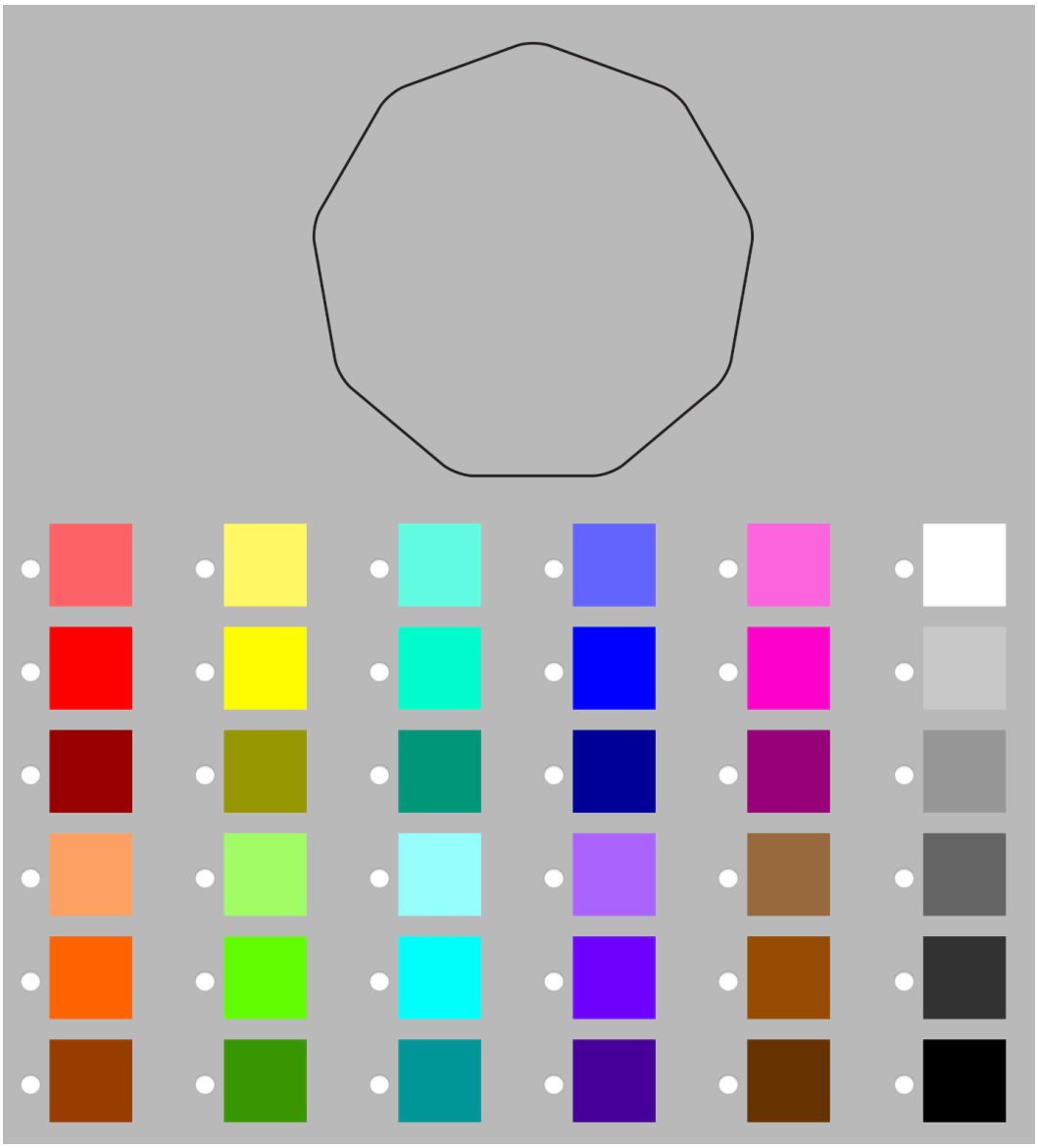


Figure 3.4 The way in which the shape and colours were presented to participants during the colour-shape matching task block with non-randomised colours in Experiments 3A, 3B, 3C, and 3D. The 36 colours were chosen to cover a breadth of hues (in descending rows of three, column by column: red, orange, yellow, green, aquamarine, sky, blue, purple, pink, brown, white/grey, grey/black), presented both at full saturation (rows two and five) and at different levels of lightness (rows one and four: lighter than the fully saturated second row; rows three and six: darker than the fully saturated fifth row). All shapes and colours throughout the experiment were presented on a grey background (#BCBCBC).

After participants had chosen a colour for each shape, they were presented with four blocks in a random order and they were asked to rate the valence (very unpleasant-very pleasant) and arousal (not at all arousing-very arousing) of all the colours and shapes in the study. To avoid any lexical ambiguity and confusion, the participants were reminded that "arousing is meant in a non-sexual sense, it refers to a general state of activation and energy."

In the final section of the study, the participants completed an array of psychometrics and individual differences questions including the BFI (Big Five Inventory; John, Naumann, & Soto, 2008), TAS-20 (measures alexithymia; Bagby, Parker, & Taylor, 1994), VVIQ (measures visual mental imagery; Marks, 1973), and AQ (Autism Spectrum Quotient; Baron-Cohen *et al.*, 2001), questions regarding their age, gender, visual impairments, cultural background, whether they experienced synaesthesia, and the City University online colour-blindness test ('A new web-based colour vision test', n.d.). Upon finishing, the participants were presented with a completion code and URL and referred back to Prolific.

3.2.1.4 Additional data.

Additional surveys were conducted in order to analyse the three experiments using Qualtrics surveys with participants recruited online through Prolific. Forty-one participants were asked to rate the perceptual roundedness (rounded-pointy), symmetry (asymmetrical-symmetrical), and complexity (simple-complex) of the

mandala and RF shapes presented in Experiments 3B and 3C on polar dimension rating scales, and a further twenty-five participants completed the same ratings for the 58 shapes used in Experiment 3A. Another thirty-six participants rated the 36 colours on 9 perceptual 'polar' colour dimensions: red/green (red-green), yellow/blue (yellow-blue), red (not all red-very red), green (not at all green-very green), yellow (not at all yellow-very yellow), blue (not at all blue, very blue), lightness (light-dark), saturation (unsaturated-saturated), and warmth (cold-warm).

3.2.2 Experiment 3D.

3.2.2.1 Participants.

A sample of 730 participants was recruited online on Prolific (https://prolific.co) with the requirements that participants be fluent in English, have a 100% acceptance rate on the platform in order to exclude fraudulent users and bots, and not have participated in any of the previously conducted experiments related to colour or shape presented in this thesis. Participants were recruited in six streams, one for each nationality that Prolific.co had a large sample of users for: France, Germany, Italy, Mexico, the UK, and the US. As such, for each stream, this nationality was added as an additional requirement, although only for the analysis regarding nationality were individuals excluded if they did not adhere to these six nationalities. Care was taken that experiments were started during reasonable nine to five day-time hours in each of the countries' time-zones. The other exclusion criteria were the same as in Experiments

3A, 3B, and 3C. A final sample of 568 participants (348 males, 376 females, and 3 non-binary individuals, mean age = 30.48 years, SD = 10.08 years) was included in the data analysis, which included participants from France ($n = 90$), Germany ($n = 97$), Italy ($n = 84$), Mexico ($n = 87$), the UK ($n = 102$), the US ($n = 97$), dual nationalities ($n = 16$), or other nationalities ($n = 5$).

3.2.2.2 Materials.

The materials used for Experiment 3D were the same as described above for Experiments 3A, 3B, and 3C.

3.2.2.3 Design and procedure.

The design and procedure used for Experiment 3D was very similar to the previous experiments with the same Qualtrics and Prolific.co platform and recruitment methodology being used once again. Participants completed the three shape-colour matching blocks (one for each of the three stimuli sets: geometric, mandala, and RF shapes) in a random order and were given the same instructions as in the previous three experiments. Each block was preceded by a small array of the stimuli the participants were about to rate, to indicate that a new set of stimuli was about to be seen. Colour choices were only presented in the static formation since it was found, as described above, that there were no significant differences in colour choices between the static and random conditions. Additionally, first click, last click, and page submit times were taken for each shape-colour match, though this was invisible to the

participant. Instead of a separate sample rating the colours on their perceptual qualities as in Experiments 3A-3C, each participant rated the 36 colours themselves using the same rating scales described above.

In the final section of the study, the participants completed questions regarding their age, gender, visual impairments, cultural background, whether they experienced synaesthesia, and the City University online colour-blindness test ('A new web-based colour vision test', n.d.). Upon finishing, the participants were presented with a completion code and URL and referred back to Prolific.

3.3 Results

3.3.1 Shape-colour associations.

3.3.1.1 A comparison across experiments 3A-3D and stimuli sets using LMMs.

Q-Q plots were inspected for each continuous measure of colour choices noted above. The measures for red/green, yellow/blue, lightness, saturation, and warmth were found to be normally distributed. As such these were the colour properties tested in the following analyses.

Three categorical measures were entered as fixed effects for the categorical models: angularity (coded 0 for round and 1 for angular shapes), symmetry (coded 0 for

asymmetrical and 1 for symmetrical), and complexity (coded in ascending ordinal levels of complexity). Complexity levels were specific to the stimuli set, so it is prudent not to generalise across levels but instead use them as an indicator of the direction of the effect. Angularity was simplified for Experiment 3A to a binary categorical measure despite there being three levels of angularity.

The continuous scales of angularity, symmetry, and complexity were standardized and centred at zero to allow for easier interpretation of their effect, as were any other continuous predictors (such as shape liking, shape arousal, openness, alexithymia, autism, and visual mental imagery) used in any models in this chapter. This means that the co-efficient represents the change in the colour characteristics (or other dependent variable) for every one standard deviation increase in the predictor variable. Models were initially tested that added random slopes for participants and these did not improve model fit. As such it was decided that an intercept-only model for the random effect of participant was preferable.

3.3.1.1.1 Red/Green.

The results, including beta-values, standard errors, and significance levels for red/green as an outcome variable can be seen in Table 3.2. In Experiment 3A, for geometric shapes, angularity and symmetry were significantly associated with increases in greenness of colour choices in the categorical and continuous model. Rounder and more symmetrical shapes, therefore, resulted in redder colour choices.

*Table 3.2 Table showing the results for the LMMs of perceptual shape characteristics predicting the red/green colour dimension across all Experiments 3A-3D and stimuli sets. Intercepts and coefficients are followed by their standard error in brackets. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Both fixed and random effects are represented, and the relevant category that is being compared to the reference category is indicated next to the predictors. When predictors were entered as continuously rated dimensions this is indicated with an R. Interpretations of all other tables showing the results of LMMs can be interpreted in the same way.*

		Geometric		Mandala		RF	
Parameters		**3A**	**3D**	**3B**	**3D**	**3C**	**3D**
Regression coefficients (fixed effects)							
Intercept		62.38 (1.76)***	47.26 (.38)***	46.64 (1.76)***	46.53 (.71)***	47.29 (1.61)***	48.54 (.76)***
Angularity	=0	-1.96(.90)*	.94 (.32)**	-.20 (1.39)	2.74 (.53)***	-4.38 (1.36)**	1.21 (.64)
Symmetry	=0	-2.09 (.82)*	.98 (.29)**	.58 (1.39)	-40 (.53)	-.24 (1.36)	2.30 (.64)***
Complexity	=1	3.55 (1.80)*	-.38 (.63)	1.76 (1.97)	-1.41 (.75)	-.13 (1.67)	-1.54 (.78)*
	=2	.64 (1.43)	-1.07 (.50)*	2.20 (1.97)	-1.78 (.75)*	-2.29 (1.67)	-1.00 (.78)
	=3	1.67(.90)	-1.33 (.32)***	-.19 (1.97)	1.29 (.75)		
Variance components (random effects)							
Residual		628.18 (14.71)***	690.24 (5.43)	525.16 (23.25)***	639.08 (.9.80)***	417.98 (20.58)***	686.74 (12.30)***
Participants		155.20 (29.35)***	35.24 (2.80)***	14.65 (8.27)	48.85 (5.31)***	19.14 (8.98)*	39.14 (5.81)***

The simplest shapes were associated with greener colour choices in comparison to the most complex shapes. However, if these findings are compared to those of Experiment 3D separated by stimulus choice, these results are not replicated. For geometric shapes, Experiment 3D found that round and asymmetrical shapes were greener, and angular and symmetrical shapes were redder, in contrast to Experiment 3A. Additionally, also in contrast to Experiment 3A, it was the middle two levels of complexity (out of four) that were found to be redder than the most complex shapes.

No significant associations were found for Experiment 3B for mandala shapes, whilst Experiment 3D did find significant predictors for red/green. In particular, like for the geometric shapes of Experiment 3D, round shapes were found to be greener, with angular shapes being redder. Additionally, it was the second most simple shapes that were found to be redder than more complex shapes.

Experiment 3C replicated one of the effects of Experiment 3A for RF shapes – more angular shapes were associated with greener colour choices, and, as such, rounder shapes resulted in redder colour choices. However, this result was not replicated in Experiment 3D for RF shapes. Rather, it was found that asymmetrical shapes were greener, whilst symmetrical shapes were redder, whilst the simplest shapes were the reddest. Both these findings replicated findings for other stimuli sets in Experiment 3D, but not the findings of Experiment 3A, 3B, 3C.

Overall, consistent results for angularity were found in Experiments 3A and 3C, whereby, round geometric and RF shapes were redder than angular shapes. However, the opposite trend was found for geometric and mandala shapes in Experiment 3D. In regard to symmetry, Experiment 3A and 3D found inconsistent results, with the former finding symmetrical geometric shapes to be greener, whilst the latter found symmetrical geometric and RF shapes were, in fact redder. No consistent results were found for complexity across experiments examining the same stimuli, nor across all experiments taken together.

3.3.1.1.2 Yellow/Blue.

The results for yellow/blue as an outcome variable can be seen in Table 3.3. For the geometric shapes in Experiment 3A, second simplest (out of four complexity levels) shapes, had significantly bluer colours chosen for them than the most complex shapes. This result was not replicated in Experiment 3D for geometric shapes: it was the second most complex shapes which were found to be yellower than the most complex shapes. The reverse to Experiment 3A was also found in Experiment 3B for mandala shapes. Here it appears that the second simplest mandalas resulted in significantly yellower colour choices than the most complex. In Experiment 3D, it was the simplest and second most complex shapes which were significantly more yellow than the most complex shapes – practically, the reverse trend to Experiment 3B. In regard to

angularity and symmetry, Experiment 3B did not find any significant effects. Rounder and more symmetrical mandala shapes were found to be yellower in Experiment 3D.

The results for the RF shapes of Experiment 3C coincided in part with those of Experiment 3A: The most complex shapes, resulted in yellower colour choices, whilst simpler shapes were associated with bluer colour choices. No such significant findings were found for Experiment 3D for RF shapes. However, like for mandala shapes in Experiment 3D, round RF shapes were found to be significantly yellower and angular RF shapes were significantly bluer. No significant findings were found for symmetry for RF shapes in Experiment 3C and 3D.

In sum, no significant results for angularity and symmetry were found across all three Experiments 3A, 3B, and 3C, whilst for mandala and RF shapes, Experiment 3D did find some significant predictors of yellow/blue chosen colour characteristics. Specifically, Experiment 3D replicated the effect of angularity in mandala and RF shapes, such that round shapes were yellower. The results for complexity were consistently inconsistent, compared across stimuli and experiments. The only part replicated result was that that there was trend for simpler shapes being bluer and more complex shapes being yellower in both Experiments 3A and 3C. Neither of these results were consistently replicated in Experiment 3D, although the second most complex geometric and mandala shapes were yellower than the most complex shapes.

*Table 3.3 Table showing the results for the LMMs of perceptual shape characteristics predicting the yellow/blue colour dimension across all Experiments 3A-3D and stimuli sets. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

		Geometric		Mandala		RF	
Parameters		**3A**	**3D**	**3B**	**3D**	**3C**	**3D**
Regression coefficients (fixed effects)							
Intercept		57.21 (1.81)***	53.90 (.39)***	51.02 (2.96)***	54.00 (.83)***	46.22 (2.15)***	54.92 (.81)***
Angularity	=0	-.08(.96)	-.12 (.35)	.69 (1.58)	-1.92 (.64)**	-1.34 (1.76)	-1.46 (.68)*
Symmetry	=0	-1.16(.88)	-.01 (.32)	-.57 (1.58)	2.18 (.64)**	-.81 (1.76)	-.47 (.68)
Complexity	=1	.07(1.91)	-1.28 (.70)	.60 (2.23)	-2.84 (.91)**	5.34 (2.16)*	-.81 (.83)
	=2	4.73 (1.52)**	.36 (.56)	-5.39 (2.23)*	.04 (.91)	5.17 (2.16)*	-1.40 (.83)
	=3	1.86 (.96)	-.83 (.35)*	2.61 (2.23)	-3.10 (.91)**		
Variance components (random effects)							
Residual		710.10 (16.65)***	844.18 (6.64)***	677.44 (30.00)***	942.87 (14.46)***	700.12 (34.47)***	786.66 (14.09)***
Participants		162.26(30 .85)***	27.74 (2.51)***	34.01 (13.23)*	35.66 (5.69)***	54.82 (18.70)**	43.69 (6.59)***

3.3.1.1.3 Lightness.

The results for lightness as an outcome variable can be seen in Table 3.4. In Experiment 3A, geometric symmetrical shapes were found to be darker and asymmetrical shapes were found to be lighter. This result was replicated in Experiment 3D for geometric shapes. No significant results were found for angularity for geometric shapes in either of the experiments. In regard to complexity, Experiment 3A found a strong trend for the simplest shape being associated with lighter colours than the most complex shapes. The second most simple and second most complex shapes were also found to be lighter than the most complex shapes, albeit to a lesser degree. Experiment 3D only replicated this for the second most complex shapes.

In Experiment 3B, round mandala shapes were associated with lighter colours and angular shapes were matched with darker colours, in line with the results of Spector and Maurer (2008, 2011). The only other shape set and experiment that found a significant result for angularity was Experiment 3D for RF shapes, which also found that round shapes were associated with lighter colours. Experiment 3B did not find any significant effects of symmetry for mandala shapes, but Experiment 3D found that asymmetrical shapes were associated with darker colours. For complexity, only Experiment 3B found significant results for mandala shapes: it appeared that there was a trend for simpler shapes (in particular the middle two levels of complexity) to be lighter than the most complex mandalas.

Experiment 3C and 3D found consistent evidence for the reverse trend for RF shapes in regard to complexity, here it appears that the simplest shapes (3C) and simpler shapes (3D) were in fact associated with darker colours than the most complex shapes. For angularity and symmetry, however, the two experiments did not support each other's results. In Experiment 3D, round RF shapes were matched with lighter colours, whilst Experiment 3C found no significant results. In Experiment 3C asymmetrical shapes were associated with lighter colours, with Experiment 3D finding no significant results.

Overall, there were few significant results for angularity, but where there were significant results, they were consistent across stimuli sets: In both Experiment 3B (mandala shapes) and Experiment 3D (RF shapes) round shapes were lighter and angular shapes were darker. For symmetry, Experiment 3A (geometric shapes) and Experiment 3C (RF shapes) found that asymmetrical shapes were lighter and symmetrical shapes were darker. In Experiment 3D the opposite effect of symmetry on lightness for geometric shapes and mandala shapes was seen, whereby asymmetrical shapes were darker and symmetrical shapes were lighter. For complexity there appeared to be a rift between stimuli sets, although the two experiments for each stimuli set generally agreed: For geometric and mandala shapes, it appears that the most complex shapes are generally darker than some or all of the simpler shapes. For RF shapes, the most complex shapes instead are lighter than some or all of the simpler shapes.

*Table 3.4 Table showing the results for the LMMs of perceptual shape characteristics predicting the lightness colour dimension across all Experiments 3A-3D and stimuli sets. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

		Geometric		Mandala		RF	
Parameters		**3A**	**3D**	**3B**	**3D**	**3C**	**3D**
Regression coefficients (fixed effects)							
Intercept		48.73 (1.25)***	43.95 (.49)***	50.96 (2.14)***	47.73 (.90)***	43.98 (2.28)***	42.55 (.93)***
Angularity	=0	-.07 (.99)	-.47 (.38)	-4.59 (1.58)**	-.92 (.66)	1.26 (1.83)	-1.78 (.75)*
Symmetry	=0	-2.64 (.90)**	.99 (.34)**	-.26 (1.58)	1.97 (.66)**	-4.17 (1.83)*	-.01 (.75)
Complexity	=1	-13.23 (1.96)***	-.78 (.75)	-4.03 (2.24)	-1.41 (.93)	6.18 (2.24)**	4.33 (.92)***
	=2	-3.85 (1.56)*	.14 (.59)	-8.38 (2.24)***	-.13 (.93)	2.93 (2.24)	3.73 (.92)***
	=3	-3.63 (.99)***	-1.59 (.38)***	-4.86 (2.24)*	-1.74 (.93)		
Variance components (random effects)							
Residual		749.83 (17.56)***	959.91 (7.55)***	682.15 (30.31)***	988.31 (15.16)***	751.06 (36.98)***	962.55 (17.24)***
Participants		49.22 (10.99)***	70.21 (5.15)***	56.70 (17.14)**	86.18 (8.84)***	77.42 (23.07)**	93.81 (10.43)***

3.3.1.1.4 Saturation.

The results for saturation as an outcome variable can be seen in Table 3.5.

*Table 3.5 Table showing the results for the LMMs of perceptual shape characteristics predicting the saturation colour dimension across all Experiments 3A-3D and stimuli sets. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

		Geometric		Mandala		RF	
Parameters		**3A**	**3D**	**3B**	**3D**	**3C**	**3D**
Regression coefficients (fixed effects)							
Intercept		60.79 (.55)***	57.83 (.64)***	60.32 (.99)***	60.80 (.90)***	61.35 (.98)***	56.37 (.95)***
Angularity	=0	-.38 (.45)	.25 (.32)	-1.28 (.76)	-1.82 (.55)**	-2.69 (.85)**	.44 (.66)
Symmetry	=0	-.94 (.41)*	.50 (.30)	.31 (.76)	.17 (.55)	-1.34 (.85)	-.03 (.66)
Complexity	=1	-2.58 (.41)*	1.10 (.65)	-.60 (1.08)	1.07 (.78)	.39 (1.05)	1.49 (.80)
	=2	.90 (.89)**	.34 (.51)	-1.13 (1.08)	.13 (.78)	1.65 (1.05)	1.47 (.80)
	=3	-1.40 (.45)**	-.51 (.32)	-1.11 (1.08)	1.34 (.78)		
Variance components (random effects)							
Residual		155.36 (3.64)***	718.26 (5.65)***	157.30 (6.97)***	686.45 (10.53)***	164.29 (8.09)***	733.65 (13.14)***
Participants		9.09 (2.08)***	181.68 (11.53)***	7.71 (3.04)*	203.56 (14.65)***	3.32 (2.86)	201.06 (15.61)***

Only Experiment 3D for mandala shapes and Experiment 3C for RF shapes found significant results for angularity. In both experiments round shapes were less saturated and angular shapes were more saturated. Only Experiment 3A found significant results for symmetry, whereby symmetrical geometric shapes were associated with more saturated colours. Experiment 3A was also the only experiment where significant results for complexity were seen: Here, the simplest geometric shapes (in comparison to the most complex shapes with the most sides), were associated with less saturated colour choices. Shapes with three sides (triangles), however, had more saturated colours associated with them. Squares and other variants of four-sided shapes followed the trend of being less saturated than their more complex nine-sided counterparts.

3.3.1.1.5 *Warmth.*

Warmth has often been used as secondary characteristic of colours that can be predicted by shape characteristics (Albertazzi, Da Pos, *et al.*, 2013; Albertazzi, Malfatti, *et al.*, 2015; Chen, N., 2015), although, unlike here, it is rarely tested as a dimension but rather simply a division of colours completed by the experimenter. The results for warmth as an outcome variable can be seen in Table 3.6. Contrary to this previous research, fewer associations between warmth of colours chosen and shape predictors than might be expected were found. Angularity failed to predict colour warmth across the all four experiments for all stimuli sets.

*Table 3.6 Table showing the results for the LMMs of perceptual shape characteristics predicting the warmth colour dimension across all Experiments 3A-3D and stimuli sets. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

		Geometric		Mandala		RF	
Parameters		**3A**	**3D**	**3B**	**3D**	**3C**	**3D**
Regression coefficients (fixed effects)							
Intercept		45.94 (.91)***	45.49 (.48)***	46.61 (1.56)***	46.04 (.84)***	47.94 (1.66)***	43.39 (.87)***
Angularity	=0	-.44 (.75)	.29 (.35)	-7.31 (1.25)	-.18 (.61)	2.38 (1.41)	1.05 (.70)
Symmetry	=0	-.12 (.68)	-.28 (.32)	.41 (1.25)	-1.35 (.61)*	-.31 (1.41)	.19 (.79)
Complexity	=1	-3.02 (1.48)*	1.03 (.70)	-1.44 (1.77)	2.69 (.86)**	-2.58 (1.72)	.66 (.86)
	=2	-.76 (1.18)	-.09 (.55)	1.31 (1.77)	.64 (.86)	.01 (1.72)	.71 (.86)
	=3	-1.64 (.75)*	1.34 (.35)***	-2.29 (1.77)	2.03 (.86)*		
Variance components (random effects)							
Residual		426.53 (9.99)***	836.86 (6.58)***	425.01 (18.82)***	843.17 (12.91)***	444.91 (21.91)***	833.17 (14.92)***
Participants		23.68 (5.49)***	74.56 (5.29)***	6.27 (5.75)	86.23 (8.29)***	21.68 (9.77)*	85.43 (9.28)***

Only Experiment 3D found a significant result for symmetry, whereby asymmetrical mandala shapes were associated with colder colours and symmetrical mandala shapes

were more likely to result in warmer colour choices. Whilst there were a few significant results for complexity these were inconsistent within stimuli sets. Experiment 3A found that the simplest (circles and ovals) and second most complex shapes (four-sided shapes) were associated with colder colours. In the replication experiment 3D, the second most complex shapes were instead found to be associated with warmer colours. In Experiment 3D both of these levels of complexity for mandala shapes were also found to be associated with warmer colours.

3.3.1.1.6 Shape-colour associations – LMMs: Summary.

None of the explored shape predictors consistently predicted colour characteristics consistently across all three stimuli sets, especially when taking into consideration the replication of each stimuli set in Experiment 3D. Indeed, sometimes the replication explicitly contradicted the trend found in the first experiment conducted for each stimuli set. Consider some pertinent examples of these inconsistencies: When Experiments 3A, 3B, and 3C are compared, it was especially the colour choices for the mandala shapes of Experiment 3B that were often not well predicted by the chosen shape predictors. But between Experiment 3A (geometric shapes) and 3C (RF shapes) there were some consistencies if considered alone:

1. Angularity was associated with greener colours, whilst rounder shapes were associated with redder colours.

2. Symmetry was associated with lighter colours, whilst asymmetry was associated with darker colours.
3. Complexity was associated with yellower colours, whilst simpler shapes were associated with bluer colours.

However, Experiment 3D found the opposite trend for red/green for both geometric shapes and mandala shapes: angular shapes were associated with redder colours and rounder shapes were associated with greener colours. This finding is in line both with the findings of this thesis (see Chapter 4) and those of Malfatti (2014). In regard to symmetry and lightness, Experiment 3D again found the opposite trend for geometric shapes and mandala shapes: asymmetrical shapes were associated with darker colours and symmetrical shapes were found to be matched with lighter colours. In respect to complexity and the yellow/blue colour property, Experiment 3D did not find any results that contradicted the trend within the stimuli sets of geometric and RF shapes, but did find, like Experiment 3B, that the most complex shapes were associated with blue more than at least some of the levels of the less complex shapes. It can be seen, therefore, that the replication study often contradicted the results within stimuli sets, but also strengthened the evidence for the fact that the shape characteristics could not consistently predict colour properties across stimuli sets.

That is not to say that no such shape-colour associations may exist, but that they can be immensely stimuli-dependent and that participants are likely highly variant in how

they respond to these shapes. Additionally, the large number of choices of colours may be adding such large amounts of variation in choices that it is more difficult to find consistent trends across different shape stimuli. It may also be that an unexamined aspect of the shapes, such as another variable of their perceptual nature or associations, are driving these differences. This could especially be the case for the mandala shapes, which often showed contrasting results to the other two shape sets, and, have a decidedly different feel and aesthetic to the geometric and RF shapes. It may be overall that shapes require a different parameterisation than the ones the experiments in this chapter limited themselves to – in this case, angularity, symmetry, and complexity. Especially shapes that mirror the perceptual appearances of biological forms, may need to be analysed differently (Albertazzi, Canal, Dadam, & Micciolo, 2014; also see Gielis, 2017) and, indeed, it may be useful to remember that shape can be created by more cues than simple lines (e.g., shading, see Koenderink, Wagemans, Van Doorn, & Albertazzi, 2015). Additionally, and this will be touched on later in the discussion, it may even require a reconsideration of the phenomenological understanding of shape and stimuli more generally (see Albertazzi, 2018). Although, it should be noted, that even when these predictors are continuously rated to allow for more differentiation, no consistent results are found, for example between the stimuli sets of Experiments 3A, 3B, and 3C (see Appendix 6.10 for these results).

There are a number of differences between Experiments 3A, 3B, and 3C, on the one hand, and Experiment 3D, on the other. First, in Experiment 3D every stimuli set was

rated by the same participant. Second, Experiment 3D's colour characteristics were based on each individual's perceptual colour ratings on their specific computer screen, rather than an average taken from another sample. Third, Experiment 3D had a much larger sample size than the other three experiments, meaning that it had higher power and the possibility to detect smaller effect sizes. Additionally, it means that it has sufficient power to test for further interaction effects, such as, between shape characteristics and of other factors such as stimuli set, nationality, and gender. Fourth, steps were specifically taken to make sure large enough groups of six nationalities were present in the sample, allowing not only for a more global picture of colour-shape correspondences, but also the option of testing for differences between these nationalities. With this in mind, the effect of certain individual differences, stimuli effects, and shape interactions are on chosen colour characteristics can be tested in Experiment 3D, in a way that cannot be done for Experiments 3A, 3B, and 3C. This will offer a better understanding of where the large amount of variance in chosen colours for shapes may be coming from that was explored and discovered above. It may of course also turn out that shape-colour associations cannot be well accounted for by these other factors either, pointing to the potential conclusion that colour-shape correspondences simply represent a highly variant phenomenon.

A final note should be made – the list of differences could be seen as sufficient evidence for the fact that the same results should not be expected to be found in Experiment 3D as in the first three Experiments (3A, 3B, and 3C). However, if this was the case,

neat and consistent results should be found if the datasets are combined, and experiment is entered as a main effect alongside the shape predictors, and as an interaction effect with the shape predictors. These models should show that for each stimuli set, experiment was a defining driver of differences in colour properties. Whilst, for some colour properties within certain stimuli sets there are significant results, especially for geometric shapes, this is by no means the case throughout (quite the opposite in fact for some stimuli sets and colour properties). Indeed, the results of these LMMs run for each stimuli set separately, which can be seen in Appendix 6.11, much rather point to the fact that colour choices are highly variant across all participants, rather than more similar within each experiment, as might be expected if experimental conditions had exceedingly strong effects on colour choices. Indeed, this conclusion will be mirrored when how much variance shape predictors actually account for (even within the same experiment) in chosen colour characteristics is considered below.

3.3.1.2 The effect of interactions between shape characteristics.

First, Experiment 3D is explored in more depth by examining whether interaction effects between shape characteristics affect colour choices. Two types of models are presented in Table 3.7 and Table 3.8 for each colour property. First, a Simple Model that looks at the effect of angularity, symmetry, and complexity on each colour property. Since it was necessary to compare across stimuli sets, complexity was entered as a continuously rated factor, since no categorical classification was able to capture

complexity changes in a balanced way across the three stimuli sets (to examine pairwise contrasts, however, this rated complexity measure had to be binned into 3 equally sized categorical levels). Second, an Interaction Model is presented that tests the effect of the shape characteristics of angularity, symmetry, complexity, and their interactions on colour dimensions. Here the shape characteristics were entered as fixed effects, alongside their two-way and three-way interactions between one another. Participant was entered as a random effect for both models (intercept only model).

*Table 3.7 Table showing the results for the LMMs of perceptual shape characteristics predicting the red/green, yellow/blue and lightness colour dimensions for simple (only direct effect of shape predictors) and interaction models (include interactions between these shape predictors) for Experiment 3D. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

Parameters		Red/Green		Yellow/blue		Lightness	
		Simple Model	Interaction Model	Simple Model	Interaction Model	Simple Model	Interaction Model
Regression coefficients (fixed effects)							
Intercept		46.61 (.31)***	46.50 (.33)***	53.45 (.31)***	53.13 (.33)***	44.10 (.41)***	43.55 (.43)***
Angularity	=0	1.60 (.25)***	2.21 (.36)***	-.75 (.27)**	-.06 (.40)	-.12 (.29)	1.24 (.43)**
Symmetry	=0	.92 (.24)***	1.28 (.32)***	.26 (.27)	.81 (.36)*	.70 (.29)*	1.82 (.39)***
Complexity	R	.35 (.12)**	.40 (.21)	.19 (.14)	-.04 (.23)	.85 (.15)***	.63 (.25)*
Angularity	0*0		-1.05 (.50)*		-1.33 (.56)*		-2.67 (.60)***

***Symmetry**							
Angularity	0*R	.77 (.33)*		.06 (.37)		.35 (.39)	
***Complexity**							
Symmetry	0*R	-.46 (.32)		.47 (.36)		.16 (.39)	
***Complexity**							
Angularity							
***Symmetry**	0*0* R	-1.02 (.51)*		.07 (.58)		.09 (.61)	
***Complexity**							
Variance components (random effects)							
Residual		685.66 (4.42)***	685.40 (4.42)***	859.00 (5.53)***	858.80 (5.53)***	979.84 (6.31)***	979.37 (6.31)***
Participants		33.95 (2.49)***	33.96 (2.49)***	27.94 (2.25)***	27.94 (2.25)***	64.96 (4.54)***	64.97 (4.54)***

In the Simple Model, angular shapes are found to be redder and bluer, with round shapes, thus, being greener and yellower. Symmetrical shapes were found to be redder and lighter, and, therefore, asymmetrical shapes were associated with greener and darker colours. Increasing complexity resulted in greener (vs. red), darker (vs. lighter), and more saturated (vs. unsaturated) colour choices.

*Table 3.8 Table showing the results for the LMMs of perceptual shape characteristics predicting the saturation and warmth colour dimensions for simple and interaction models for Experiment 3D. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

Parameters		Saturation		Warmth	
		Simple Model	Interaction Model	Simple Model	Interaction Model
Regression coefficients (fixed effects)					
Intercept		58.24 (.60)***	58.15 (.61)***	46.02 (.42)***	46.22 (.44)***
Angularity	=0	.32 (.25)	.44 (.37)	.23 (.27)	-.30 (.40)
Symmetry	=0	.22 (.25)	.39 (.33)	-.32 (.27)	-.67 (.36)
Complexity	R	.39 (.13)**	.63 (.21)**	-.22 (.14)	.02 (.23)
Angularity *Symmetry	0*0		-.34 (.52)		.93 (.56)
Angularity *Complexity	0*R		-.47 (.34)		-.42 (.36)
Symmetry *Complexity	0*R		-.23 (.33)		-.34 (.36)
Angularity *Symmetry *Complexity	0*0*R		.20 (.53)		.42 (.57)
Variance components (random effects)					
Residual		722.21 (4.65)***	722.16 (4.65)***	842.62 (5.43)***	842.54 (5.43)***
Participants		182.12 (11.32)***	182.12 (11.32)***	73.94 (4.97)***	73.94 (4.97)***

In the Interaction Model shape characteristics are found to interact with one another to affect colour choices in regard to red/green, yellow/blue, and lightness. These interaction effects can be seen in Figure 3.5 and the 'Interaction Model' columns of Table 3.7. The results of saturation and warmth are shown in Table 3.8. First, the interaction effects that affect the colour property red/green will be examined. Whilst angular shapes were redder than round shapes for both asymmetrical (mean difference = -1.16, SE = .35, p = .001, 95% CI (-1.85, -.47)) and symmetrical shapes. This effect was particularly pronounced for symmetrical shapes (mean difference = -2.21, SE = .36, $p < .001$, 95% CI (-2.91, -1.51)). Additionally, within angular shapes, symmetrical shapes were significantly redder than asymmetrical shapes (mean difference = -1.28, SE = .33, $p < .001$, 95% CI (-1.92, -.65)). Angular shapes were also redder than round shapes across all complexity levels - low (mean difference = -1.20, SE = .46, p = .008, 95% CI (-2.19, -.31)), medium (mean difference = -2.41, SE = .44, $p < .001$, 95% CI (-3.28, -1.55)), and high (mean difference = -1.63, SE = .45, $p < .001$, 95% CI (-2.51, -.76)). Within round shapes, low complexity shapes were redder than both medium (mean difference = -1.38, SE = .45, p = .002, 95% CI (-2.26, -.51)) and high complexity shapes (mean difference = -1.05, SE = .46, p = .022, 95% CI (-1.94, -.15)).

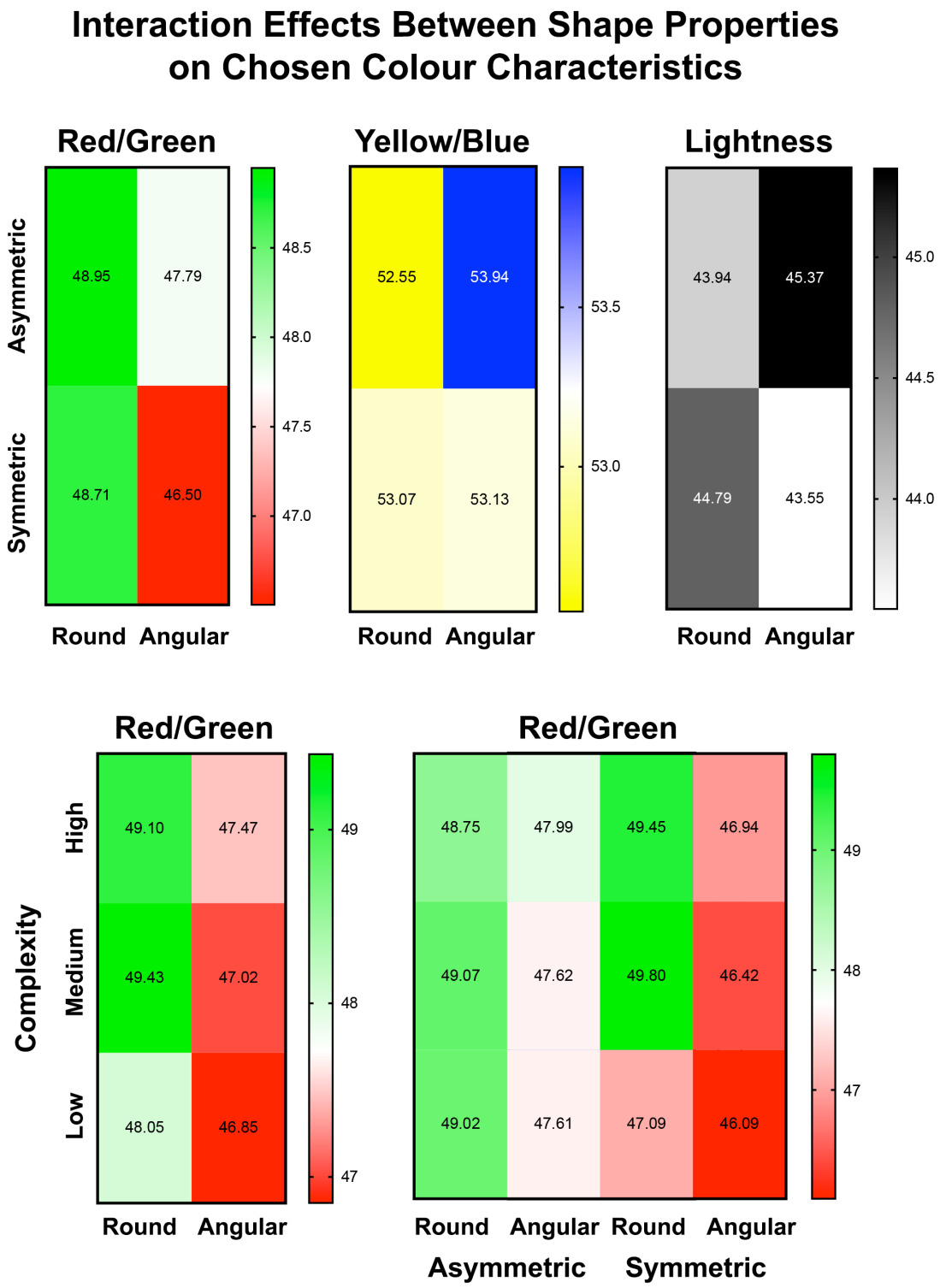


Figure 3.5 Significant interaction effects for the LMM models testing the Interaction Models for Experiment 3D. Care should be taken to read the graphs as showing relative trends (redder than, lighter than), rather than indicating actual indicators of associated colours. The same holds true of all graphs of this type shown below. The number in each cell indicates the mean (2 d.p.) colour characteristic for that particular category of shape.

There was also a three-way interaction for red/green between the three shape characteristics. Three-way interactions can be difficult to disentangle, especially since strict corrections for multiple comparisons would make most effects have a p-value over the one required for significance. The most significant pairwise comparisons, alongside Figure 3.5, are considered to give an indication of where the crux of this three-way interaction may lie. Within round symmetrical shapes, low complexity shapes were significantly redder than medium (mean difference = -2.71, SE = .65, $p <$ .001, 95% CI (-3.99, -1.44)) and high complexity shapes (mean difference = -2.36, SE = .65, $p <$ .001, 95% CI (-3.64, -1.09)). Within round low complexity shapes, symmetrical shapes were redder than asymmetrical shapes (mean difference = -1.93, SE = .54, $p <$ .001, 95% CI (-3.00, -.87)). Within both symmetrical medium (mean difference = -3.73, SE = .69, $p <$ .001, 95% CI (-4.72, -2.02)) and high complexity shapes (mean difference = -2.51, SE = .66, $p <$ .001, 95% CI (-3.80, -1.21)), angular shapes were redder than round shapes.

For yellow/blue there was an interaction effect between symmetry and angularity. For asymmetrical, but not symmetrical, shapes angular shapes were significantly bluer than round shapes (mean difference = 1.38, SE = .40, $p <$ .001, 95% CI (.62, 2.17)). Additionally, there was less significant and smaller effect within angular shapes but not round shapes, whereby asymmetrical shapes were bluer than symmetrical shapes (mean difference = .81, SE = .36, p = .026, 95% CI (.09, 1.52)).

For lightness (light/dark) there was an interaction effect between symmetry and angularity. For asymmetrical shapes, angular shapes were darker than round shapes (mean difference = 1.43, SE = .42, p = .001, 95% CI (.60, 2.26)). For symmetrical shapes, angular shapes were lighter than round shapes (mean difference = 1.24, SE = .43, p = .004, 95% CI (.41, 2.08)). Within angular shapes, asymmetrical shapes were found to be significantly darker than symmetrical shapes (mean difference = 1.82, SE = .39, p < .001, 95% CI (1.06, 2.58)). Such a finding highlights the complexity of colour-shape associations, and thus, that it is difficult to make general statements, such as that angularity is associated with darkness (e.g., Spector & Maurer, 2008, 2011).

It should be noted that when LMMs were run to test for interaction effects between the three main factors of angularity, symmetry and complexity for Experiments 3A, 3B, and 3C, across the board, these were not significant for any colour properties. This is surprising on some level perhaps, since there are 12 distinct groups that can be made up of the different angularity, symmetry, and complexity groups. It would certainly not be unexpected that there may be interactions between these factors. Again, this may depend on the type of stimuli: Malfatti (2014) did not find any significant interactions using RM ANOVAs for her data on line shapes, but there were several interaction effects for closed geometric shapes. Another reason Experiments 3A, 3B, and 3C do not show significant interaction effects between shape properties, or the effects may be variable as for Malfatti (2014), may be the sample size. Finding a

significant interaction effect requires a larger sample size than a main effect (Aguinis, Beaty, Boik, & Pearce, 2005; Kenny, 2018; Shieh, 2019). Perhaps this is why when testing for interaction effects for Experiment 3D, indications that levels of shape characteristics have an influence on each other's effects on the chosen colour properties of red/green, yellow/blue, and lightness are found.

Finally, readers can peruse the results for interaction models run with only continuously rated variables in Appendix 6.12 to see that using polar binary categorical dimensions versus polar rated continuously rated dimensions results in many consistent findings, but can also throw up differences, which further complicate the analysis of colour-shape correspondences (an issue discussed in Chapter 5, Section 5.2.2.1 and 5.2.2.3).

3.3.1.3 The effect of stimuli set in Experiment 3D.

Since each individual saw all stimuli sets in Experiment 3D, the effect of the stimuli set can be tested, with each participant having their own random intercept for the outcome variable. Two types of models are presented in Table 3.9 and Table 3.10 for each colour property that explore the effect of stimuli set in Experiment 3D. The Simple Model that looks at the effect of angularity, symmetry, and complexity on each colour property had the three shape characteristics entered as fixed effects and is the same model that was compared to the Interaction Model above. In a second model (Stimuli Set Model), testing the effect of stimuli set, the factors of angularity,

symmetry, complexity, and stimuli set were entered as fixed effects, alongside the interaction effects of stimuli set with angularity, symmetry, and complexity. Participant was entered as a random effect for both models (intercept only model).

*Table 3.9 Table showing the results for the LMMs of perceptual shape characteristics predicting the red/green, yellow/blue and lightness colour dimensions for Simple (only direct effect of shape predictors) and Stimuli Set Models (include interactions between these shape predictors and stimuli set) for Experiment 3D. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

Parameters		Red/Green		Yellow/blue		Lightness	
		Simple Model	Stimuli Set Model	Simple Model	Stimuli Set Model	Simple Model	Stimuli Set Model
Regression coefficients (fixed effects)							
Intercept		46.61 (.31)***	46.64 (.34)***	53.45 (.31)***	53.62 (.34)***	44.10 (.41)***	43.37 (.44)***
Angularity	=0	1.60 (.25)***	1.30 (.31)***	-.75 (.27)**	-.11 (.35)	-.12 (.29)	-.13 (.37)
Symmetry	=0	.92 (.24)***	.70 (.30)*	.26 (.27)	-.18 (.34)	.70 (.29)*	.64 (.36)
Complexity	R	.35 (.12)**	.50 (.17)**	.19 (.14)	.30 (.19)	.85 (.15)***	.62 (.20)**
Stimuli set	=1		-1.12 (.59)		-1.87 (.66)**		3.19 (.70)***
	=2		1.63 (.64)*		.76 (.72)		.52 (.77)
Angularity *Stimuli set	0*1		1.59 (.64)*		-1.58 (.71)*		-.79 (.76)
	0*2		.07 (.71)		-1.30 (.80)		-2.02 (.85)*

Symmetry *Stimuli set	0*1	-.32 (.63)		2.33 (.70)**		1.32 (.75)	
	0*2	1.51 (.70)*		-.32 (.79)		-.46 (.84)	
Complexity *Stimuli set	R*1	.08 (.32)		.55 (.36)		-.24 (.38)	
	R*2	.86 (.60)		.17 (.67)		-3.76 (.71)***	
Variance components (random effects)							
Residual		685.66 (4.42)***	684.91 (4.41)***	859.00 (5.53)***	858.44 (5.52)***	979.84 (6.31)***	977.44 (6.30)***
Participants		33.95 (2.49)***	33.96 (2.49)***	27.94 (2.25)***	27.95 (2.25)***	64.96 (4.54)***	64.99 (4.54)***

*Table 3.10 Table showing the results for the LMMs of perceptual shape characteristics predicting the saturation and warmth colour dimensions for Simple and Stimuli Set Models for Experiment 3D. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

		Saturation		Warmth	
Parameters		**Simple Model**	**Stimuli Set Model**	**Simple Model**	**Stimuli Set Model**
Regression coefficients (fixed effects)					
Intercept		58.24 (.60)***	57.66 (.62)***	46.02 (.42)***	46.00 (.45)***
Angularity	=0	.32 (.25)	.53 /.32)	.23 (.27)	.12 (.35)
Symmetry	=0	.22 (.25)	.46 (.31)	-.32 (.27)	-.03 (.34)

Complexity	R	.39 (.13)**	.08 (.17)	-.22 (.14)	-.44 (.19)*
Stimuli set	=1		4.02 (.60)***		2.16 (.65)**
	=2		-.74 (.66)		-2.31 (.72)**
Angularity *Stimuli set	0*1		-2.42 (.65)***		-.52 (.71)
	0*2		-.21 (.73)		.89 (.79)
Symmetry *Stimuli set	0*1		-.28 (.64)		-1.28 (.70)
	0*2		-.42 (.72)		.25 (.78)
Complexity *Stimuli set	R*1		-.35 (.33)		-.41 (.35)
	R*2		-1.13 (.61)		.06 (.66)
Variance components (random effects)					
Residual		722.21 (4.65)***	721.00 (4.64)***	842.62 (5.43)***	841.92 (5.42)***
Participants		182.12 (11.32)** *	182.13 (11.32)** *	73.94 (4.97)***	73.94 (4.97)***

For all colour properties there was a significant main effect of stimuli set for at least one comparison of stimuli set levels. The results can be visually inspected in Figure 3.6. Pairwise comparisons indicated that for red/green, RF shapes were significantly greener than both mandala (mean difference = 2.90, SE = .54, $p < .001$, 95% CI (1.84,

3.96)) and geometric shapes (mean difference = 2.42, SE = .44, $p < .001$, 95% CI (1.56, 3.28)).

For yellow/blue, mandala shapes were yellower than both RF (mean difference = -1.45, SE = .60, $p = .017$, 95% CI (-2.63, -.26)) and geometric shapes (mean difference = -1.59, SE = .43, $p < .001$, 95% CI (-2.33, -.66)). Mandala shapes were found to be darker than both RF (mean difference = 4.22, SE = .64, $p < .001$, 95% CI (2.96, 5.49)) and geometric shapes (mean difference = 3.50, SE = .46, $p < .001$, 95% CI (2.61, 4.39)).

Mandala shapes were found to be more saturated than both RF (mean difference = 3.73, SE = .55, $p < .001$, 95% CI (2.65, 4.82)) and geometric shapes (mean difference = 2.67, SE = .39, $p < .001$, 95% CI (1.91, 3.44)). In regard to warmth, RF shapes were colder than both mandala (mean difference = -3.00, SE = .60, $p < .001$, 95% CI (-4.17, -1.83)) and geometric shapes (mean difference = -1.74, SE = .49, $p < .001$, 95% CI (-2.69, -.79)). Mandala shapes were colder than geometric shapes (mean difference = -1.26, SE = .42, $p = .003$, 95% CI (-2.09, -.43)).

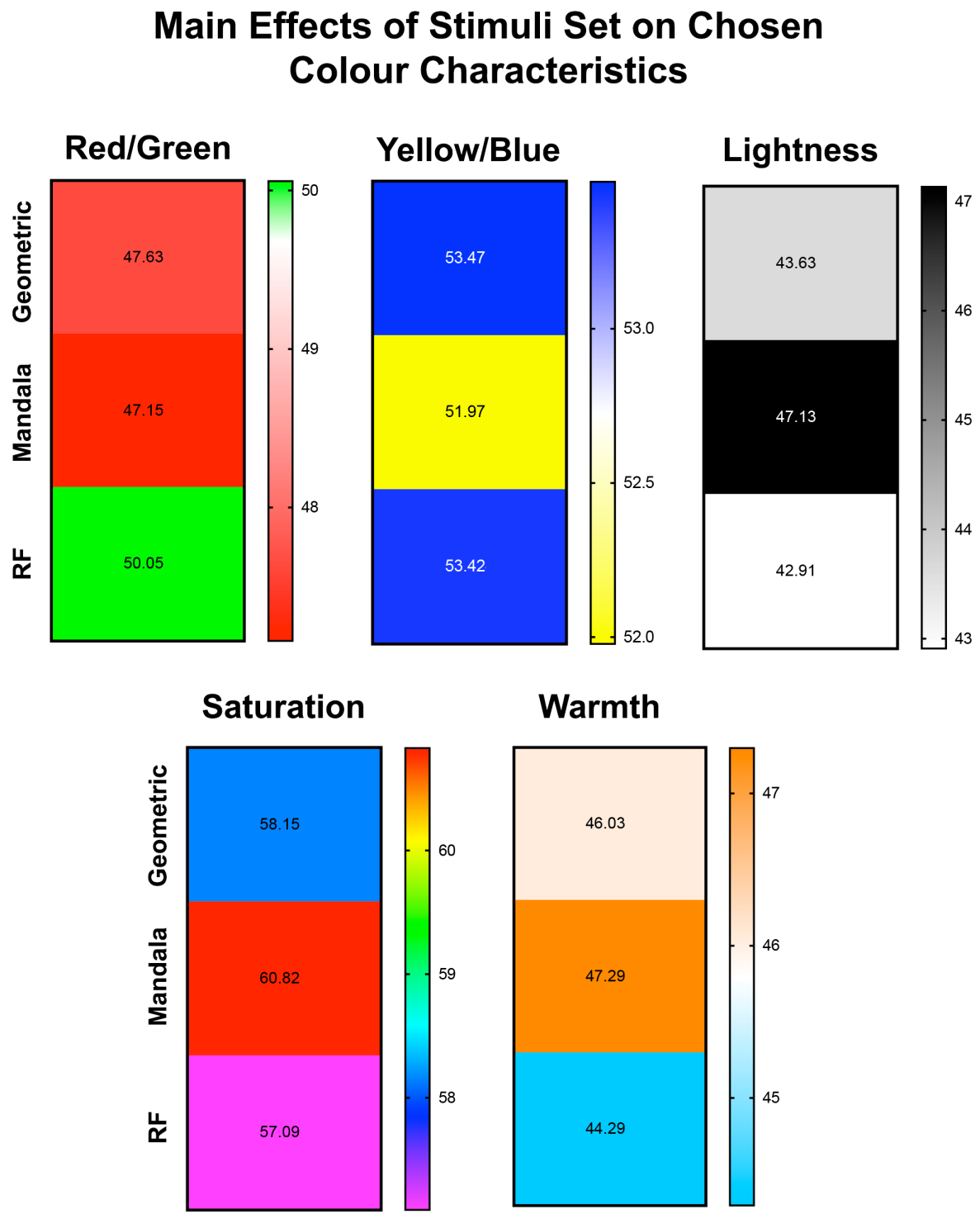


Figure 3.6 Graphs showing the main effects of stimuli sets on the five tested colour dimensions in Experiment 3D. The number in each cell indicates the mean (2 d.p.) colour characteristic for that particular category of shape.

In sum, it appears that mandala shapes were matched with yellower, darker, and particularly saturated colours in comparison to geometric and mandala shapes. RF shapes were more associated with greener and colder colours than the other two stimuli sets. A number of interaction effects of stimuli set with shape characteristics were found and can be visually inspected in Figure 3.7 (the interested reader can find the results of these pairwise comparisons in Appendix 6.13). The main takeaway here is that it is clear that it is not always one stimuli set that has varying effects but that interactions with angularity and symmetry are varied across the three kinds of shape stimuli.

One suggestion may be that such stimulus effects detailed above are driven by differences in shape characteristics of angularity, symmetry, and complexity that may exist between the stimuli sets that the categorical variables are not capturing. In other words, maybe the effects are found because one stimuli set simply is more angular, or is perceived as more symmetrical, and this is being washed away by the broad binary categories. This, however, is unlikely to be the central reason for the main and interaction effects of stimuli sets on chosen colour properties.

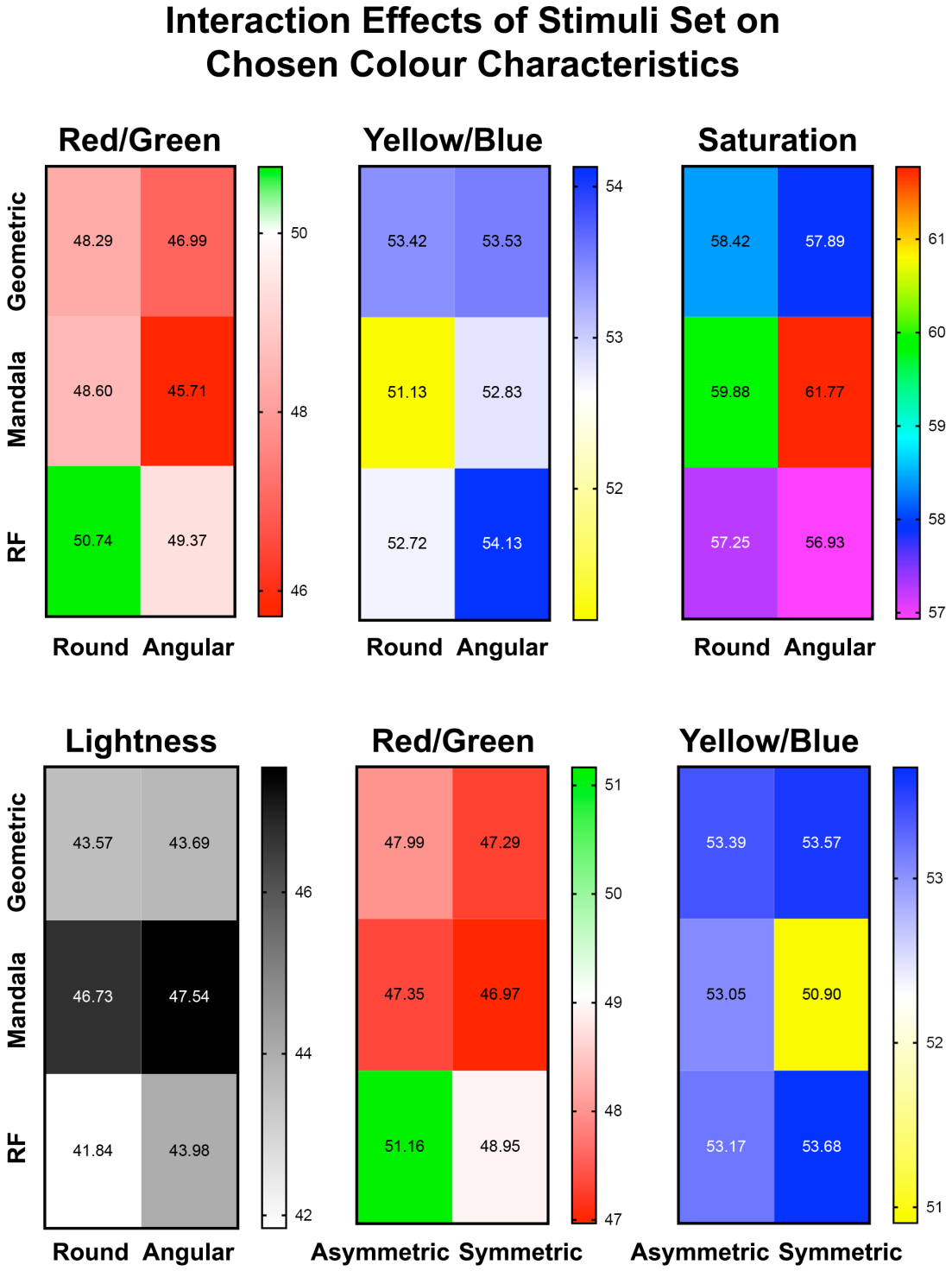


Figure 3.7 Graphs showing the interaction effects of stimuli sets with perceptual shape characteristic predictors on the five tested colour dimensions in Experiment 3D. The number in each cell indicates the mean (2 d.p.) colour characteristic for that particular category of shape. The interaction effects for lightness and complexity are not shown since complexity, as discussed, does not divide into categories across its range well when comparing the stimuli sets (the pairwise comparisons can be seen in Table 6.18 in Appendix 6.13 however).

This is because for angularity and symmetry the categorical variables were checked to similarly divide shapes across the stimuli sets in terms of mean angularity and symmetry. However, a stronger testament is the fact that even if continuously rated variables are used for the three shape characteristics and stimuli sets are compared, consistent results are not found either (the interested reader can inspect such results for Experiments 3A, 3B, and 3C, for example, in Appendix 6.10). Additionally, if the above LMMs are re-run for Experiment 3D using only continuously rated shape characteristics, indeed, the exact same interaction effects are found for red/green, yellow/blue, lightness, and saturation (with one additional significant effect found for lightness, see Appendix 6.14). That does not mean that more nuanced differences between these shapes – their real-word associations, other perceptual differences that exist between them, their aesthetics – are not driving these effects of stimuli set. It simply means that the studied characteristics of angularity, symmetry, and complexity are not capturing these differences. As such, these three shape characteristics may also not be able to satisfactorily capture, if they exist, any shape characteristics that can predict chosen colour properties across a range of shape stimuli.

3.3.1.4 The effect of nationality in Experiment 3D.

To test for the effect of nationality in Experiment 3D, participants were selected if they belonged to one of the six chosen nationalities: France, Germany, Italy, Mexico, UK, and US. Additionally, participants were asked in what country they grew up in

and were only included if this was the same as their nationality. Individuals who noted dual nationalities or several countries they grew up in were excluded. This ensured that large samples were available for each nationality and that the individuals spent the years growing up in the same country, exposed to, what may be, arguably, more similar cultural influences and potential object and affective associations for specific shapes. This left a total of 520 participants. The effect of nationality was tested by entering the effect of participant as a random effect (intercept only) as before, alongside fixed effects of angularity, symmetry, rated complexity, and the interaction effects of nationality with these three shape characteristics. The dependent variables were the usual five colour characteristics.

*Table 3.11 Table showing the results for LMMs testing the effect of perceptual shape predictors, nationality, and their interactions for the five tested colour dimensions of Experiment 3D. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

Parameters		Red/Green	Yellow/blue	Lightness	Saturation	Warmth
		Regression coefficients (fixed effects)				
Intercept		47.84 (.79)***	54.05 (.78)***	45.97 (1.01)***	57.31 (1.46)***	47.63 (1.05)***
Angularity	=0	1.47 (.62)*	-1.84 (.69)**	-.16 (.73)	.40 (.63)	.52 (.68)
Symmetry	=0	.96 (.61)	-1.12 (.68)	-.37 (.72)	.03 (.62)	.80 (.67)

Complexity	R	.48 (.31)	-.41 (.35)	.83 (.37)*	.33 (.32)	-.31 (.34)
Nationality	=1	-2.83 (1.15)*	-1.13 (1.15)	-2.50 (1.48)	-1.82 (2.13)	-2.96 (1.54)
	=2	-2.11 (1.13)	.02 (1.12)	-1.70 (.145)	6.78 (2.09)**	-.84 (1.51)
	=3	-.65 (1.15)	-2.40 (1.14)*	-6.52 (1.47)***	-1.86 (2.12)	-3.26 (1.53)*
	=4	-2.24 (1.14)	1.38 (1.14)	.44 (1.46)	.15 (2.11)	-2.12 (1.53)
	=5	-.17 (1.10)	-1.49 (1.09)	-1.87 (1.41)	.74 (2.03)	-.96 (1.47)
Angularity *Nationality	0*1	.29 (.90)	1.79 (1.01)	.77 (1.07)	.79 (.92)	-.25 (1.00)
	0*2	.02 (.88)	1.11 (.98)	-1.27 (1.05)	.02 (.90)	-.11 (.98)
	0*3	.43 (.89)	2.22 (1.00)*	.68 (1.07)	.07 (.92)	-.94 (.99)
	0*4	.45 (.89)	.83 (1.00)	.31 (1.06)	-.84 (.91)	-1.17 (.99)
	0*5	-.23 (.86)	1.10 (.96)	.64 (1.02)	-.41 (.88)	.42 (.95)
Symmetry *Nationality	0*1	1.59 (.89)	1.81 (.99)	1.47 (1.06)	.32 (.91)	-1.75 (.98)
	0*2	.39 (.87)	1.64 (.97)	1.48 (1.03)	.28 (.89)	-1.90 (.96)*
	0*3	-1.71 (.88)	2.90 (.99)**	2.00 (1.05)	-.65 (.90)	-2.17 (.98)*
	0*4	-.02 (.88)	-.18 (.98)	.17 (1.05)	.79 (.90)	-.15 (.97)
	0*5	-.15 (.85)	2.37 (.94)*	1.63 (1.01)	.46 (.87)	-1.02 (.94)

Complexity *Nationality	R*1	.18 (.45)	.66 (.51)	.22 (.54)	.34 (.46)	.13 (.50)
	R*2	-.47 (.44)	.73 (.50)	-.49 (.53)	.28 (.45)	.49 (.49)
	R*3	.00 (.45)	.80 (.50)	.18 (.54)	.32 (.46)	-.31 (.50)
	R*4	-.30 (.45)	.82 (.50)	.21 (.53)	-.04 (.46)	.13 (.50)
	R*5	-.23 (.43)	.72 (.48)	-.23 (.51)	-.31 (.44)	-.04 (.48)
Variance components (random effects)						
Residual		692.42 (4.66)***	863.88 (5.81)***	981.72 (6.61)***	727.51 (4.90)***	847.56 (5.70)***
Participants		34.69 (2.67)***	28.59 (2.41)***	62.10 (4.58)***	170.55 (11.17)***	74.26 (5.25)***

The results of these five nationality models are shown in Table 3.11. The significant main effects of nationality alone are depicted in Figure 3.8. For each colour property, at least one nationality differed significantly from another level of nationality. In the case of red/green, the US had significantly greener colour choices than Mexico (mean difference = -2.03, SE = 1.00, p = .042, 95% CI (-3.98, -.07)). The largest difference for yellow/blue was also between these two countries, with the Mexico choosing bluer colours than the US (mean difference = 1.71, SE = .95, p = .071, 95% CI (-.15, 3.56)).

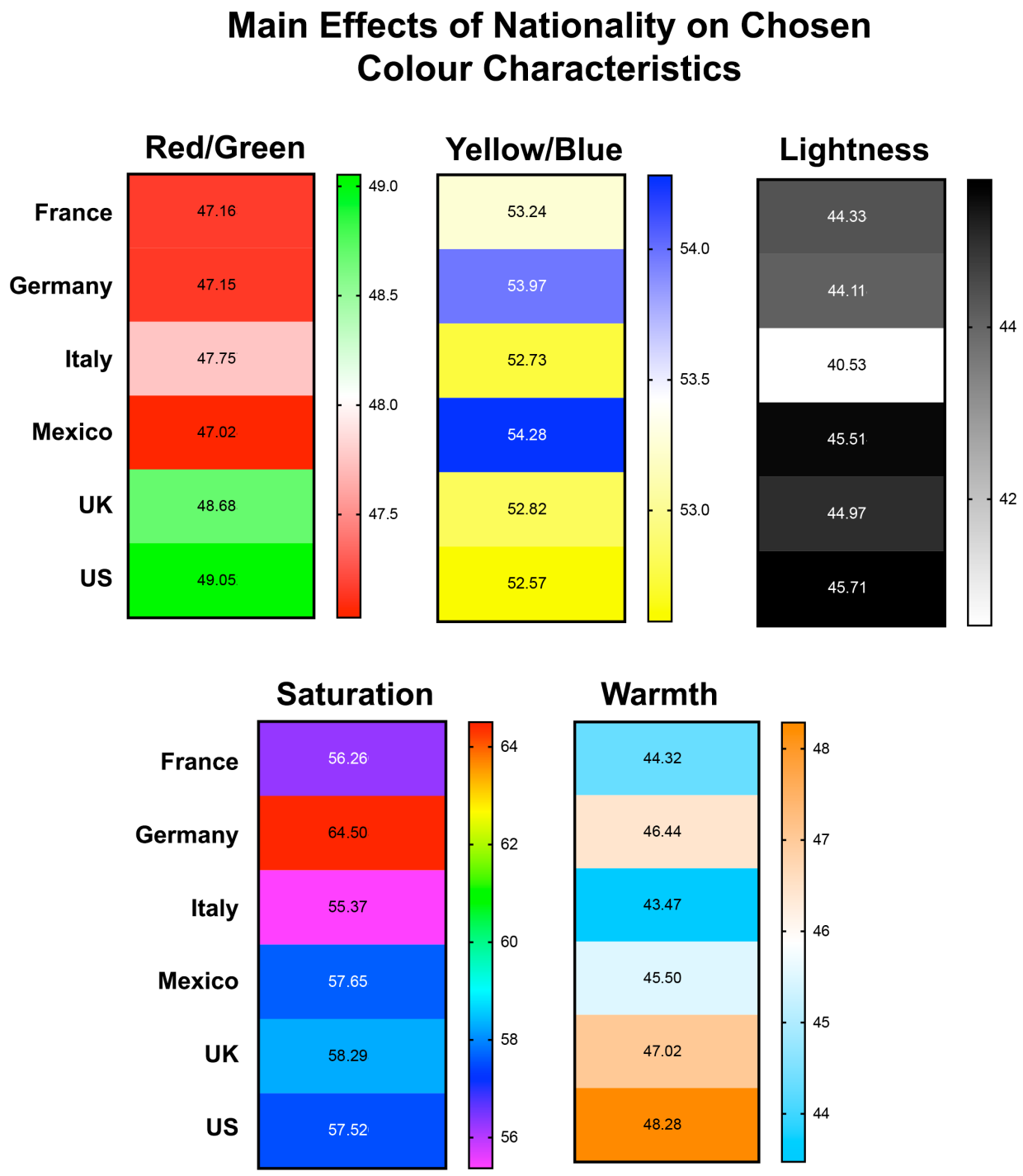


Figure 3.8 Graphs showing the main effect of nationality on colour dimensions for the nationality models tested using LMMs for Experiment 3D. The number in each cell indicates the mean (2 d.p.) colour characteristic for that particular category of shape.

In regard to lightness, Italy chose significantly whiter colours than all other countries: France (mean difference = -3.80, SE = 1.35, $p = .005$, 95% CI (-6.45, -1.26)), Germany (mean difference = -3.59, SE = 1.32, $p = .007$, 95% CI (-6.18, -1.00)), Mexico (mean difference = -4.98, SE = 1.34, $p < .001$, 95% CI (-7.60, -2.36)), the UK (mean difference = -4.44, SE = 1.29, $p = .001$, 95% CI (-6.97, -1.92)), and the US (mean difference = -5.18, SE = 1.31, $p < .001$, 95% CI (-7.74, -2.62)).

Germany was found to choose significantly more saturated colours than all other countries: France (mean difference = 8.24, SE = 2.07, $p < .001$, 95% CI (4.18, 12-31)), Italy (mean difference = 9.13, SE = 2.06, $p < .001$, 95% CI (5.09, 13.17)), Mexico (mean difference = -2.89, SE = 2.05, $p = .001$, 95% CI (2.82, 10.87)), the UK (mean difference = 6.21, SE = 1.98, $p = .002$, 95% CI (2.33, 10.09)), and the US (mean difference = 6.98, SE = 2.01, $p = .001$, 95% CI (3.04, 10.91)). The US had significantly warmer colour choices than France (mean difference = 3.96, SE = 1.41, $p = .005$, 95% CI (1.20, 6.72)), Italy (mean difference = 4.81, SE = 1.40, $p = .001$, 95% CI (2.07, 7.55)), and Mexico (mean difference = 2.78, SE = 1.39, $p = .046$, 95% CI (.05, 5.52)). Additionally, the UK had warmer colour choices than Italy (mean difference = 3.55, SE = 1.38, $p = .010$, 95% CI (.85, 6.25)).

It should be noted that the main effects of colour choice can of course also be confounded with the fact that individuals from the different countries may have differed in how they rated the colours to begin with, due to average differences in

screens, lighting conditions, or cultural differences in rating behaviour and colour perceptions, amongst other factors. Indeed, in a MANOVA on the average colour ratings across all 36 colours for five colour characteristics, nationality did, indeed, significantly influence lightness ($F(5, 524) = 4.31$, $p = .001$), saturation ($F(5, 524) = 5.74$, $p < .001$), and warmth ratings ($F(5, 524) = 4.26$, $p = .001$). The country showing the main difference for these colour properties, Italy, Germany, and the US, respectively, indeed, showed the highest or lowest rating for that particular nationality. So, it is likely that these initial colour ratings are playing a part in lightness, saturation and warmth effects, although they are not affecting red/green and yellow/blue main effects in the same way.

When the interaction effects are inspected, especially when comparing how individuals may differ across nationality levels as to the effect of shape characteristics within each nationality level, one gets to the crux of examining how different nationalities may affect individuals' colour-shape associations rather than overall colour choices. The significant interaction effects are presented in Figure 3.9. In regard to yellow/blue, it is the US that shows a significant difference between round and angular shapes, with round shapes being associated with yellower colour choices ((mean difference = -1.84, SE = .69, $p = .008$, 95% CI (-3.19, -.49)). Italian participants exhibited a significant difference between asymmetrical and symmetrical shapes, with symmetrical shapes being yellower than asymmetrical shapes (mean difference = -1.78, SE = .71, $p = .013$, 95% CI (-3.18, -.38)).

For warmth, it can be seen in Figure 3.9, that there is a general trend across all nationalities that symmetrical shapes are warmer than asymmetrical shapes. This appears to be most pronounced for Italy (mean difference = 1.37, SE = .71, p = .053, 95% CI (-.015, 2.76)). However, Mexico and the US do not show this trend. Overall, it appears that nationality can result in differential effects in how shape properties affect chosen colour characteristics, although such interaction effects were limited in terms of what colour dimensions were affected.

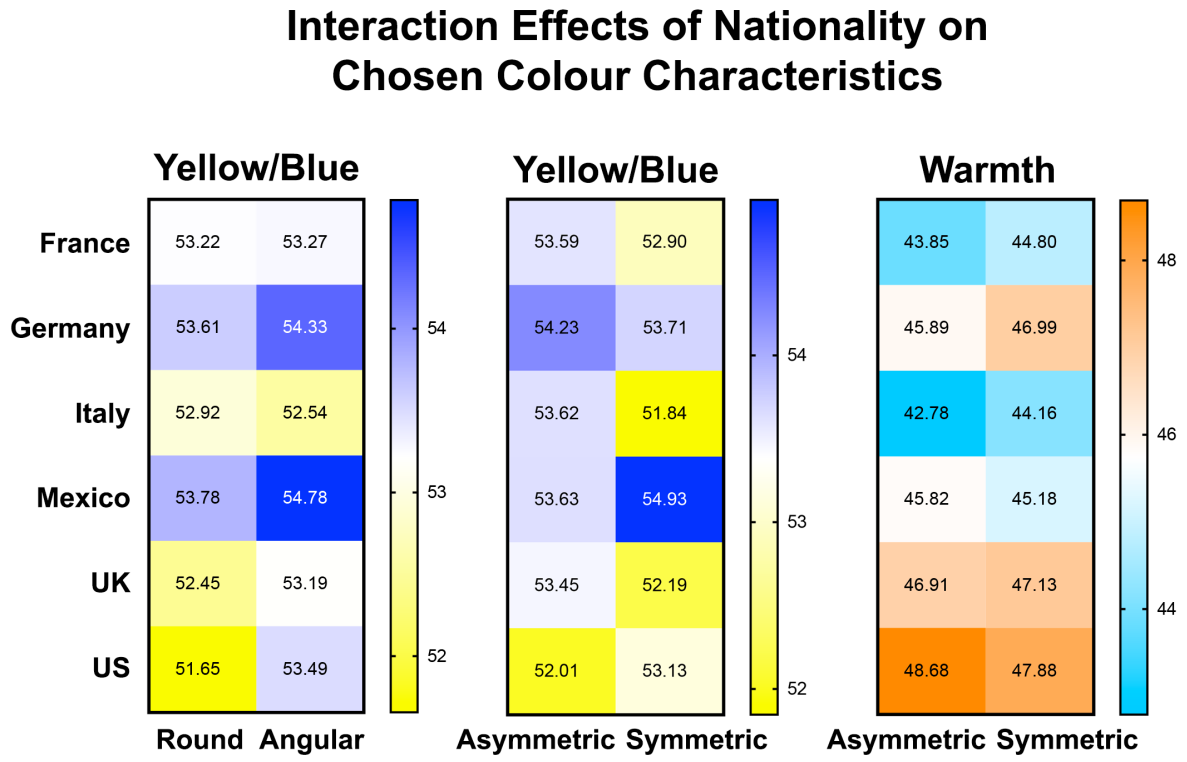


Figure 3.9 Graphs showing the interaction effects of nationality with perceptual shape characteristics on colour dimensions for the nationality models tested using LMMs for Experiment 3D. The number in each cell indicates the mean (2 d.p.) colour characteristic for that particular category of shape.

3.3.1.5 The effect of gender in Experiment 3D.

The effect of gender was tested in the same way as nationality, just that the main effect of gender and interaction effects of gender with the shape characteristics were added as fixed effects alongside the shape predictor variables. Participants who were male or female were included in the sample. Individuals who were non-binary were excluded, since they made up too small of a sample ($n = 6$). The effects of gender are shown in Table 3.12 and Figure 3.10.

Males chose colours that were bluer and lighter, whilst females chose colours which were on average yellower and darker. When checking whether males and females rated colours differently to begin with, it was found using a MANOVA that this is the case for yellow/blue ($F(1, 571) = 4.46$, $p = .035$), lightness ($F(1, 571) = 5.18$, $p = .023$), and saturation ($F(1, 571) = 14.97$, $p < .001$). Males initially rated colours as bluer (mean = 54.11, SE = .25), lighter (mean = 45.52, SE =.40) and less saturated (mean = 56.36, SE = .74) than females (mean = 53.73, 46.80, 60.34, SE = .24, .39, .72, respectively). This is in line with the main effect findings of the effect of gender on colour choices.

But significant interaction effects show that gender had some influence on how shape characteristics affected colour choices. For males, symmetrical shapes were bluer than asymmetrical shapes, whilst for females, symmetrical shapes were significantly yellower (mean difference = -1.19, SE = .38, $p = .002$, 95% CI (-1.93, -.44)).

*Table 3.12 Table showing the results for LMMs testing the effect of perceptual shape predictors, gender, and their interactions for the five tested colour dimensions of Experiment 3D. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

Parameters		Red/Green	Yellow/blue	Lightness	Saturation	Warmth
Regression coefficients (fixed effects)						
Intercept		46.77 (.44)***	52.08 (.43)***	44.59 (.58)***	59.98 (.83)***	46.13 (.59)***
Angularity	=0	1.54 (.35)***	-1.01 (.39)**	.07 (.41)	.87 (.35)*	.58 (.38)
Symmetry	=0	.49 (.34)	1.19 (.38)**	1.15 (.41)**	.42 (.35)	-.67 (.38)
Complexity	R	.39 (.17)*	.17 (.19)	1.01 (.21)***	.33 (.18)	-.21 (.19)
Gender	=0	-.25 (.63)	2.73 (.62)***	-1.06 (.83)	-3.69 (1.19)**	-.37 (.85)
Angularity *Gender	0*0	.10 (.49)	.47 (.55)	-.39 (.59)	-1.07 (.51)*	-.64 (.55)
Symmetry *Gender	0*0	.85 (.49)	-1.83 (.54)**	-.86 (.58)	-.32 (.50)	.68 (.54)
Complexity *Gender	R*0	-.07 (.25)	.08 (.28)	-.30 (.30)	.09 (.25)	-.03 (.28)
Variance components (random effects)						
Residual		683.84 (4.42)***	856.44 (5.54)***	978.78 (6.33)***	721.74 (4.67)***	842.06 (5.45)***
Participants		34.01 (2.50)***	26.95 (2.20)***	64.90 (4.55)***	176.38 (11.02)***	73.68 (4.98)***

For males, there was no significant difference in saturation between round and angular shapes. For females, however, round shapes were significantly associated with more saturated colours than angular shapes (mean difference = .87, SE = .36, $p = .014$, 95% CI (.18, 1.57)). In sum, gender did appear to show some significant interaction effects with shape characteristics, highlighting that it is a factor that may affect chosen colour characteristics. Whether it does so in a meaningful way, however, will be considered in the next section.

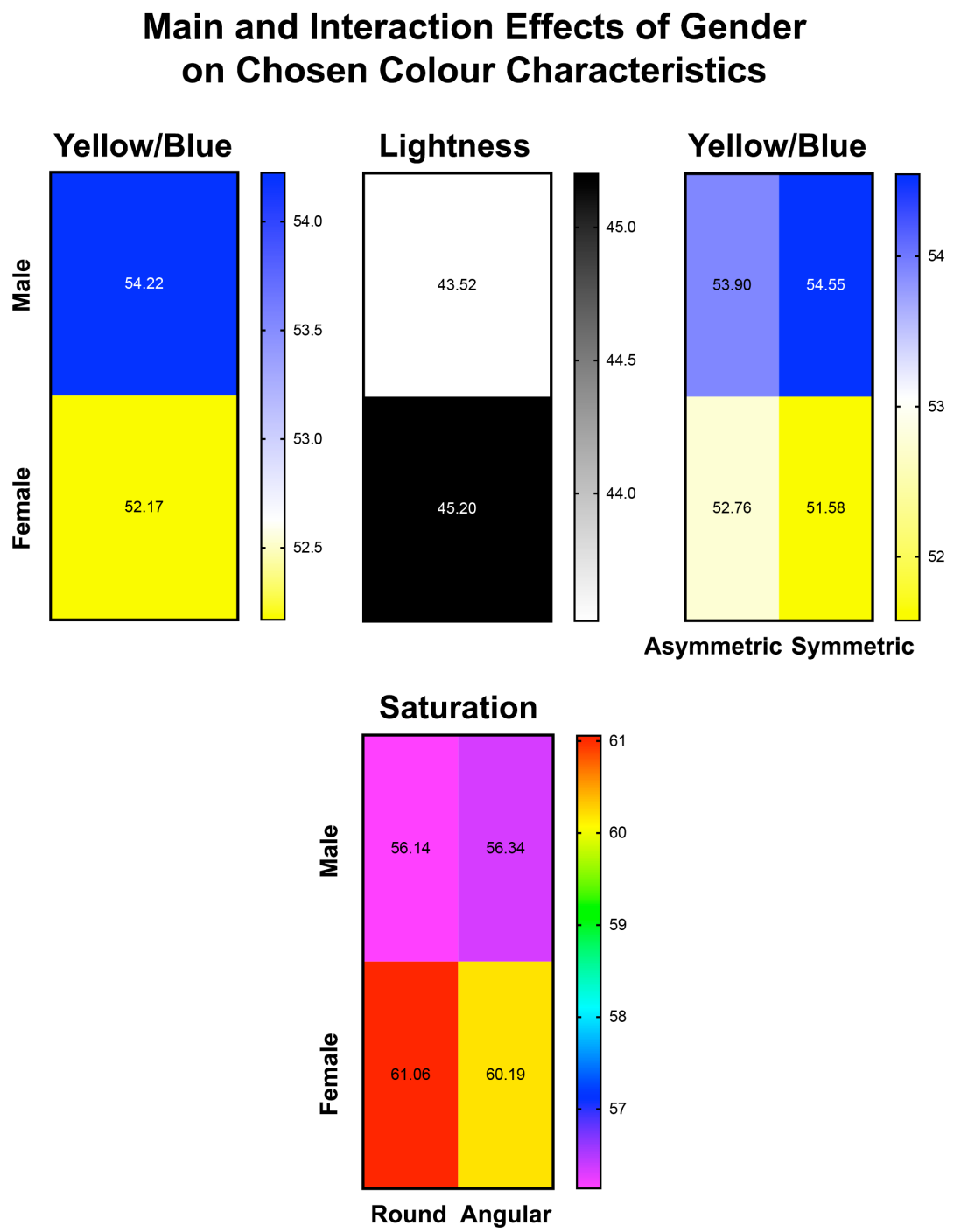


Figure 3.10 Graphs showing the main effects of gender and the interaction effects of gender with perceptual shape characteristics on colour dimensions for the nationality models tested using LMMs for Experiment 3D. The number in each cell indicates the mean (2 d.p.) colour characteristic for that particular category of shape.

3.3.2 Evaluating models using AIC and variance explained for Experiment 3D.

The more in-depth analysis of Experiment 3D above has shown that the shape characteristics of angularity, symmetry, and complexity as well as the interactions between shape characteristics, stimuli set, nationality, and gender can affect chosen colour characteristics. Beta-values in simple models without interaction effects are informative since they tell us the change created by a specific categorical level or change in one standard deviation of a standardised variable, in the dependent colour characteristic variable. When interaction effects are added, such beta-values become less intuitively interpretable. Additionally, there are other ways to capture how well these models are performing. One is by comparing AIC values between models. A lower AIC indicates a better fitting model. Burnham and Anderson (2004) indicate that:

> Some simple rules of thumb are often useful in assessing the relative merits of models in the set: Models having $\Delta_i \leq 2$ have substantial support (evidence), those in which $4 \leq \Delta_i \leq 7$ have considerably less support, and models having $\Delta_i > 10$ have essentially no support. These rough guidelines have similar counterparts in the Bayesian literature (Raftery, 1996). (p. 271)

Here the values are positive since they define Δ_i as the difference between any model and the lowest AIC model. For the sake of ease of understanding, the AIC of the model that is being evaluated is taken and the AIC value of the model it is being compared to is deducted from it. So, for example, if one wanted to know if adding the random effect of participant (Random Model) is an improvement compared to the Empty Model (no fixed effects, no random effects, just the dependent variable), the Empty

Model AIC is subtracted from the Random Model AIC. A negative value then indicates an improvement of the Random Model over the Empty Model. If it is of the order -4 to -7, it now means that the Random Model has considerably more support than the Empty Model, and so on, using the guidelines set out by Burnham and Anderson (2004) above. The results for these changes in AIC values can be seen in Table 3.13.

*Table 3.13 Graph showing the results of calculation showing the residual variance, AIC values, change in AIC values to previous models, and percentage of variance explained by the random of effects of participant, the fixed effects of predictors, and the total variance explained in each colour dimensions, for each model, for Experiment 3D. Models tested are described in the text of the thesis and correspond to previous descriptions of the build for each model except in the case of the Nationality and Gender Models. Residual cells can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level.*

Model		Red/Green	Yellow/ Blue	Lightness	Saturation	Warmth
Empty Model	Residual	720.53 (4.61)***	887.17 (5.68)***	1045.79 (6.70)***	904.51 (5.79)***	916.67 (5.87)***
	AIC	459237.61	469382.61	477403.81	470326.53	470977.67
Random Model	Residual	686.58 (4.42)***	859.23 (5.54)***	980.84 (6.32)***	722.39 (4.65)***	842.73 (5.43)***
	Participants	33.94 (2.49)***	27.94 (2.25)***	64.95 (4.54)***	182.11 (11.32)***	73.93 (4.97)***
	AIC	457827.05	468580.70	475357.34	461135.69	468095.45

	ΔAIC to Empty Model	-1410.56	-801.91	-2046.48	-9190.84	-2882.22
	% Variance explained by random effect of participant	4.71	3.15	6.21	20.13	8.07
Simple Model	**Residual**	685.66 (4.42)***	859.00 (5.53)***	979.84 (6.31)***	722.21 (4.65)***	842.62 (5.43)***
	Participants	33.95 (2.49)***	27.94 (2.25)***	64.96 (4.54)***	182.12 (11.32)***	73.94 (4.97)***
	AIC	457768.37	468573.86	475314.10	461129.64	468094.92
	ΔAIC Compared to Random Model	-58.68	-6.84	-43.24	-6.05	-.53
	% Variance explained by predictors	.13	.03	.09	.02	.01
	Total % variance explained	4.84	3.18	6.31	20.15	8.08
Interaction Model	**Residual**	685.40 (4.42)***	858.80 (5.53)***	979.37 (6.31)***	722.16 (4.65)***	842.54 (5.43)***
	Participants	33.96 (2.49)***	27.94 (2.25)***	64.97 (4.54)***	182.12 (11.32)***	73.94 (4.97)***
	AIC	457757.64	468570.74	475299.36	461134.09	468098.35
	ΔAIC Compared to Simple Model	-10.73	-3.12	-14.74	4.45	3.43

	% Variance explained by predictors	.16	.05	.14	.02	.02
	Total % variance explained	4.87	3.20	6.35	20.16	8.09
Stimuli Set Model	Residual	684.91 (4.41)***	858.44 (5.52)***	977.44 (6.30)***	721.00 (4.64)***	841.92 (5.42)***
	Participants	33.96 (2.49)***	27.95 (2.25)***	64.99 (4.54)***	182.13 (11.32)***	73.94 (4.97)***
	AIC	457731.44	468558.74	475211.85	461064.76	468071.10
	ΔAIC Compared to Simple Model	-36.93	-15.12	-102.25	-64.88	-23.82
	% Variance explained by predictors	.23	.09	.32	.15	.09
	Total % variance explained	4.94	3.24	6.53	20.29	8.15
Nationality Model	Residual	685.35 (4.41)***	858.38 (5.53)***	979.53 (6.31)***	722.09 (4.65)***	842.24 (5.43)***
	Participants	33.32 (2.45)***	27.18 (2.21)***	61.59 (4.34)***	171.85 (10.70)***	71.80 (4.85)***
	AIC	457793.88	468583.79	475329.08	461145.97	468114.39
	ΔAIC Compared to Simple Model	25.51	9.92	14.98	16.33	19.48

	% Variance explained by predictors	.26	.18	.45	1.17	.29
	Total % variance explained	4.97	3.33	6.66	21.30	8.35
Gender Model	Residual	685.60 (4.42)***	858.65 (5.53)***	979.73 (6.31)***	722.05 (4.65)***	842.53 (5.43)***
	Participants	33.87 (2.49)***	26.84 (2.19)***	64.28 (4.49)***	177.38 (11.03)***	73.49 (4.95)***
	AIC	457779.02	468553.84	475319.31	461120.74	468102.77
	ΔAIC Compared to Simple Model	10.65	-20.02	5.21	-8.90	7.85
	% Variance explained by predictors	.15	.19	.17	.56	.07
	Total % variance explained	4.86	3.34	6.38	20.70	8.14

For all colour properties except warmth, the fixed effects of angularity, symmetry, and rated complexity reduce the AIC value by an amount that indicates there is more support for the Simple Model than for the Random Model alone. The evidence is particular decisive for colour properties red/green and lightness. The other models are now compared to this Simple Model. The Interaction Model is supported strongly over the Simple Model for red/green and lightness, and to a lesser degree for yellow/blue. For saturation and warmth, however, the Interaction Model does not improve fit over

and above the Simple Model. The Stimuli Set Model shows across the board that taking into account stimuli set improves model fit compared to the Simple Model alone, showing in terms of the values that there is very strong support that this model is a better fit. This highlights well that colour-shape associations are stimuli-dependent.

The Nationality Model and Gender Model had to be re-run without participant restrictions in order to allow comparisons to the Simple Model. The Nationality Model resulted in a worse fit than the Simple Model alone – all AIC values are higher when compared to the Simple Model. In regard to the Gender Model, there was evidence that including gender improved model fit for yellow/blue and lightness, showing strong support that these models were a better fit than the Simple Model. However, for the other three colour characteristics, AIC values were positive and, as such, the Simple Model was found to be superior. In sum, then, the effect of stimulus is important to take into account for all colour properties. Taking into account the effect of shape characteristic interactions or gender, results in improved model fit for some colour properties, whilst nationality does not improve model fit for any colour property.

The other way to compare models is to consider how much variance in colour choices is explained by the random and fixed predictors. This gives a better idea of how much variability in participant choices can actually be accounted for by predictors. To determine the effect of random predictors the Empty Model is compared to the Random Model as follows:

$$\frac{\sigma^2_{Empty\ Model} - \sigma^2_{Random\ Model}}{\sigma^2_{Empty\ Model}}$$

Equation 3.1

Here σ^2 is the estimate of the residual variance. This allows to calculate the total variance explained by the fixed and random effects by each model by simple replacing σ^2 values such that:

$$\frac{\sigma^2_{Empty\ Model} - \sigma^2_{Model\ under\ consideration}}{\sigma^2_{Empty\ Model}}$$

Equation 3.2

The result of Equation 3.2 is then multiplied by 100 for a percentage. However, to determine what percentage of variance is explained by the fixed effects alone for each tested model the following was calculated:

$$\frac{(\sigma^2_{Random\ Model} + \gamma^2_{0\ participant\ Random\ Model}) - (\sigma^2_{Tested\ Model} + \gamma^2_{0\ participant\ Tested\ Model})}{(\sigma^2_{Random\ Model} + \gamma^2_{0\ participant\ Random\ Model})}$$

Equation 3.3

$\gamma^2_{0\ participant}$ is the estimate of the variance accounted for by the random effect of the intercept of participant. The result of the Equation 3.3 is again multiplied by 100 to result in a percentage. The above equations were adapted from Carson and Beeson (2013). The results of what percentage of variance is explained by fixed effect predictors and the total variance explained by a model (including the random effect of participant) for each model is detailed in Table 3.13. What is immediately apparent is

that for all models, predictor fixed effect variables explain a minimal amount of variance (generally less than 1%). Most of the total explained variance is accounted for by the random effect of participant, with this random effect accounting for a large amount of variance in saturation of colour choices in particular. Consider, for example, the Stimuli Set Model, which performed particularly well in terms of the reduction in AIC value in comparison to the Simple Model. The total variance accounted for by the model was 4.94% for red/green, but only .23% were accounted for by the fixed effect predictors. The same was true for the other colour properties: yellow/blue (3.24% total vs. .09% predictors), lightness (6.53% vs. .32%), saturation (20.29% vs. .15%), and warmth (8.15% vs. .09%).

The same methodology can be used to test the models in Table 3.13 above for Experiments 3A, 3B, and 3C. The results can be seen in Table 3.14, and show, similarly, that a very limited amount of variance is explained by the fixed effect predictors of angularity, symmetry, and complexity, and that most of the total variance explained derives from introducing the random effect of participant as an intercept.

Table 3.14 Graph showing the results of calculation showing the residual variance, AIC values, change in AIC values to previous models, and percentage of variance explained by the random of effects of participant, the fixed effects of predictors, and the total variance explained in each colour dimensions, for each model, for Experiments 3A-3C. Models tested are described in the text of the thesis and correspond to previous descriptions of the build for each model. Residual cells can be read as coefficient (standard error)$^{significance\ level}$.

Model		Red/Green	Yellow/ Blue	Lightness	Saturation	Warmth
		Experiment 3A				
Empty Model	AIC	35285.82	35687.28	35406.80	29506.92	33225.66
Random Model	AIC	34645.97	35098.63	35277.17	29394.19	33119.73
	ΔAIC to Empty Model	-639.84	-588.64	-129.63	-112.74	-105.93
	% Variance explained by random effect of participant	19.74	18.52	6.03	5.47	5.24
Simple Model	AIC	34640.68	35095.64	35223.57	29374.78	33121.04
	ΔAIC Compared to Random Model	-5.29	-2.99	-53.61	-19.41	1.31
	% Variance explained by predictors	.33	.39	1.60	.75	.22
	Total % variance explained	20.07	18.91	7.63	6.22	5.46

Experiment 3B						
Empty Model	**AIC**	9938.85	10250.46	10298.64	8651.24	9697.48
Random Model	**AIC**	9936.08	10239.92	10272.97	8640.75	9698.03
	ΔAIC to Empty Model	-2.77	-10.53	-25.67	-10.49	.55
	% Variance explained by random effect of participant	2.69	4.64	7.40	4.63	1.42
Simple Model	**AIC**	9943.60	10235.64	10260.59	8646.29	9702.73
	ΔAIC Compared to Random Model	7.52	-4.29	-12.37	5.54	4.70
	% Variance explained by predictors	.22	1.24	1.88	.39	.48
	Total % variance explained	2.91	5.88	9.29	5.02	1.90
Experiment 3C						
Empty Model	**AIC**	8042.34	8530.09	8617.72	7182.26	8094.64
Random Model	**AIC**	8037.43	8514.55	8593.02	7182.82	8088.62
	ΔAIC to Empty Model	-4.91	-15.54	-24.70	.56	-6.02

	% Variance explained by random effect of participant	4.20	7.12	9.10	1.80	4.56
SIMPLE MODEL	AIC	8032.82	8513.90	8587.82	7175.86	8090.70
	ΔAIC Compared to Random Model	-4.60	-.65	-5.21	-6.96	2.08
	% Variance explained by predictors	1.33	.89	1.32	1.62	.62
	Total % variance explained	5.53	8.00	10.43	3.42	5.19

3.3.3 Emotional mediation in Experiments 3A-3C.

If perceptual shape characteristic predictors only explain a limited amount of variance in colour choices at the choice-by-choice level in Experiments 3A-3D, let us now turn to testing another mechanism which may explain colour-shape matches: the emotional mediation hypothesis (Palmer, Schloss, Xu, & Prado-León, 2013). Data was collected in Experiments 3A-3C to determine what each participant's liking and arousal ratings were for each shape and colour. As before, LMMs were used with participant entered as a random effect (intercept only model). The fixed effect predictors entered where shape liking and shape arousal, whilst for each experiment the dependent variables of chosen colour liking and arousal were tested in separate models. The results can be

seen in Table 3.15 alongside the same analyses as conducted above for perceptual shape characteristics of how much variance is explained by random effects alone, fixed effects alone, and the total variance explained.

For all experiments, except for Experiment 3C (chosen colour liking), the corresponding shape affective dimension positively predicts the same chosen colour dimension. That is to say, there is good evidence that individuals choose colours they like for shapes they like more and choose colours they find more arousing for shapes they find more arousing. Additionally, and likely because of the correlation between shape liking and shape arousal found in Experiment 3A ($r = .85$, $p < .01$ and 3C ($r = .25$, $p < .01$), sometimes shape liking also predicted chosen colour arousal, and shape arousal predicted chosen colour liking.

When considering the percentage of variance explained, it is clear that larger totals of variance in chosen colour affective dimensions are explained by affective shape characteristics for Experiments 3A-3C, than was the case generally for perceptual shape predictors (see Table 3.14 above, and note the exception of Experiment 3C for chosen colour liking). The fixed effects of shape affective dimensions also appear to be more effective at explaining variance on their own than the shape's perceptual characteristics. Overall, this points to the fact that affective evaluations of shapes and colours likely play an important part in what colours individuals choose for each shape.

*Table 3.15 Table showing the results of LMMs predicting chosen colour liking and arousal for Experiments 3A-3C, based on the predictors of shape liking and arousal. The percentage of variance explained by the random effect of participant, the fixed effect predictors of the model, and the total model are shown as well. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

	Experiment 3A		Experiment 3B		Experiment 3C	
Parameters	**Chosen colour liking**	**Chosen colour arousal**	**Chosen colour liking**	**Chosen colour arousal**	**Chosen colour liking**	**Chosen colour arousal**
Regression coefficients (fixed effects)						
Intercept	61.50 (1.54)***	57.86 (1.57)***	64.84 (1.46)***	61.37 (1.86)***	48.85 (1.54)***	39.54 (2.07)***
Shape liking	3.39 (.49)***	1.70 (.52)**	3.95 (.80)***	1.09 (.85)	-.65 (1.07)	1.82 (.97)
Shape arousal	-.84 (.52)	2.39 (.55)***	2.19 (.80)**	2.31 (.85)**	.05 (.93)	2.54 (1.15)*
Variance components (random effects)						
Residual	623.38 (141.06) ***	705.81 (16.53) ***	413.00 (18.33) ***	447.16 (20.26) ***	611.11 (30.14) ***	644.87 (31.84) ***
Participants	141.06 (26.98) ***	145.33 (27.91) ***	119.15 (25.85) ***	208.95 (41.25) ***	125.95 (29.50) ***	268.10 (54.35) ***
Percentage of Variance Explained						
% Variance explained by random effect of participant alone	19.74	18.52	29.24	33.87	16.88	31.56

% Variance explained by predictors compared to Random Model	2.74	2.81	11.21	5.74	-.12	3.61
Total % variance explained	22.48	21.33	40.45	39.61	16.76	35.17

3.3.4 Intuitiveness and processing fluency.

3.3.4.1 The effect of shape characteristics on intuitiveness ratings in Experiments 3A, 3B, and 3C.

The effect of angularity, symmetry, and complexity on the experienced intuitiveness of colour choices was tested using an LMM for each of the three models (one for each experiment) with participant entered as a random effect. The result can be seen in Table 3.16. For mandala and RF shapes, matches made for round shapes were experienced as significantly more intuitive. For geometric and RF shapes, symmetrical shapes resulted in more intuitive matches than asymmetrical shapes. The only effects of complexity were seen for the simplest geometric shapes (circles and ovals), which resulted in more intuitive matches than the more complex nine-sided shapes, and the second most complex shapes (four-sided shapes), which resulted in less intuitive matches than the most complex nine-sided shapes.

*Table 3.16 Table showing the results for LMMs predicting intuitiveness of matches for Experiments 3A-3C based on perceptual shape predictors. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable.*

Parameters		Experiment 3A	Experiment 3B	Experiment 3C
Intercept		67.52 (2.24)***	60.19 (2.87)***	58.38 (2.67)***
Angularity	=0	-.04 (.81)	3.37 (1.08)**	3.94 (1.25)**
Symmetry	=0	-4.99 (.74)***	.74 (1.08)	-2.58 (1.25)*
Complexity	=1	5.35 (1.61)**	2.33 (1.53)	2.91 (1.53)
	=2	1.76 (1.28)	.17 (1.53)	.67 (1.53)
	=3	-2.61 (.81)**	.80 (1.53)	

Leaning on the elicited heightened pleasure individuals experience from stimuli experienced with perceptual ease and fluency (Reber, Schwarz, & Winkielman, 2004), it was predicted that shape liking and the interaction between shape liking and chosen colour liking could affect experienced intuitiveness of matches. Intuitiveness is suggested as a proxy meta-cognitive measure of perceptual and conceptual fluency that is elicited by the shape characteristics initially, and the coherence of the colour-shape match made in the second instance. Indeed, across all three experiments (see Table 3.17) it was found that shape liking positively predicts intuitiveness, resulting in higher intuitiveness ratings for a match made for a shape that is liked more. Chosen colour liking has a positive effect on intuitiveness only for Experiment 3B. For Experiment

3A and 3B the interaction effect between shape liking and chosen colour liking is significant. It was found that with increased shape liking, the positive effect of chosen colour liking on intuitiveness is maximised, increasingly so for chosen colours that are liked more.

*Table 3.17 Table showing the results for LMMs predicting intuitiveness of matches for Experiments 3A-3C based on shape liking, chosen colour liking, and their interaction. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level.*

Parameters	Experiment 3A	Experiment 3B	Experiment 3C
Intercept	64.26 (2.10)***	62.65 (2.51)***	60.24 (2.28)***
Shape liking	3.80 (.41)***	1.78 (.66)**	3.66 (.69)***
Chosen colour liking	.50 (.42)	1.73 (.69)*	.26 (.70)
Shape liking*Chosen colour liking	1.19 (.37)**	1.37 (.58)*	.29 (.61)

3.3.4.2 The effect of individual differences on intuitiveness ratings in Experiments 3A, 3B, and 3C.

Next it is considered whether the individual difference measures of openness, visual mental imagery (VVIQ), alexithymia, and autism (AQ) predicted differences in the intuitiveness of matches (the same LMM set-up was used as has been throughout). The results are shown in Table 3.18. For geometric shapes (Experiment 3A),

individuals with higher levels of openness and autism rated their matches as more intuitive. For RF shapes (Experiment 3C), those higher in autism also rated their matches as significantly more intuitive. No other effects were found to be significant for the three experiments.

*Table 3.18 Table showing the results of LMMs predicting intuitiveness based on individual difference measures for Experiments 3A-3C. Alexithymia was coded according to the cut-off points set out by Bagby, Parker, & Taylor (1994; 1= no alexithymia, 2 = in-between score , 3 = alexithymic). VVIQ scores should be remembered indicate more vivid mental imagery the lower they are. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

Parameters		Experiment 3A	Experiment 3B	Experiment 3C
Intercept		65.11 (4.16)***	71.63 (4.73)***	60.71 (5.19)***
Openness	R	6.01 (2.22)**	5.10 (2.68)	2.51 (2.42)
Age	R	1.73 (2.01)	-1.63 (2.41)	.57 (2.48)
VVIQ	R	2.15 (2.22)	-.00 (2.56)	-.85 (2.51)
AQ	R	5.50 (2.34)*	-4.45 (2.97)	5.73 (2.72)*
Alexithymia	=1	6.10 (5.31)	-11.74 (6.32)	.77 (6.41)
	=2	-4.13 (5.32)	-.62 (7.39)	2.93 (6.62)
Gender	=0	-3.47 (4.23)	-7.70 (5.13)	-4.57 (5.02)

3.3.4.3 Effect of shape characteristics on processing fluency in Experiment 3D.

Finally, the speed at which individuals completed the task and reacted to the stimuli to make their matches was examined. In particular, the effect of angularity, symmetry, and rated complexity on individuals' first click, last click, and page submit times (in seconds) were tested. Outliers that were $z = 3$ above the mean of the standardised versions of the three variables were excluded from the analysis for each model separately (Osborne & Overbay, 2004). The results of the LMMs can be seen in Table 3.19. Consistent results were found across the three measures, although the beta-values are very small: angularity resulted in no significant effects, symmetrical shapes resulted in faster processing of the task, and complex shapes resulted in faster processing of the task.

*Table 3.19 Table showing the results of LMMs of perceptual shape characteristics predicting processing fluency measured as first click, last click and page submit times (in seconds) for Experiment 3D. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

Parameters		First Click	Last Click	Page Submit
Intercept		3.45 (.08)***	4.45 (.09)***	5.76 (.10)***
Angularity	=0	-.00 (.03)	.02 (.03)	.03 (.04)
Symmetry	=0	.10 (.03)**	.12 (.03)**	.12 (.04)**
Complexity	R	-.03 (.02)*	-.05 (.02)**	-.06 (.02)**

Since no individual affective ratings were taken in Experiment 3D, the average shape liking and arousal ratings were extracted from Experiments 3A-3C. Average shape liking, arousal, and their interaction term were entered into the model to predict response times. Neither shape liking nor shape arousal had direct effects on time spent on each shape-colour match (indeed, this remained true when the models were tested without the interaction term). However, the interaction term between average shape liking and arousal was highly significant, whereby when both average shape liking and shape arousal were high, time spent on all measures of task duration was significantly reduced. When shape liking was low, however, it was the highest arousal shapes which resulted in longer time spent on the task.

*Table 3.20 Table showing the results of LMMs of affective shape characteristics and their interaction predicting processing fluency measured as first click, last click and page submit times (in seconds) for Experiment 3D. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level..*

Parameters	First Click	Last Click	Page Submit
Intercept	3.54 (.07)***	4.57 (.09)***	5.87 (.10)***
Average shape liking	-.00 (.02)	.01 (.02)	.02 (.02)
Average shape arousal	-.00 (.02)	-.01 (.02)	-.01 (.02)
Average shape liking*Average shape arousal	-.04 (.01)**	-.08 (.02)***	-.08 (.01)***

3.3.5 Effect of shape characteristics on affective shape evaluations in Experiments 3A-3C.

As reviewed above, the preference of curvature over angularity has been a much-researched field of study. LMMs with the fixed effects perceptual shape characteristics as categorical and continuously rated measures were tested for each experiment with shape liking and shape arousal as the dependent variables. Participant was entered as a random effect. The results for shape liking can be seen in Table 3.21. There was a relatively consistent trend that round shapes were indeed preferred over angular shapes, although, the categorical and continuous models for each experiment were not always both significant. For symmetry, however, all models were consistent: symmetrical shapes were liked more than asymmetrical shapes, and this effect was particularly pronounced, as seen by the beta-value, for geometric shapes in Experiment 3A. For complexity there was a slightly more complex and stimuli set dependent effect. For both geometric and RF shapes, simpler shapes were liked more than the most complex shapes. For geometric shapes this effect was more pronounced the simpler shapes became.

For mandala shapes, however, the simplest shapes were disliked more, and there was a continuous trend that more complex shapes were liked more. Specifically, for the categorical model, the simplest mandalas, lacking the fractal complex snowflake appearance of the more complex versions, appear to have been disliked significantly compared to the other complexity levels.

*Table 3.21 Table showing the effect of perceptual shape characteristics (both as categorical variables – Categorical Model – and continuous variables – Continuous Model –) on shape liking for Experiments 3A-3C. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

		Experiment 3A		Experiment 3B		Experiment 3C	
Parameters		**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**
Intercept		58.07 (1.71)***	53.18 (1.57)***	62.07 (2.29)***	59.49 (1.78)***	46.79 (1.70)***	54.51 (1.15)***
Angularity	= 0 / R	2.07 (.86)*	-.18 (.41)	2.20 (1.29)	-1.47 (.65)*	13.45 (1.25)***	-7.32 (.74)***
Symmetry	= 0 / R	-20.98 (.78)***	9.70 (.42)***	-2.83 (1.29)*	1.66 (.65)*	-4.80 (1.25)***	2.60 (.64)***
Complexity	=1 / R	14.43 (1.71)***	-4.73 (.44)***	-8.68 (1.82)***	3.50 (.66)***	5.15 (1.54)**	1.19 (.74)
	=2 / R	12.18 (1.36)***		-2.31 (1.82)		5.05 (1.54)**	
	=3 / R	6.19 (.86)***		1.93 (1.82)			

Indeed, it is likely that in light of the findings of symmetry and liking being associated, that the reduced number of rotational symmetry axes of the lowest complexity mandalas caused this particular finding. It should be noted though that adding an interaction effect of continuously rated symmetry and complexity to predict the shape liking of Experiment 3B's mandalas, is non-significant (p = .84). Additionally, the significance of the continuous complexity predictor, and the fact that liking for complex shapes also increased after the jump from level 1 to level 2 complexity, indicates that

this particular set of stimuli, as has been suggested by previous findings (Adkins & Norman, 2016), simply exhibits a different association between complexity and liking than the other types of shapes tested. No significant association between the interaction between symmetry and complexity was found for the RF shapes of Experiment 3C.

However, the geometric polygon shapes of Experiment 3A did show that there was a significant interaction effect between continuously rated complexity and symmetry on shape liking (b = -1.17, SE = .37, p = .002, 95% CI (-1.91, -.44)). The results were examined using the categorical variables to allow for pairwise comparisons. When comparing within asymmetrical and symmetrical shapes, low and medium complex shapes were more liked than shapes high in complexity. Crucially though, when comparing within complexity levels, symmetrical shapes were liked significantly more than asymmetrical shapes for low (mean difference = -5.03, SE = 2.17, p = .021, 95% CI (-9.30, -.77)) and medium complex shapes (mean difference = -5.89, SE = 2.18, p = .007, 95% CI (-10.15, -1.63)). This difference was in the same direction but not significant for high complexity shapes (mean difference = -3.49, SE = 2.17, p =.11, 95% CI (-7.75, .78)). This indicates that high complexity causes the difference between asymmetrical and symmetrical shapes to converge in terms of shape liking. Counter to what may be expected by research highlighting that symmetry increases liking of complexity (Bies *et al.*, 2016; Day, 1968; Eisenman & Gellens, 1968), it should be noted that this interaction effect does not occur because high complexity symmetrical shapes

are rated higher in liking in comparison to medium complexity symmetrical shapes. Rather the decrease in shape liking from medium to high complexity levels within asymmetrical shapes is smaller than for symmetrical shapes.

*Table 3.22 Table showing the effect of perceptual shape characteristics (both as categorical variables – categorical models – and continuous variables – continuous models) on shape arousal for Experiments 3A-3C. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

		Experiment 3A		Experiment 3B		Experiment 3C	
Parameters		**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**
Intercept		55.83 (2.10)***	50.76 (1.99)***	62.42 (2.36)***	56.30 (1.81)***	48.93 (2.49)***	43.85 (2.14)***
Angularity	= 0 / R	-2.17 (.87)*	1.65 (.41)***	.70 (1.34)	-1.95 (.68)	-.80 (1.28)	.39 (.75)
Symmetry	= 0 / R	-10.49 (.79)***	5.73 (.43)***	-1.16 (1.34)	.84 (.68)	-3.55 (1.28)**	1.91 (.65)**
Complexity	=1 / R	1.74 (1.72)	-.37 (.44)	-15.28 (1.90)***	5.73 (.69)***	-5.80 (1.57)***	2.28 (.75)**
	=2 / R	5.01 (1.37)***		-6.15 (1.90)**		-2.91 (1.57)	
	=3 / R	.87 (.87)		-2.15 (1.90)			

The results for shape arousal can be found in Table 3.22 above. For angularity, there were only significant effects found for the geometric shapes of Experiment 3A, whereby round shapes were rated as less arousing and the more angular a shape was, the more

arousing it was rated. In regard to symmetry, asymmetrical geometric and RF shapes were rated as less arousing than their symmetrical counterparts. No effects of symmetry on shape arousal were found for mandala shapes. For complexity, both mandala and RF shapes which were more complex shapes were rated as more arousing. This effect was not replicated for geometric shapes, where it was the triangular shapes which were rated as more arousing than the most complex shapes.

3.3.5.1 Effect of individual differences on shape preferences.

Since affective appraisals of shapes and colours appear to play an important role in what colours are matched to what shapes, it becomes pertinent to examine what individual differences may exist in how individuals react to certain shape characteristics in terms of their preference evaluations. Following the methodology of Cotter *et al.* (2017), an LMM was conducted for each individual difference measure for each Experiment (3A, 3B, 3C) with shape characteristics as the level 1 predictors (angularity and symmetry as categorical predictors, complexity as a continuous rated predictor that was standardised), and the individual difference measure of openness, extraversion, visual mental imagery (VVIQ), alexithymia, or autism (AQ) for each participant entered as standardised continuous level 2 predictor. The interaction effects between these two levels were also entered as fixed effects. The dependent variable of interest was shape liking and the random effect of participant was entered as an intercept. In this way it is possible to test whether certain individual differences

changed how specific shape characteristics affected shape liking, which could in turn play a crucial role in explaining why colour-shape correspondences are so variant between individuals.

For the geometric shapes in Experiment 3A, the interaction term between categorical angularity and openness was significant ($F(1, 3648) = 4.00$, $p = .045$). With increased openness shape liking for round shapes decreased in comparison to angular shapes (b = -1.69, SE = .85, $p = .045$, 95% CI (-3.35, -.03)), in particular from around half a standard deviation above the mean onwards of standardised openness scores. In other words, openness had a positive moderating influence on angular shape liking, instead of curved shape liking. Openness was also found to have a positive moderating effect on complexity ($F(1, 3648) = 4.45$, $p = .035$), such that with increasing openness, increasing complexity had a more positive effect on shape liking ($b = .91$, SE = .43, p =.035, 95% CI (.06, 1.75)). This appeared to be particularly driven by an increased liking for three sided and four-sided shapes, and reduced liking for circles and ovals, from around one standard deviation above the mean onwards.

The interaction term between categorical angularity and VVIQ scores ($F(1, 3648)$ = = 5.57, $p = .018$) and symmetry category and VVIQ scores ($F(1, 3648) = 25.99$, $p <$ .001) were found to be significant. With increasing VVIQ scores, and thus decreasing visual mental imagery, round shapes (vs. angular shapes) were more liked ($b = 1.99$, SE = .84, $p = .018$, 95% CI (.34, 3.64)). Visual inspection of this trend highlighted

that this effect really begins at a VVIQ score one standard deviation above the mean: with increasing VVIQ scores, and thus decreasing visual mental imagery, asymmetrical shapes were rated as more liked (b = 4.16, SE = .82, $p < .001$, 95% CI (2.56, 5.76)). However, this positive moderating effect appears to not exist above one standard deviation away from the mean of VVIQ scores. In other words, decreasing VVIQ scores, and increasing visual mental imagery skills, contributed to increased liking of angular and symmetrical shapes for VVIQ scores between the mean to one standard deviation above it.

The interaction term between angularity and extraversion scores was found to be significant (F(1, 3648) = 10.27, p = .001), with liking for round (vs. angular shapes), being negatively moderated by increasing extraversion (b = -2.70, .84, p = .001, 95% CI (-4.36, -1.05)). For complexity, the reverse trend was seen (F(1, 3648) = 10.04, p = .002), whereby, increasing extraversion had a positive moderating effect on the effect of complexity on shape liking (b = 1.36, SE = .43, p = .002, 95% CI (.52, 2.20)).

The alexithymia interaction term with complexity was found to be significant (F(1, 3648) = 12.14, $p < .001$), as was the AQ interaction term with complexity (F(1, 3648) = 10.25, p = .001). For both increasing alexithymia (b = -1.50, SE = .43, $p < .001$, 95% CI (-2.34, -.65)) and autistic traits (b = -1.38, SE= .43, p = .001, 95% CI (-2.22, -.53)), the effect of complexity on shape liking was negatively moderated. This appeared to be particularly true for both effects at around 1.5-2 standard deviations

above the mean and beyond in alexithymia and autistic traits. The interaction term between symmetry and alexithymia was also found to be significant ((F(1,3648) = 4.67, p = .031). Alexithymia positively moderated the effect of asymmetrical (vs. symmetrical) shapes on shape liking (b = 1.77, SE = .82, p = .031, 95% C (.16, 3.37)): especially with increasing alexithymia scores from one standard deviation below the mean to one standard deviation above the mean, liking of asymmetrical shapes began increasing and approaching the liking scores of symmetrical shapes. From one standard deviation above the mean onwards, however an increasing trend of asymmetrical shapes being liked less and less is seen, with symmetrical shape liking remaining more constant.

In Experiment 3B, the effect of complexity in particular on shape liking appeared to be affected by individual differences. The interaction term between complexity and openness was significant (F(1, 1020) = 16.41, $p < .001$), whereby mandala shapes with below average complexity being particularly disliked by those lower on openness in comparison to those higher on openness (b = -2.61, SE = .64, $p < .001$, 95% CI (-3.87, -1.34)). Complexity and VVIQ scores also interacted significantly (F(1, 1020) = 16.13, $p < .001$), whereby with increasing VVIQ scores, the effect of higher complexity was negatively moderated (b = -2.56, SE = .64, $p < .001$, 95% CI (-3.85, -1.32)). Additionally, it appeared that for mandala shapes below mean complexity, especially those with medium high VVIQ scores, exhibited particular low shape liking. Complexity and AQ scores (F(1, 1020) = 11.79, p = .001) as well as alexithymia scores

($F(1, 1020) = 8.00$, $p = .005$) interacted significantly for mandala shapes. For alexithymia, it appears that higher complexity shapes' liking decreases, or becomes closer to that of lower complexity shapes, with increasing alexithymia (b = -1.83, SE = .65, $p = .005$, 95% CI (-3.09, -.56)). With increasing AQ scores, it appears that the distance between high complexity and low complexity shapes diverges more, with low complexity shapes being liked less and high complexity shapes being liked more (b = 2.21, .64, $p = .001$, 95% CI (.95, 3.48)). It should be noted that both exhibit a strong trend for shapes between -1.5 standard deviations below the mean in complexity up to mean complexity shapes: the higher in alexithymia and autistic traits, the more liked these lower complexity shapes are. Those lowest and highest in alexithymia diverge drastically here. This distance decreases as complexity tends towards the mean, for all levels of AQ and alexithymia except the highest quartile. No significant effects were found for extraversion.

For the RF shapes of Experiment 3C, the interaction term between angularity and AQ scores was significant ($F(1, 825) = 4.21$, $p = .041$). Scoring higher on the autism spectrum scale resulted in a moderating effect on shape liking such that liking for round shapes increased in comparison to angular shapes (b = 2.59, SE = 1.26, p = .041, 95% CI (.11, 5.06)). This effect was particularly strong as AQ scores increased upwards of one standard deviation above the mean

Individual differences clearly seem to be able to affect shape liking by moderating the relationship different shape characteristics have with shape liking. They do not necessarily do this in a unitary way across stimuli, again highlighting the differential effects shapes can have, and the fact that how we perceive and react to shapes likely goes beyond the perceptual parameterisations of angularity, symmetry, and complexity. The notion of arousal is one that is picked up not only by the aesthetic sciences as an important factor in preferences and aesthetic appraisals (Berlyne, 1960, 1971; Palmer, Schloss, & Sammartino, 2013) but also may be differentially related to, enjoyed, or disliked by individuals with different cognitive and psychological traits (e.g., Mehrabian, 1995, 1996a). Therefore, it is pertinent to consider how individual difference measures may be affecting shape liking by moderating or interacting with the generally positive effect of shape arousal on shape liking. Or, in other words, is shape liking being affected differentially because how individuals with such traits may react to shape arousal?

LMMs were run for the three experiments, which tested the effect of shape arousal on shape liking, with openness, extraversion, visual mental imagery, alexithymia, and autistic traits, and their interaction term with shape arousal being entered into each model (i.e. five models for each of the Experiments 3A, 3B, 3C).

It was found for Experiment 3A that whilst openness did not have a direct effect on shape liking, shape arousal did ($b = 11.93$, SE $= .47$, $p < .001$, 95% CI (11.00, 12.86)).

Crucially, the interaction term between shape arousal and openness was positive in direction and significant (b = 1.21, SE = .48, p = .013, 95% CI (.26, 3.15)), indicating that with increasing in openness, the positive effect of higher shape arousal (vs. lower shape arousal) on shape liking increased.

Similarly, for Experiment 3A, the VVIQ had no significant main effect on shape liking, whilst shape arousal did (b = 11.61, SE = .48, p < .001, 95% CI (10.66, 12.56)). Here it was found, as one might expect based on the findings above, the reverse: the interaction term between shape arousal and the VVIQ was significant and negative (b = -2.03, SE = .50, p < .001, 95% CI (-3.00, -1.05)). It appears that this interaction effect is driven by the fact that as shape arousal increases, lower VVIQ scores (better visual mental imagery) result in higher shape liking than higher VVIQ scores for some levels of shape arousal. Additionally, a convergence of the difference between higher and lower arousal levels was seen in terms of their associated mean shape liking levels with increasing VVIQ scores. As well as a convergence of the difference between higher and lower VVIQ scores in terms of their associated mean shape liking levels with increasing shape arousal.

When testing the alexithymia models, there too was a significant effect of shape arousal on shape liking (b = 12.20, SE = .47, p < .001, 95% CI (11.28, 13.11)) but no significant direct effect of alexithymia on shape liking. The interaction effect between alexithymia and shape arousal on shape liking is significant (b = -3.90, SE = .45, p < .001, 95% CI

(-4.77, -3.03)). Visual inspection of the data shows that this effect is driven by the lowest alexithymia scores (vs. higher ones) resulting in a negative moderating effect of shape arousal on shape liking in some cases. No significant interaction effects were found for extraversion and autistic traits in Experiment 3A.

In Experiment 3B it was found that when testing the for the effect of visual mental imagery, shape arousal (b = 11.18, SE = .69, $p < .001$, 95% CI (9.83, 12.52)), VVIQ scores alone (b = 3.16, SE = 1.44, p = .032, 95% CI (.28, 6.03)), and the interaction effect between the two had significant effects on shape liking (b = -3.54, SE = .76, $p < .001$, 95% CI (-5.03, -2.04)). This particular interaction effect is particularly difficult to disentangle based on visual inspection of graphs, but it appears that with increasing shape arousal, the effect of the VVIQ on shape liking reverses, such that low VVIQ scores becomes less associated with lower shape liking, and more associated with higher shape liking. This is in line with the findings of Experiment 3A: it appears that having more vivid visual mental imagery means that the positive effect of shape arousal on shape liking is increased. No significant interaction effects were found for openness, extraversion, alexithymia, and autistic traits in Experiment 3B. Alexithymia did have a significant direct effect on shape liking, however, with increasing alexithymia resulting in increased shape liking (b = 3.74, SE = 1.29, p = .005, 95% CI (1.16, 6.33)), and the same effect was found for extraversion though it was only marginally significant (b = 2.71, SE = 1.36, p = .050, 95% CI (-.00, 5.42)).

In Experiment 3C a significant interaction effect was found only for autistic traits: shape arousal had a positive and significant influence on shape liking (b = 6.59, SE = .81, $p < .001$, 95% CI (5.01, 8.18)), AQ scores had no direct effect on shape liking, but the interaction term was significant and negative (b = -2.11, SE = .81, p = .009, 95% CI (-3.69, -.52)). As individuals scored higher on autistic traits, the positive effect of shape arousal on shape liking decreased in comparison to lower arousal shapes. Visual inspection of the data verified this, showing that the distance between the least and highest arousing shapes is quite high at the lowest AQ scores, but converges (with liking for low arousal shapes increasing, and high arousal shapes decreasing), with increasing autistic traits.

In sum, whilst the results were not consistent across stimuli sets, overall, shape arousal is found to have a large positive effect on shape liking, but this effect is moderated by certain individual differences. Individuals who were more open and had more vivid mental imagery, were likely to have a greater positive effect of shape arousal on shape liking. Individuals with higher levels of alexithymic and autistic traits, were more likely to have a negative moderating effect on the positive effect of shape arousal on shape liking. In Experiment 3B, it was found that alexithymia had a direct positive effect on shape liking, indicating that it may be a specific negative reaction to shape arousal that individuals with higher alexithymic and autistic traits are experiencing for some shapes.

3.3.6 Colour preferences.

The average preferences for colours across Experiments 3A, 3B, and 3C are shown in Table 3.23 below. As predicted by Palmer and Schloss's (2010) EVT of colour preference, blues and cyans were rated the most pleasant, whilst brown hues were found to be the least pleasant. Overall, cooler hues were liked more, and warmer hues were liked less. Incidentally, the data when compared to the rank of frequency of choices of each colour across the three experiments (final column of Table 3.23) also highlights that individuals do not simply consistently pick colours they like the most for shapes, but rather match their preference level of the colour to that of the shapes presented, as shown by the emotional mediation results above (see Table 3.15). However, it does appear that the least liked and least chosen colours do coincide more strongly. A Wilcoxon Signed Ranks Test shows that there are 18 ranks where frequency of colour choice is ranked lower, 15 ranks where colour liking is ranked lower, and 3 ties. Its non-significance points to the fact that the two lists of ranks are not associated (z = -.11, p = .915). Additionally, as in Experiment 3D, the most common colour choices across Experiment 3A, 3B, and 3C are (though in slightly different rank order): saturated yellow, saturated red, white, black, and saturated blue.

Table 3.23 Table showing both the mean and standard deviation of liking scores as well as the rank of how many times the colour was chosen across all matches ('Choice Rank') in Experiments 3A-3C. Colours are ordered in descending order of average liking.

Colour	Colour name	Mean liking	Standard deviation	Choice rank
19	Light Blue	66.57	21.58	16
27	Dark Pink	65.11	22.62	17
20	Saturated Blue	64.73	22.73	5
26	Saturated Pink	62.00	25.34	11
24	Dark Purple	61.24	24.30	27
14	Aquamarine	61.14	25.43	24
22	Light Purple	60.71	25.05	13
23	Saturated Purple	60.54	24.63	22
18	Dark Sky	60.48	25.10	29
1	Light Red	60.42	24.57	23
13	Light Aquamarine	60.38	24.43	34
25	Light Pink	59.26	25.79	12
17	Saturated Sky	59.19	27.71	25
16	Light Sky	58.94	26.68	18
31	White	58.92	26.71	3
3	Dark Red	58.64	25.86	15
5	Saturated Orange	58.05	25.56	8
12	Dark Green	57.43	25.56	6
2	Saturated Red	56.74	27.27	2
8	Saturated Yellow	55.49	26.60	1
11	Saturated Green	54.23	26.50	9

15	Dark Aquamarine	53.96	27.73	20
33	Grey	53.93	29.28	21
32	Light Grey	53.79	26.95	7
21	Dark Blue	52.88	28.01	14
36	Black	52.62	31.99	4
35	Darkest Grey	52.04	29.97	32
34	Dark Grey	50.68	28.83	28
7	Light Yellow	49.00	28.38	10
10	Light Green	46.96	26.14	26
4	Light Orange	46.46	27.61	19
6	Dark Orange	44.80	29.61	36
28	Light Brown	43.24	28.56	30
9	Dark Yellow	41.93	28.02	31
30	Dark Brown	41.41	28.36	35
29	Saturated Brown	40.81	28.86	33

3.4 Discussion

On the question of whether, at the choice-by-choice level, shape characteristics predictors are able to account for large amounts of variance in shape-colour matches, consistently within and across stimuli sets, the results of this chapter recommend scepticism. Indeed, it is bordering on surprising how consistently inconsistent shape predictors perform within stimuli sets across experiments, across stimuli sets within the same experiment, and across stimuli sets across different experiments. Additionally,

beta coefficients and percentages of variance explained by perceptual shape predictor variables highlight the limited effect size shape characteristic predictors have when averaging across stimuli categories is avoided. What the use of LMMs has shown additionally is that it drastically improves model fit and the percentage of variance explained in chosen colour characteristics to account for clustering of participants as a random effect.

In Dreksler and Spence (2019)[19], the fact was highlighted that the lack of consistent results between Experiments 3A-3C may derive from cultural differences, the pitfalls of the online methodology resulting in variation in colour lightness and hue through differences in monitors between participants, as well as the fact that colour-shape correspondences may be a highly stimuli-dependent phenomenon. By running Experiment 3D, the case for the fact that colour-shape correspondences depend on the type of stimuli that are presented to individuals was strengthened. Additionally, it was shown that nationality accounts for negligible amounts of variance in colour-shape

[19] It should be noted that, as previously mentioned, the publication Dreksler & Spence (2019) analyses the same data as Experiments 3A, 3B, and 3C. However, as highlighted previously, different kinds of analyses are used in the publication (between-participant ANOVAs and MANOVAs, as well as correlation analyses and multiple stepwise linear regressions, instead of LMMs). The reasons for this change will not be reiterated as it has been discussed in detail. The similarities in the results lie in the fact that they highlight the lack of consistent results across stimuli sets and the evidence for emotional mediation of colour-shape correspondences. Whilst direct comparisons cannot always be made between the specific results due to the different methodologies used in Dreksler & Spence (2019) and the current thesis, the different choices in analysis methods do often lead to contradictory results where such comparisons are possible. Indeed, this is not surprising since the paper also highlighted exactly this finding: that different analysis methods often result in different colour-shape associations being found. Nevertheless, some common results exist: roundness is associated with redness both in Dreksler & Spence's (2019) Experiment 1 and 3 in certain analyses, as well as Experiment 3A and 3C, for example.

correspondences, especially when compared to the variance that exists from person-to-person, and even within individuals. As such, whatever new sample one may take from the population, it is likely that significant shape-colour association trends are found. However, it is exceedingly difficult to find consistent ones across experiments and kinds of shape stimuli, even when experiments are sufficiently powered and take care to systematically vary shapes to explore specific perceptual shape characteristic conditions. The issue of inadvertent differences in colour presentation in Experiments 3A, 3B, and 3C were mitigated as far as was possible using an online methodology in Experiment 3D, and yet it was found that perceptual shape predictors accounted for limited amounts of variance when the analysis move beyond the averaged item categories other methodologies rely on.

Whilst nationality and gender do show significant interaction with shape predictors, they do not necessarily improve model fit meaningfully, or at all. Additionally, models that take into account individual differences in affective appraisals of shape and colour, would likely be able to capture such differences at the more fine-grained and nuanced person-level. If one considers how gender or nationality differences would be explained, it is likely that explanations would quickly fall back on what the semantic and emotional associations are that may create such differences between nations or genders. This seems particularly pertinent in the light of previous research that shows that there are individual differences in how shapes and colours are appraised even if overall trends can be found (e.g., Corradi *et al.*, 2019; Güçlütürk *et al.*, 2016; Street *et al.*,

2016). This is further supported by the results of Experiments 3A, 3B, and 3C, that showed that individual differences moderate the effect of shape characteristics on shape liking, as well as the effect of shape arousal on shape liking.

What is clear is that the affective appraisals of shape and colour play an important role in determining colour-shape correspondences. Emotional mediation results were far more consistent in highlighting that participants varied their choice of colours in terms of how their valence and arousal level aligned with the presented shape's valence or arousal level. Indeed, larger fractions of variance of individual choices were accounted for using these emotional mediation models for Experiments 3A, 3B, and 3C.

If emotional appraisals of stimuli are crucial to colour-shape correspondences, the effect of shape characteristics on affective appraisals becomes more important to understand and determine. As predicted, symmetrical shapes were liked more than asymmetrical shapes. The effect of curvature, whilst slightly less consistent across all models, showed under at least one conception of shape characteristics (categorical vs. continuous) for Experiments 3A, 3B, and 3C, that round shapes were preferred to angular shapes. Results for complexity were, fittingly, and as one might expect based on the reviewed literature (e.g., Nadal *et al.*, 2010), more complex. As predicted, mandala shapes were preferred the more complex they became (Adkins & Norman, 2016). The reverse was seen for geometric and RF shapes: Liking reduced linearly with increasing complexity

for geometric shapes, meanwhile, the least and medium complex RF shapes were both preferred to a similar degree compared to the most complex RF shapes. For shape arousal no effect of shape characteristic was found to be consistent across all three stimuli sets. For geometric shapes, for example, symmetry resulted in stark increases in arousal ratings, whilst it did not at all for mandala shapes, and to far lesser degree for RF shapes. Complexity, which has been found to generally increase arousal (Berlyne, 1961, 1963; Berlyne *et al.*, 1963; Bryson & Driver, 1969; Day, 1967; Eisenman, 1966; Jang *et al.*, 2018; Marin & Leder, 2013; Van Paasschen, Zamboni, Bacci, & Melcher, 2014), only did so for mandala and RF shapes, and not the geometric shapes which most reflected the polygon stimuli that have been used in previous research. Interestingly, angularity was associated with increased arousal only for geometric shapes.

Individual differences in openness, vividness of visual mental imagery, extraversion, and autistic and alexithymic traits, had significant moderating effects on how shape characteristics – perceptual and affective – affected shape liking. Whilst the results are described below, caution is urged from the reader to be careful to consult the full results above, since interaction effects were rarely linear or consistent across different levels of traits or shape characteristics. It was predicted for openness that liking for curvature would increase, yet the reverse was found: liking for angularity instead increased and liking for curvature decreased. Since Cotter *et al.* (2017) found mixed results for the effect of openness on curvature between their stimuli sets, perhaps this

speaks to the fact that other underlying affective and perceptual features may be important in determining the effect of openness in this domain. The fact that contradicting results were found for in Experiments 3A and 3B for the moderating effect of complexity, where with increasing openness, low complexity shapes were disliked less and liked more, respectively, points to the same conclusion. When testing the effect of openness on how shape arousal affected shape liking, initial evidence was found that increasing openness increased the positive effect of shape arousal on shape liking. The fact that openness had a positive moderating effect on the effect of shape arousal on shape liking, is in line with its conception of capturing the motivation to seek out and need to engage with new and a variety of engaging experiences (McCrae & Costa, 1997).

Due to the increased ability of those high in visual mental imagery skills to hold images in their mind's eye, it was predicted that they would be more reactive to the perceptual characteristics and affective associations of shapes. Indeed, like with openness, there was some evidence that for some stimuli, those with more vivid visual mental imagery had a stronger positive effect of shape arousal on shape liking than those with less vivid mental imagery. For geometric shapes, those with lower mental imagery skills preferred curvature and asymmetry, and those with more vivid mental imagery skills shows an increased liking for symmetry and angularity. For mandala shapes, those with higher mental imagery skills, showed increased dislike of shapes below mean complexity.

Extraversion appeared to show few moderating effects on the perceptual and affective shape characteristics' effects on shape liking. Significant effects for perceptual shape characteristics were only found for Experiment 3A where extraversion resulted in liking round shapes less (and angular shapes more) and liking complexity more. However, counter to expectations (Mehrabian, 1995, 1996a), this was not driven by differential reactions to arousal: there was no increase in shape liking based on increased shape arousal for those higher in extraversion in any experiment.

It was predicted that higher autistic and alexithymic traits could make individuals less sensitive to arousal. Indeed, individuals with higher levels of alexithymic and autistic traits, were more likely to have a negative moderating influence on the positive effect of shape arousal on shape liking. In Experiments 3A and 3B, nuanced interactions of alexithymic and autistic traits with complexity were found that tended to highlight decreased liking of complexity for those with higher autistic and alexithymic traits. The prediction that autistic traits would be related to increased liking for symmetry was not found. Instead, higher alexithymic traits were associated with increased liking for asymmetry and higher autistic traits were associated with increased liking for curvature. In sum, it was shown that looking at individual differences in aesthetic preferences, especially by building on our understanding of personality constructs in terms of how they react to affective stimuli, is a fruitful area of research. In particular it highlights why perceptual shape characteristics may be so inconsistent in predicting colour characteristics – not only are shape characteristics differentially related to

valence and arousal depending on stimuli, but this may further be affected by individual differences in how those who are appraising the stimuli may react to them.

If affective responses to shape and colour affect colour-shape correspondences (which they seem to), and affective responses in terms of liking and arousal, for example, were universally consistent, then, one might expect perceptual shape predictors to have more consistent and replicable effects in terms of prediction colour characteristics than they were found to have in the experiments of this chapter. Since this is not the case, this strongly speaks in favour of Street *et al.*'s (2016) call to action in considering the tension between attempting to find universal affective and aesthetic responses, alongside the growing evidence that notable individual differences exist.

Indeed, modern appraisal theories offer a useful framework for understanding how emotions are elicited and are induced differentially in individuals (Scherer, 2001). In his criticism of Berlyne's 'new experimental aesthetics' movement, Silvia (2005), highlights that individual appraisals of events offer a better marker of emotions (Roseman & Evdokas, 2004), than relying on explanations that require a universal association between objective features of stimuli and specific emotions (e.g., arousal). He notes in comparison to appraisal theories:

> We see contrasts with Berlyne's emphasis on objective stimulus features, such as objective complexity and novelty, as causes of aesthetic responses. Appraisal theories would recast this by contending that an "objectively complex" object will affect aesthetic responses only inasmuch as a person subjectively appraises the

> object as "complex." The person's subjective appraisals mediate between emotions and the outer world. (Silvia, 2005, p. 346)

This raises the possibility that researchers should be asking individuals to rate:

1. Their perception of the perceptual dimensions of colour (as was the case in Experiment 3D);
2. Their individual affective appraisals of the stimuli (as was the case in Experiment 3A, 3B, and 3C);
3. How complex, angular, or symmetrical (or other shape characteristic of interest) they feel each shape is, rather than rely on average ratings from separate samples.

Indeed, this is in line with the sentiment Albertazzi (2018) expresses about developing an authentic experimental phenomenology that does not simply assume "the perceiver is supposed to represent a set of objective properties of the external physical environment" (p. 1). Indeed, the inconsistencies in shape characteristic-colour dimension associations across stimuli, experiments, and participants, as well as the important role of individual affective appraisals and individual differences the experiments of Chapter 3 have highlighted, point to the fact that there is value in capturing the subjective phenomenological experience of individuals. Ultimately, such an approach would further and deepen our understanding of perceptual, aesthetic, and artistic phenomena and experiences, such as colour-shape correspondences. For future researchers this offers a unique possibility into understanding how colour-shape

correspondences arise and manifest at the individual level. However, ample study durations will have to be planned in, most likely with breaks, in the light of the fact that sufficient stimuli have to be used per condition, to make sure the experiment is adequately powered to detect effects (Brysbaert & Stevens, 2018).

Now the question is considered that was inspired by the first preliminary laboratory experiments conducted for this thesis in the now asbestos-ridden and abandoned Experimental Psychology department building at the University of Oxford: How intuitive do individuals feel their matches are, and why? In terms of intuitiveness, matches made for round mandalas and RF shapes were experienced as more intuitive. Symmetrical geometric and RF shape matches were rated as more intuitive and felt more 'right' to individuals. Both of these findings are in line with roundness and symmetry being liked more, as well as symmetry and potentially roundness being processed more quickly and easily (Bertamini *et al.*, 2019; Makin, Pecchinenda, & Bertamini, 2012; Reber & Schwarz, 2006; Ruta *et al.*, 2014; Wagemans *et al.*, 1993). Complexity affected intuitiveness only for geometric shapes – the simplest shapes (circles and ovals) resulted in very intuitive colour matches compared to the other levels of complexity. Matches made for four-sided shapes (squares, trapezium, etc.) were experienced as the least intuitive. Since round and symmetrical shapes were preferred, it was consistent to find that matches made for shapes individuals liked more, increased rated intuitiveness of the match. The chosen colour's liking only had

a positive effect on intuitiveness for mandalas, whilst the interaction between shape liking and chosen colour liking increased intuitiveness for geometric and RF shapes.

Individual differences had few effects on experienced intuitiveness. Only in Experiment 3A for geometric shapes did openness increase intuitiveness ratings as had been predicted. In Experiment 3A and 3C, as predicted based on the associated cognitive, perceptual and emotional processing of autistic traits, those with higher levels of autistic traits experienced shape-colour matches as being more intuitive. Visual mental imagery, despite predictions that it may make matches more intuitive if individuals could hold the match in their minds eye better, showed no significant associations with intuitiveness.

The fact that the intuitiveness question may be latching onto something other than only perceptual fluency, or may be driven by other mechanisms, is highlighted by the fact that shape characteristics and shape liking affected time taken on the task very differently than intuitiveness. Angularity, unlike for intuitiveness, had no effect on processing fluency. Symmetry and increased complexity, however, both reduced the time taken on the task. In regard to symmetry this is in line with perceptual fluency accounts of why symmetry is preferred. However, for the type of shape stimuli presented there is no straightforward reason ground in fluency theory why more complex shapes would be processed more quickly. Indeed, because the relationships between complexity and liking and arousal ratings were so inconsistent, they do not

offer a possible explanation for this effect either. For naturalistic stimuli added information may increase the chance of identification and, thus, increased complexity may be argued to improve processing fluency of such tasks. However, it is unlikely that the same holds true for the shape stimuli used in these experiments, which do not need to be interpreted for identification or categorisation in a way where added complexity aids this process.

The relationship between shape affective appraisals and time taken on the task highlighted the importance of high-positive valence in combination with high arousal for processing of the matches. Whilst neither shape liking nor shape arousal had significant effects on the time taken to complete each match, the interaction between the two had significant effects on how quickly the task was completed. For shapes that were low in liking, high arousal shapes were processed more slowly, but for shapes high in liking and arousal, processing time decreased significantly.

So why are matches made for shapes which are more liked rated as more intuitive, but they are not processed more quickly unless high liking is combined with high arousal. To begin with, it may be that intuitiveness and time taken are latching on to separate constructs or overlapping but different aspects of the same construct of processing fluency (e.g., perceptual vs. conceptual fluency). Additionally, it is important to remember that for predicting processing fluency in terms of time taken on task in Experiment 3D, only average not individual ratings of shape liking and arousal were

available for analysis. As such, future researchers would need to determine to what extent intuitiveness ratings and time taken to complete a task correlate when individual appraisals are used, to truly make judgements how intuitiveness ratings are related to processing fluency.

Why do shapes that are liked more result in more intuitive ratings of the match? For one, shapes that are liked more may make the affective appraisal response more present and salient to the individual, making it potentially easier to choose a colour that matches the shape, which in turn therefore results in a match that feels more 'right'. Moreover, a transfer of emotion could be occurring from one part of the task to the next. Positive invoked feelings by the shape could bias responses on the intuition question to be more positive. This could occur through a process of emotional contagion and sensation transfer, such that the shape induces a positive sensation at the physiological, affective, and cognitive level that could affect later evaluations made on the intuitiveness of the task. Research has shown that music, for example, can induce congruent emotions in individuals, which can in turn affect later unrelated appraisal evaluations (Juslin, 2001; Kappes, Schmidt, & Lee, 2006; Logeswaran & Bhattacharya, 2009).

The fact that in Experiment 3A and 3B participants rated their matches as particularly right when increasing shape liking was combined with increasing chosen colour liking, highlights that when both had positive valence, were increasingly positive, and were

congruent, the effect on intuitiveness was maximised. It is difficult to determine whether this is through an increase in emotional contagion and response bias, or because additionally, on top of this, these matches are simply experienced as highly congruent because of their affective alignment. Indeed, there is some indication that emotional congruence, rather than the more often noted unpleasantness of incongruence (Cytowic, 1989; Ramachandran & Hubbard, 2001b), is also important in the emotional responses to colour associations in synaesthesia (Hochel *et al.*, 2009).

Evidence suggests that higher-order perceptual characteristics in terms of grapheme and colour similarity partly drive grapheme-colour and other synaesthesia associations (Asano & Yokosawa, 2013; Brang *et al.*, 2011; Hamada, Yamamote, & Saiki, 2017; Watson, M.R., *et al.*, 2012). But the role affective and semantic associations, and more abstract properties encoded by the brain, can play between the association of synaesthetic inducers and concurrents has also been highlighted, alongside the fact that synaesthesia is more than just a perceptual phenomenon (Chiou & Rich, 2014; Cytowic & Wood, 1982; Dixon, Smilek, Cudahy, & Merikle, 2000; Grossenbacher & Lovelace, 2001; Mroczko-Wąsowicz & Nikolić, 2014; Nikolić, 2009; Ward & Simner, 2003). Indeed, even changes in mood have been found to result in colour fluctuations in grapheme-colour synaesthesia (Kay, Carmichael, Ruffell, & Simner, 2015). As such, even in a related phenomenon to colour-shape correspondences where consistency in associations is a crucial diagnostic criterium (e.g., Baron-Cohen, Harrison, Goldstein,

& Wyke, 1993; Eagleman *et al.*, 2007), emotions, moods and affective appraisals can have an influence on what colours are induced.

In sum, then, the findings of Experiments 3A-3D offer a plethora of insights into colour-shape correspondences across a much broader variety of stimuli that have been tested to date. However, this has also highlighted the immense complexity of finding consistent shape characteristics that predict colour dimensions. The results have brought to the fore the inter-individual variance in choices that may be driven by individual differences in appraisals of shape and colour stimuli and the stimuli-dependent nature of colour-shape correspondences. Whilst the field may yet be small and not be able to boast strong, replicable findings, it would also be incorrect to not further pursue the investigation of colour-shape correspondences or to write them off as a non-existent phenomenon in the light of research conducted to date. Especially since intramodal correspondences remain an understudied field and colour and shape are commonly examined features in crossmodal correspondence research, colour-shape correspondences offer an excellent inlet into exploring the relationship between intramodal and crossmodal correspondences. In support of this cause, in Chapter 5, an attempt is made to create a fertile starting ground for a new science of colour-shape correspondences that begins to attempt to grapple with these inconsistencies and challenges.

4 The Aesthetics and Art of Colour and Shape

4.1 Introduction

The previous chapter underlined the immense complexity of colour-shape correspondences at the match-by-match level when a large number of both shape and colour stimuli are used that vary across a host of dimensions. This chapter will instead focus on angularity and curvature alone as shape characteristics. The relationship of angularity versus curvature with preference and beauty appraisals has been discussed at length in Chapter 3 Section 3.1.3.1.3. In Chapter 2, Experiment 2B found initial evidence that beauty appraisals may mediate colour-shape correspondences. So, this chapter will delve into the aesthetics of colour-shape correspondences, and how they are affected by, and in turn influence, judgments of beauty.

Before the aims of this chapter are described, however, it is important to highlight that the focus on beauty judgments in this chapter as simply a rating made on a scale from ugly to beautiful, by no means aims to boil down the complexities of forming a science of aesthetics, nor the appreciation of art, to a simple, one dimensional notion of beauty. Nor is the belief implied by such a decision that reactions to art's beauty have to be understood as a unitary experience of simplistic positive valence. Clearly, art can evoke a plethora of emotions and experiences in an observer (e.g., Brattico *et al.*, 2016; Schubert, 1996; Zentner, Grandjean, & Scherer, 2008). Studying aesthetics

as a science, as well as an art form, means standing on the shoulders of giants that have poured enormous effort into paying homage to, and capturing the complexities of, the phenomena that are art, aesthetics, and the human awe of beauty. It is regrettable that there is no space here to capture their thinking and achievements and that the reader can only be directed to pertinent sources (e.g., Behrens, 1998; Fechner, 1871, 1876; Graf & Landwehr, 2015; Hevner, 1935; Leder, Belke, Oeberst, & Augustin, 2004; Marković, 2012; Redies, 2015; Rozin, 1999; Zeki, 1999; see, for excellent and insightful reviews and overviews: Celkyte, n.d.; Chatterjee & Vartanian, 2014; Dickie, 1997; Jacobsen, 2006, 2010; Lindell & Mueller, 2011; Makin, 2017; Palmer, Schloss, & Sammartino, 2013; Pelowski, Markey, Forster, Gerger & Leder, 2017; Shimamura & Palmer, 2012, especially Chapters 1, 7, and 12; Zangwill, 2019).

The choice, therefore, to focus on a single rating of beauty is one of tractability within the context of this thesis and only the first stumbling steps for the field of colour-shape correspondences, amidst centuries, if not, millennia of theorising on the aesthetics and nature of colour and form. That being said, first, the mediation of colour-shape matches by aesthetic evaluations will be investigated, since support for several dimensions of affective and semantic appraisal playing an important mediating role has been found in the previous experiments reported in this thesis. Second, whether a correspondence congruent beauty effect exists will be tested: do individuals find the coloured-in versions of shapes that correspond to their own colour-shape matches to be more beautiful? Ward *et al.* (2008) found that non-synaesthetic found the audio-visual

perceptions of those with synaesthesia to be more aesthetic. Furthermore, both crossmodal and semantic congruence have been found to result in more positive affect and evaluation and even increased buying behaviour (e.g., Areni & Kim, 1993; Hagtvedt & Brasel, 2016; Krishna, Elder, & Caldara, 2010; Mattila & Wirtz, 2001; North, Hargreaves, & McKendrick, 1997; North, Sheridan, & Areni, 2016; Spangenberg, Grohmann, Sprott, 2005; Spangenberg, Sprott, Grohmannn, & Tracey, 2006; Spence, Shankar, & Blumenthal, 2010).

Research shows that congruent stimuli, in terms of semantic associations and crossmodal correspondences, result in faster and easier processing (Bernstein & Edelstein, 1971; Chen, Y.-C., & Spence, 2010; Evans & Treisman, 2010; Gallace & Spence, 2006; Liang, Roy, Chen, & Zhang, 2013; Mandler, 1982; Marks, 1987, 2004; Parise & Spence, 2009). This may, arguably, be the case because they reflect some underlying association found in our cognitive architecture. Fluency theory would thus predict that individuals would rate their colour-shape correspondence congruent coloured-in shapes as more beautiful, insofar as beauty is aligned with positive affect (Reber, 2012).

Third, how colour and shape aesthetic appraisals contribute to coloured-in shape beauty appraisals will be evaluated. Sommer, Sommer, and Cho (2004) found that colour and form contribute to how coloured-in shapes are evaluated on semantic differential scales in regard to Osgood's dimensions of activity, value, and strength.

Colour was found to have more influence on activity and value ratings than shape. However, evaluating dimensions of aesthetic evaluation alone, Sato and Oda (2014), found that shape appraisals had a stronger influence on coloured-in shape aesthetic judgements than colour evaluations. Zhang (2019) finds developmental evidence that the importance of form (versus colour) in terms of package design preferences increases with age in children, suggesting that adults too may be more swayed by shape. In practice, buying decisions, are strongly influenced by colour. Indeed, colour has been found to be a crucial factor in terms of attracting attention, conveying flavour information, and signalling a distinctive brand (see for a review, Spence, 2016). Nevertheless, with the focus on aesthetic evaluations, whilst there is mixed and limited previous research on this question, it is predicted that shape is likely to be more influential in determining aesthetic evaluations of coloured-in shapes.

Finally, for Experiment 4B, stimuli were designed based on Kandinsky's paintings that varied along the dimension of angularity (angular, curved, and a mixture of curved and angular features). The effect of shape on beauty appraisals will be tested to see if the preference for curvature effect can be replicated not only for shapes (Experiment 4A), with which much research has been conducted (see Chapter 3, Section 3.1.3.1.3 and references therein), but also, specifically, for stimuli which are more complex and activate a contextual mindset of art and aesthetic evaluation. As in Experiments 3A and 3B, the effect of individual differences on shape appraisals discussed previously – openness and interest in the arts – will be evaluated as well.

Indeed, it would not be surprising if the preference for curvature is less pronounced in more complex painting stimuli since the emotional range and semantic subtleties that may be expressed by a more complex piece of art, could have unexpected interplays with our fundamental preference for curvature. Additionally, whilst attempts were made to change little to nothing except the angularity of the lines and vertices, it is possible that other pertinent characteristics that can have aesthetic outcomes – for example, complexity, variety, balance – could have been inadvertently affected.

Furthermore, it is possible that viewers will prefer the versions that are a mixture of curved and angular features since, more often than not, they cohere most closely to the original Kandinsky version. Cavanagh (2005) argued that over years of trial and error as individuals and across history, artists can give useful insights into the neuroscience of perception. Similarly, then, artist's choices may reflect aesthetic primitives or preferences derived from years of personal experimentation and reflection on the work that came before them. Research has shown, for example, that the chromatic and orientation choices of artists are preferred by viewers over deviations from them (Latto, Brain, & Kelly, 2000; Nascimento *et al.*, 2017). Additionally, viewers appear to be sensitive to whether the balance and original structure of a painting has been perturbed (Locher, 2003), though this does not always simply align with increased preference for more balanced images, nor the originals (Nodine, Locher, & Krupinski, 1993). Furthermore, artists and amateurs may consciously exaggerate features, such as the curvature of lips and size of the eyes, or alter features, such as stronger chin

lines, which are judged to be more attractive (Costa & Corazza, 2006; McArthur & Berry, 1987; McKelvie, 1993).

That being said, a recent study by Braun & Doerschner (2019), found specifically for abstract paintings – by Willy Baumeister, Sonka Delaunay, Hans Hoffman, Wassily Kandinsky, and Paul Klee – using an interactive colour adjustment task for features of the abstract painting, that few individuals chose the exact cluster of colours as the original painting used for that feature. Although, when the criteria for similarity were relaxed, many observers did choose colours that were roughly congruent with the original hue category of the artist. Furthermore, there was little difference between whether individuals preferred their own or the artist's original colour choice, with some cultural variations on some paintings. Overall, though, individuals preferred their adjusted version of the painting.

Additionally, the question of bidirectionality of colour-shape correspondences will be addressed in this chapter. There are, to the author's knowledge, only two experiments that have probed colour-shape correspondences by first presenting a colour and asking individuals to associate them to shapes. Lindauer (1973) asked participants in a classroom setting to generate shapes based on a colour projected on a screen, after listening to brief lecture about imagery. Campbell (1942) asked participants to match repeating patterns of varying angularity to colour combinations (see Appendix 6.4, Table 6.2, for further information of the two experiments). That is to say, no

experiment has evaluated colour-shape correspondences using a task that presented individuals with one colour and asked them to choose a singular shape they feel best matches it. Blazhenkova and Kumar's (2018) methodology does come close to probing bidirectionality by asking participants to match both an angular and curved shape to either a red or green shape, at the same time. However, the colour stimuli were limited only to the colours of red and green, nor was bidirectionality probed explicitly.

Bidirectionality has been tested and confirmed for a number of crossmodal correspondences (e.g., Ben-Artzi & Marks, 1995; Evans & Treisman, 2010; Melara & O'Brien, 1987; Occelli, Spence, & Zampini, 2009; Patching & Quinlan, 2002; Spence *et al.*, 2015; though see Spence, 2019b). Bidirectionality is generally assumed to be a feature of crossmodal correspondences (e.g., Martino & Marks, 2001; and see Deroy & Spence, 2013, for a discussion and references therein of how this differs from the evidence-base, or lack thereof, for bidirectionality in synaesthesia). As such, one might expect that for colour-shape correspondences too, bidirectional associations can be found on two tasks using the same shape and colour stimuli.

Finally, it was of interest whether, when using statistical methodologies that retain information at the case-by-case level as in Chapter 3, but for reduced stimuli sets and categorical colour outcome variables, more consistent, and less variable results could be found. Additionally, the use of an alternative forced-choice method in Experiment 4A, should also result in potentially less variance on a match-by-match level, allowing

for an analysis of colour-shape correspondences with a far more restricted range of stimuli and choices, with hopefully more consistent results. Two novel methodologies are presented in this chapter that have not been used to date to probe colour-shape correspondences. One is a task that presents a colour and asks individuals to choose between two shapes. The other presents each painting stimulus in the available colours of choice, from which the participants then choose which colour best matches the features of the painting.

Experiment 4A will probe the association between curved and angular shapes and the colours red, blue, green, yellow, and pink using the previous methodology of Chapter 3 (which will be termed the shape-colour task). Additionally, the mentioned reversed task, where each colour is presented and individuals have to choose between two shapes which were chosen to differ maximally only on curvature/angularity was presented to participants (here on in referred to as the colour-shape two alternative-forced choice (2AFC) task). In Experiment 4B, Kandinsky-inspired painting stimuli will be used to probe colour-shape correspondences. For both Experiments 4A and 4B, the variety of questions posed above that relate to the influence of aesthetics on colour-shape associations, and the effect of correspondence congruent associations on aesthetic evaluations will be investigated.

4.2 Method

4.2.1 Experiment 4A.

4.2.1.1 Participants.

A sample of 150 participants was recruited online on Prolific (https://prolific.co) with the same requirements and exclusion criteria as Experiment 3D in Chapter 3 except that participants had to be from and have grown up in the UK. After individuals were excluded from analysis, a final sample of 108 participants took part in Experiment 4A (50 identified as female, 57 identified as male, whilst 1 declined to respond about their gender identity, mean age = 36.29 years, SD = 13.45 years).

4.2.1.2 Materials.

The shape stimuli used were extracted from the previous stimuli sets used in Experiments 3A-3D, whilst four further ones were added. From each stimuli set of the previous chapter (geometric, mandala, RF pattern), the curvature/angularity ratings were examined. Shapes that were found on the polar ends (rated very round or very pointy) were identified. Other properties of the shapes (e.g., symmetry, number of sides, complexity, number of concavities) were examined to choose a pair of shapes that differed as far as possible *only* in terms of angularity and as much as possible in terms of angularity. Two further pairs of 'bubble' shapes designed on Adobe Illustrator were included which were designed to specifically vary only in terms of angularity. Additionally, the square from the geometric set was added as a further comparison for

the circle. The motivation for this was twofold– first, the square had similar ratings to the triangle in terms of being chosen to be compared to the circle and second, it meant that the full set of Kandinsky shapes also examined in Chapter 2 could be investigated using this novel methodology. Since angularity ratings were taken in the experiment it was possible to verify that all shapes did indeed belong to the shape category (round vs. angular) that were ascribed to them, with individuals rating them on the extreme ends of the semantic differential scale anchored at each end with 'round' and 'pointy'. The final set of 11 stimuli can be seen in Figure 4.1.

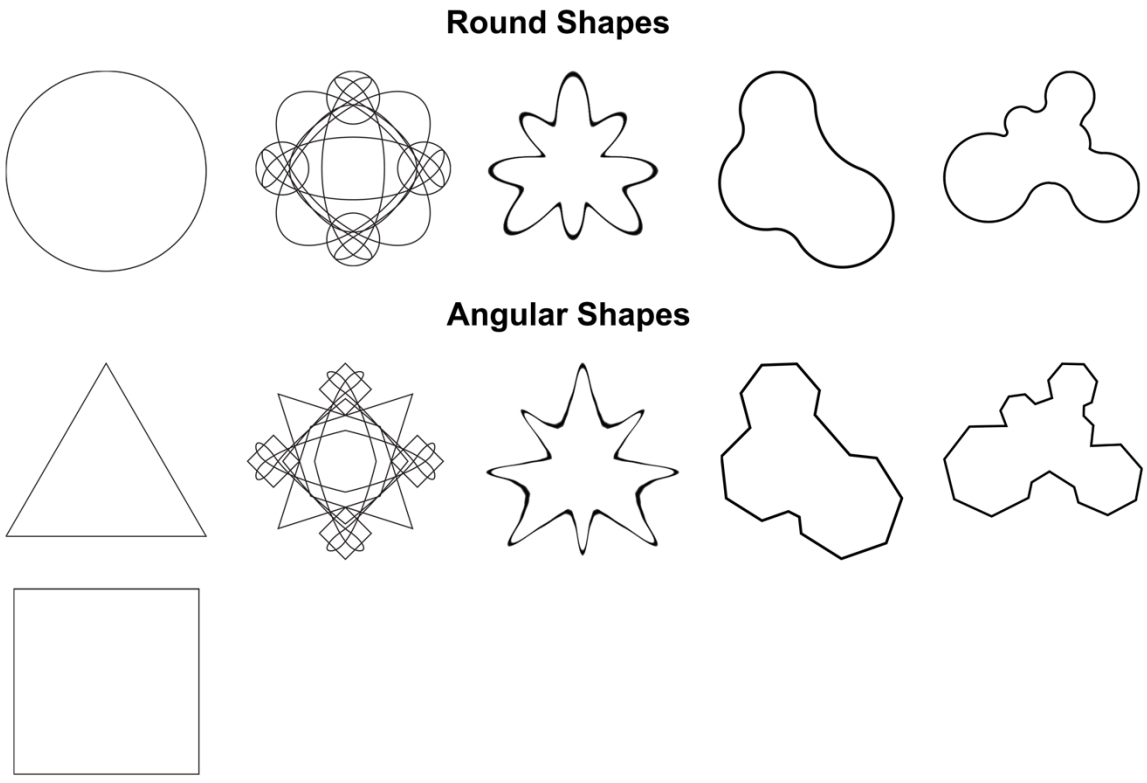


Figure 4.1 Figure showing the shape stimuli used in Experiment 4A. Each round shape was compared to its angular pair shown below it. The circle was compared to both the triangle and square. The triangle and square were also compared to one another.

The colour stimuli used were extracted from the 36 colour stimuli used in Experiments 3A-3D. The saturated versions of the colours red, yellow, blue, green, and pink were chosen (see Figure 4.2). The motivation for choosing this specific limited set of colours was to offer a breadth of hues which also included some of the main colours that have been tested in the research to date and which represent prototypical colours for many individuals (e.g., red, blue, yellow). Additionally, the aim was to investigate whether colour-shape associations differed when the colour set was reduced in terms of choices and the experiment had to be kept to a length that online participants would hopefully remain alert for. Over the course of the completion of this thesis, some experiments were run that took an hour or so to complete. It was clear from responses that individuals were often no longer paying attention after having to make so many repetitive ratings and responses. This was particularly clear in those experiments where individuals made colour ratings at the end of the experiment procedure, which can ostensibly be checked for some level of validity. As such, the choice of five colours and eleven shape stimuli allowed the experiment to take most participants between 20-30 minutes to complete and there was no indication that individuals were not responding with care throughout the study.

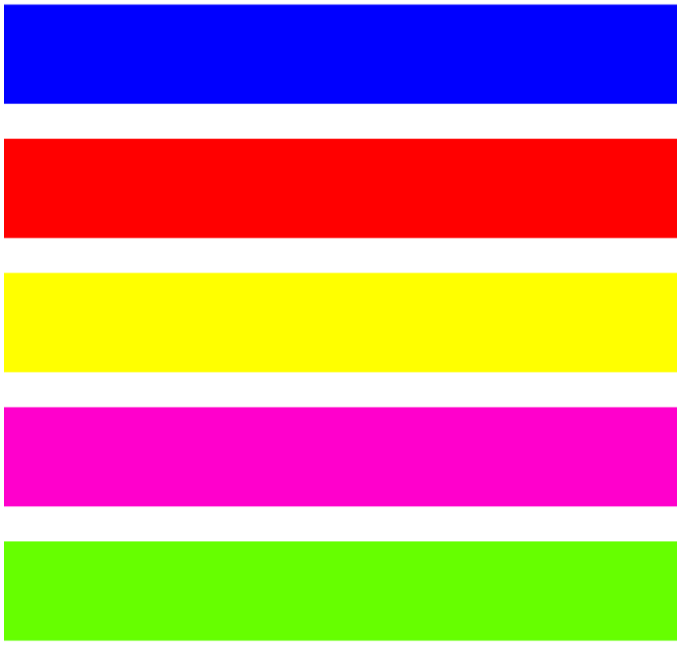


Figure 4.2 Figure showing the colour stimuli used in Experiment 4A.

4.2.1.3 Design and procedure.

The experiment was conducted using an online Qualtrics questionnaire that participants accessed through the participant recruitment platform Prolific. The background colour was set to #BCBCBC. Participants gave their informed consent to participate in the study and then proceeded to provide their Prolific ID. They were requested to sit in front of their computer, set so that the stimuli could be viewed easily, in a normally lit room that was quiet and free from distractions. An outline of the structure and instructions for each section of the study were presented to the participants.

Participants first completed two main experimental blocks, presentation of which was randomised across participants: 1) The colour-shape 2AFC block (Figure 4.3); 2) The shape-colour block (Figure 4.4). The colour-shape 2AFC block presented individuals with a colour and individuals had to choose which shape best matched this colour between each of the seven shape pairs (six of which were choices between angular versus round, except the choice between the square and triangle, see Figure 4.2 for pairs of choices). The shape-colour block presented each shape separately and asked individuals to choose one of the five colours that they felt best matched that shape. The order in which colours and shapes were presented was randomised for both blocks, both in terms of presentation stimuli and the order of choices.

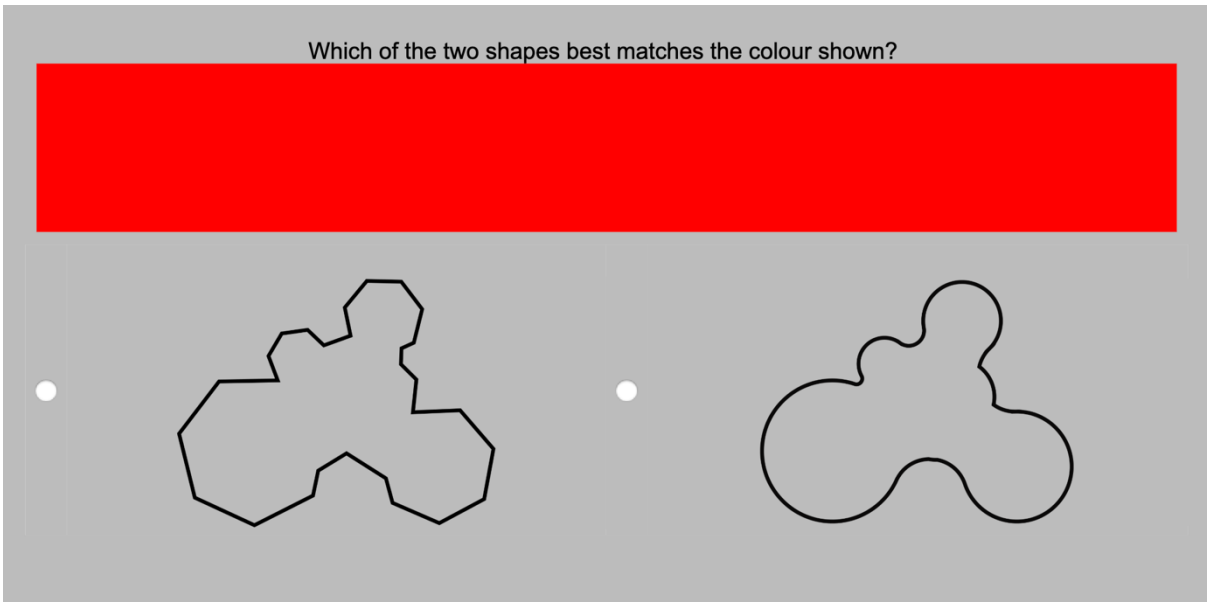


Figure 4.3 Figure showing one trial in the colour-shape 2AFC block (One of seven trials on one page, one page for each colour) in Experiment 4A.

For both blocks, and as in the experiments in Chapter 3, participants were instructed to do the following: "For each [shape/colour] please choose the [colour/shape] that you think best matches it. There are no right or wrong answers. Please answer as intuitively as possible." For the colour-shape 2AFC block, the question "Which of the two shapes best matches the colour shown?" was repeated as individuals moved down the page (see Figure 4.3). For the shape-colour block each shape was presented on an individual page with the quoted instructions at the top (see Figure 4.4).

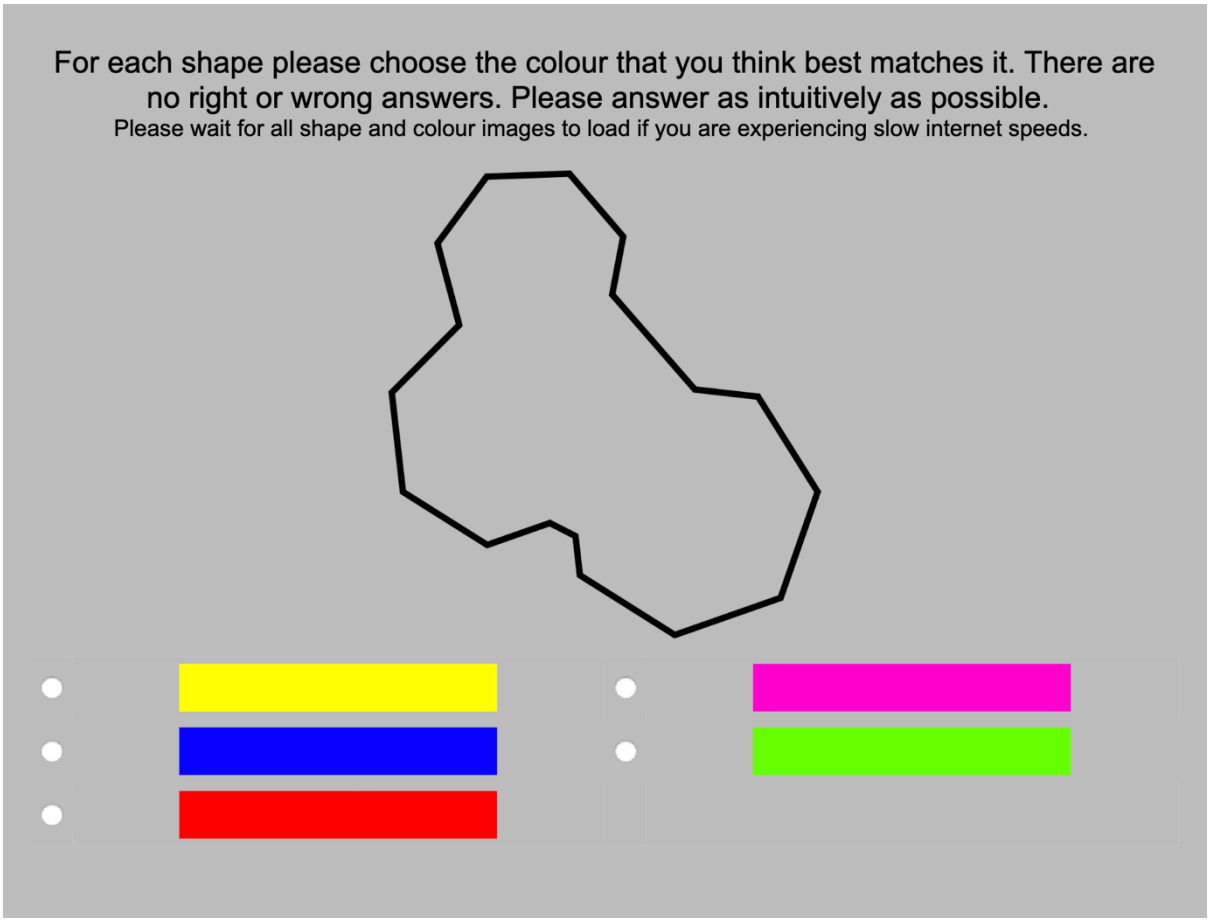


Figure 4.4 Figure showing a shape-colour block trial in Experiment 4A.

After completing both matching blocks, participants completed, in a randomised order, perceptual ratings for shapes and colours and aesthetic ratings for colours, shapes, and coloured-in shapes (all eleven shape stimuli coloured-in in each of the five colours for a total of 55 coloured-in stimuli). As in Chapter 3, all rating scale questions were rating scales anchored by two polar dimensions on each end resulting in a response of zero to a hundred (although this was not shown to the participant).

For the shape ratings participants rated each of the eleven shape stimuli on a scale from 'rounded' to 'pointy'. For the perceptual colour ratings, individuals rated the five colours on nine dimensions: red/green (red-green), yellow/blue (yellow-blue), red (not all red-very red), green (not at all green-very green), yellow (not at all yellow-very yellow), blue (not at all blue, very blue), lightness (light-dark), saturation (unsaturated-saturated), and warmth (cold-warm). This allowed some measure of how colours appeared specifically on each individual's screen. It should be noted that for the colours red, green, blue, and yellow, the individual colour ratings were usually highly polarised (0/100), indicating that the colours were presenting with some consistency, but also making these ratings difficult to use in most statistical tests due to the distribution of the data. For the aesthetic ratings, the shapes, colours, and coloured-in shapes were rated on a scale from 'ugly' to 'beautiful'.

Finally, participants completed an array of individual difference questions and psychometrics in a randomly allocated order. This included questions regarding their

age, gender, and cultural background, whether they experienced synaesthesia (the online questions drawn from the Synesthesia Battery noted above), and the City University online colour-blindness test ('A new web-based colour vision test', n.d.). Additionally, two further constructs were probed. Openness was measured using the Ten Item Personality Inventory (TIPI; Gosling, Rentfrow, & Swann, 2003), which was chosen in virtue of its short length, which fit with the requirement of a short overall experimental procedure. Individual's average interest in the arts was measured through a series of six items which focused on visual arts in particular, which were measured using the same 0-100 rating scales used above, anchored to the participant using polar dimensions and a midpoint (see Figure 4.5).

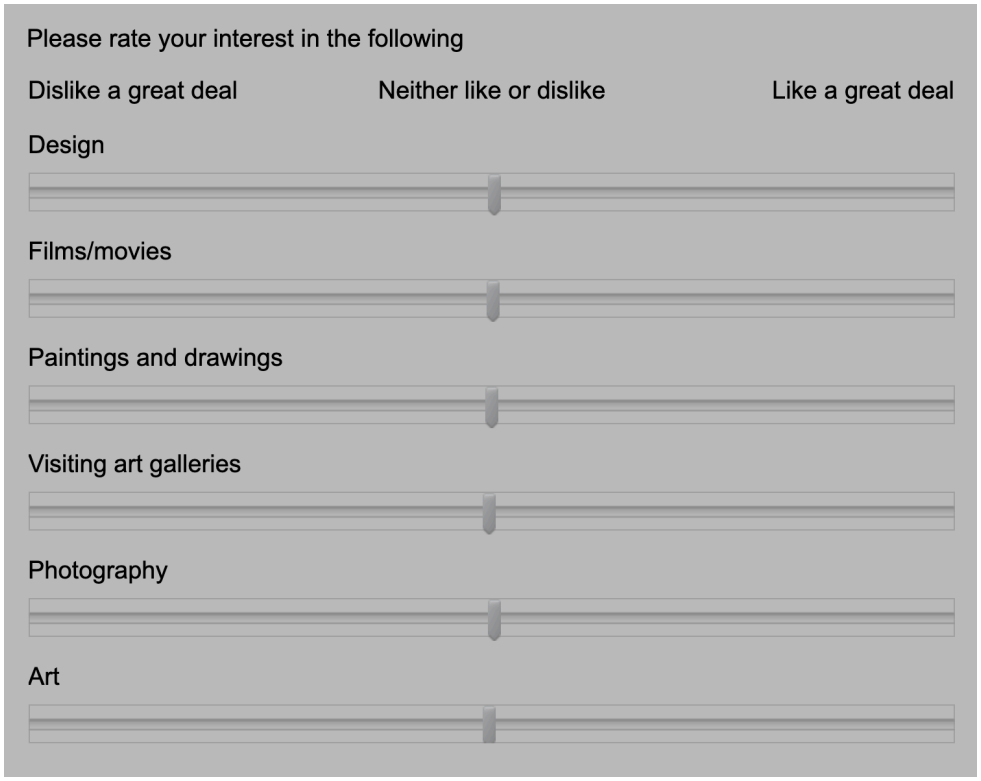


Figure 4.5 Figure showing the average interest in the arts survey that was used in Experiment 4A and 4B.

4.2.2 Experiment 4B.

4.2.2.1 Participants.

A UK sample of 148 participants was recruited online on Prolific (https://prolific.co) with the same selection requirements and exclusion criteria as in Experiment 4A. After individuals were excluded from analysis, a final sample of 107 participants took part in Experiment 4B (70 identified as female, 34 identified as male, 3 identified as non-binary, mean age = 38.09 years, SD = 13.96 years).

4.2.2.2 Materials.

Five paintings were chosen from Wassily Kandinsky's oeuvre, which was explored on https://www.wassilykandinsky.net/ and further online searches conducted through Google. The paintings were chosen for their use of geometric shapes and whether it was easily possible to create versions of them that altered the amount of curvature and angularity of the shapes that made up the painting. The works Calmed (1931), Composition II (1923)[20], Berührung (Contact) (1924), Soft Hard (1927), and Stars (1938) were chosen. The original paintings can be seen in Figure 4.6.

[20] Whilst another work called Composition II by Kandinsky was likely destroyed by the Nazis after raids of the Bauhaus school, it is unclear what the provenance of this painting is or if it was incorrectly named by the source from which it was taken (wassilykandinsky.net).

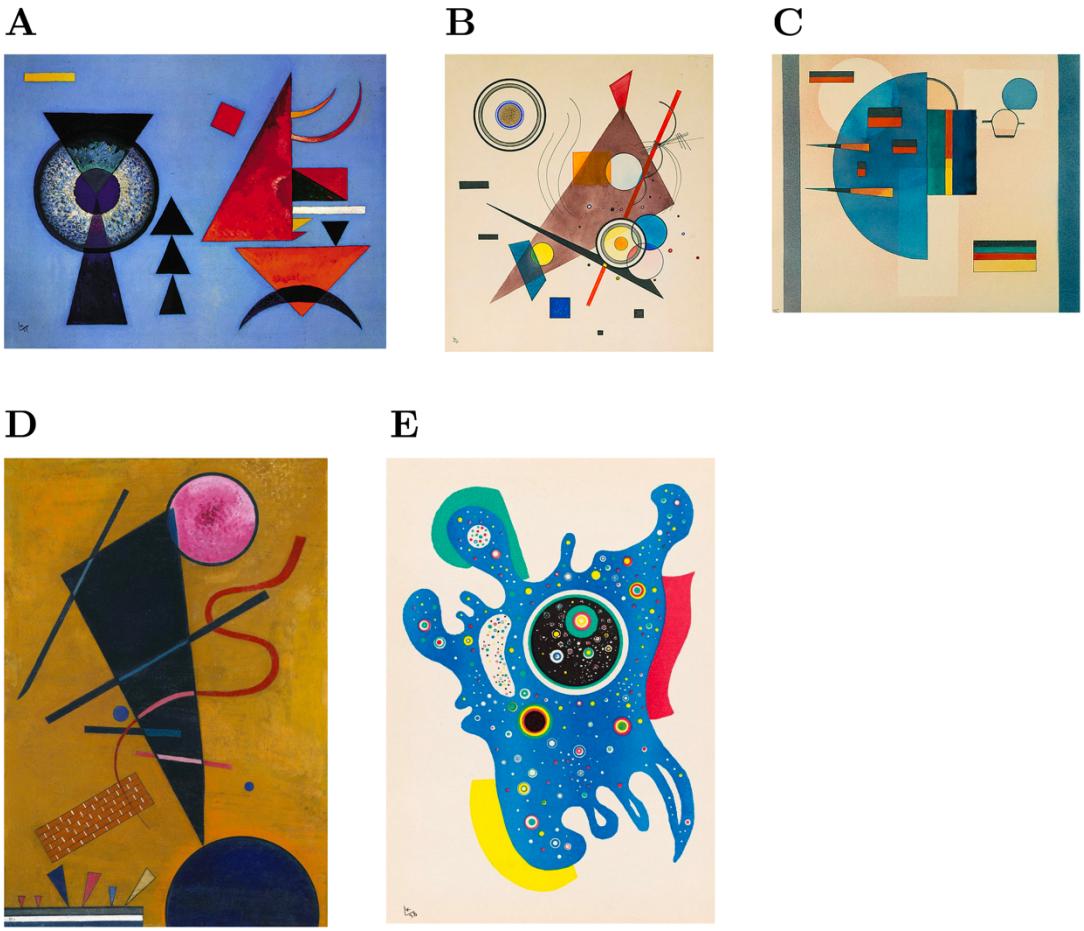


Figure 4.6 Figure showing the Kandinsky paintings used as inspiration for the painting stimuli in Experiment 4B. ***A****: Soft Hard (1927),* ***B****: Composition II (1923),* ***C****: Calmed (1931),* ***D****: Contact (1924),* ***E****: Stars (1938). Images were taken from https://www.wassilykandinsky.net/ and Wikimedia Commons.*

Adobe Photoshop was used to create round and angular versions, as well as a mixed version that contains both angular and curved elements. Except in the case of Stars, where Kandinsky's version contains mostly rounded shapes, the mixed version of the other four paintings most reflected Kandinsky's original work. Black and white, red, yellow, blue, and green versions were created of each of the 3 shape categories of

paintings. All paintings were adapted to a square format to hold this constant across stimuli. The black and white versions of all stimuli can be seen in Figure 4.7.

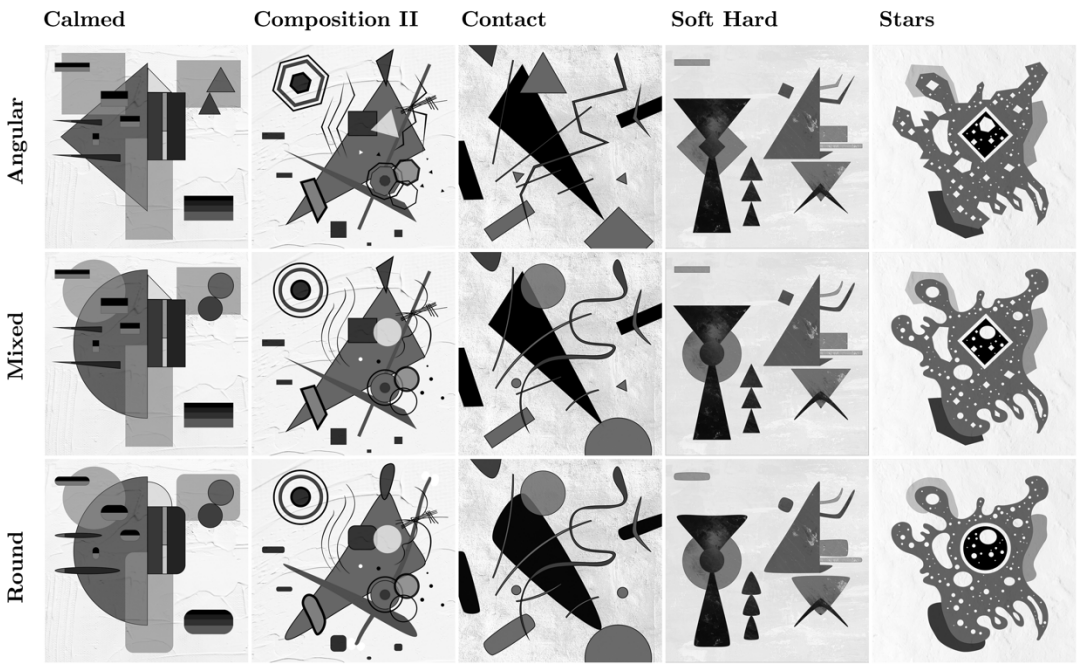


Figure 4.7 Figure showing the painting stimuli in Experiment 4B in black and white for each painting and shape category. Each painting was additionally colourised in blue, green, red, and yellow, as can be seen in Figure 4.8 below for the 'mixed' category.

The coloured-in versions of the paintings are shown for the mixed category paintings in Figure 4.8. The angular and round versions were colourised in the same way as depicted for the mixed category.

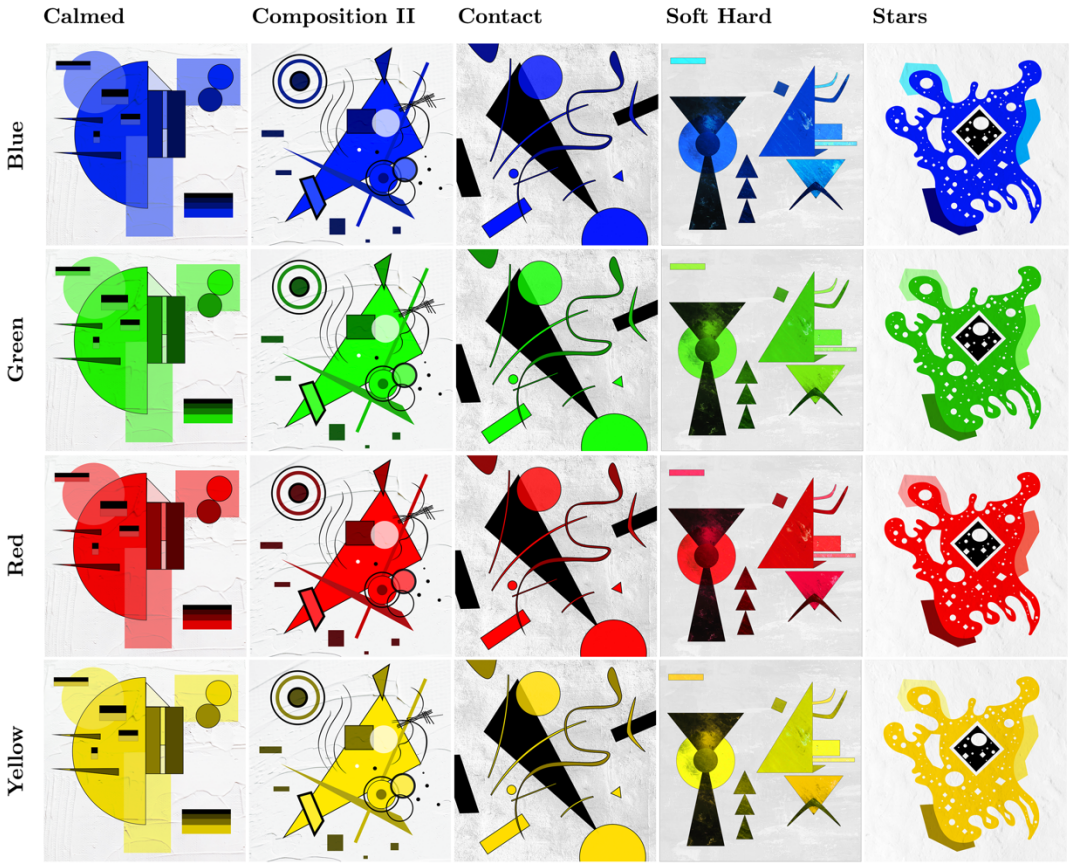


Figure 4.8 Figure showing the colourised version of the mixed category paintings for each individual painting in the colours blue, green, red, and yellow in Experiment 4B.

4.2.2.3 Design and procedure.

The experiment was conducted using an online Qualtrics questionnaire that participants accessed through the participant recruitment platform Prolific. The background colour was white with paintings being inlayed on a patch of the colour #EFEFEF during the matching task. Participants gave their informed consent to take part in the study and then proceeded to provide their Prolific ID. They were requested to sit in front of their computer, set so that the stimuli could be viewed easily, in a

normally lit room that was quiet and free from distractions. An outline of the structure and instructions for each section of the study were presented to the participants.

Before the matching task began individuals were instructed that: "You will now be shown paintings in four colours. You will have to choose the colour which you feel best matches the painting. There are no right or wrong answers. Please answer as intuitively as possible". Each of the fifteen paintings was then presented to individuals on a page in four colours in 300 by 300 pixel size. The participants were asked to choose which colour best matched the painting (see Figure 4.9).

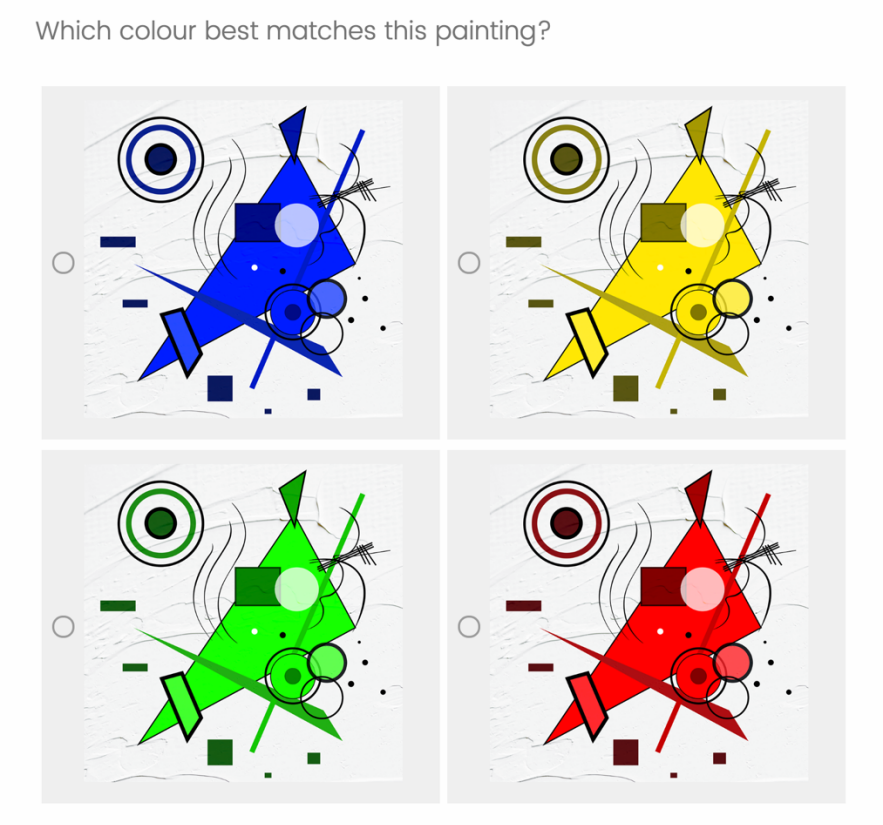


Figure 4.9 Figure showing how each painting-colour match trial looked in Experiment 4B.

After completing the painting-colour matches, individuals provided aesthetic ratings of the colours used in the paintings by being presented with all paintings in the relevant colour as an array and being asked to rate the overall colours presented. Participants also made aesthetic ratings of the black and white versions of the paintings and all 60 coloured-in versions of the painting stimuli. Additionally, the black and white paintings were rated by participants on their angularity. The same rating scales were used as in Experiment 4A. Finally, the same individual difference measures and psychometrics were collected as in Experiment 4A.

All data was analysed using IBM SPSS version 25 and RStudio for Experiments 4A and 4B. If reference is made to an LMM or multinomial logistic regression analysis it includes the random effect of participant (intercept only) and uses an ML estimation method (in the case of the LMM), unless otherwise stated. Continuous predictor variables were standardised as in previous experiments.

4.3 Results

4.3.1 Associations between angularity and colour.

4.3.1.1 Experiment 4A.

4.3.1.1.1 Colour-shape 2AFC task.

To check for within-participant effects, a Wilcoxon Signed Ranks Test was run for each colour on the sum of angular versus round shape choices. It was found that for the colour pink, participants chose round shapes significantly more than angular shapes (Z = -3.18, p = .001). For the colour red, participants chose angular shapes significantly more than round shapes (Z = -4.48, $p < .001$). This is consistent with the results of the multinomial logistic regressions that were run next to probe these associations in more detail.

The /GENLINMIXED command in SPSS was used to run a mixed generalized linear model. A binomial logistic distribution and link function was used. Colour was found to predict shape choices (F(4, 3235) = 24.27, $p < .001$). Specifically, as found previously, red was associated with angular shape choices (b = .835, SE = .11, $p <$ .001, OR = 2.30, OR CI (1.840, 2.884)) and pink was associated with round shape choices (b = -.24, SE = .11, p = .036, OR = .79, OR CI (.631, .985)). Additionally, yellow, the reference category, was associated with round shapes being more likely to be chosen (b = -.23, SE = .08, p = .006, OR = .79, OR CI (.672, .937)). Blue (b = .32, SE = .11, p = .004, OR = 1.38, OR CI (1.104, 1.714)) and green (b = .28, SE = .11,

p = .012, OR = 1.33, OR CI (1.064, 1.651)) were associated with angular shapes being more likely to be chosen.

The effects were further probed using the mblogit command in RStudio to compare the effects between reference categories. In comparison to blue, pink was less associated with angularity (b = -.56, SE = .11, p < .001) and more associated with roundedness, red was more associated with angularity (b = .52, SE = .11, p < .001) and less associated with roundness, and yellow was less associated with angularity (b = -.32, SE = .11, p = .003) and more associated with roundness. There were no significant differences in associations between angularity and roundness when comparing blue and green with one another. However, both pink (b = -.53, SE .11, p < .001) and yellow (b = -.29, SE = .11. p = .009) were less associated with angularity than green was, whilst red was more strongly associated with angularity (b = .56, SE = .11, p < .001) and less associated with roundedness than was green. All colours were less associated with angularity than pink – blue (b = -.57, SE = .11, p < .001), green (b = -.51, SE = .11, p < .001), red (b = -1.09, SE = .12, p < .001), and yellow (b = -.25, SE = .11, p = .03) – with pink thus being more strongly associated with roundness than all other colours.

All colours – blue (b = -.52, SE = .11, p < .001), green (b = -.56, SE = .11, p < .001), pink (b = -1.08, SE = .12, p < .001), and yellow (b = -.85, SE = .11, p < .001) – were less strongly associated with angularity than the colour red. Angularity was more

strongly associated with the colours blue (b = .32, SE = .11, p = .003), green (b = .28, SE = .11, p = .010), and red (b = .84, SE = .11, p < .001) than the colour yellow. Angularity was less associated with pink than the colour yellow (b = -.24, SE = .11, p = .029). It appears therefore that red had particularly strong associations with angularity, whilst pink was markedly associated with curved shapes, over and beyond all other colours. Green and blue were more associated with angularity and less associated with curved shapes than both pink and yellow, which were more associated with curved shapes.

4.3.1.1.2 Shape-colour choice.

Multinomial logistic regression models were run using RStudio (mblogit(ChosenColour ~ AngularityCategory, random = ~1|Participant) to determine whether angularity affected colour choices. It was found that angularity was less associated with pink than the colour red (b = -.63, SE = .20, p = .001), and thus that angularity was associated with red more than pink, and roundedness was associated more with pink than red. In comparison to pink, angularity was also found to be more associated with the colour green (b = .45, SE = .19, p = .019), and angularity was less associated with the colour pink. Thus, roundedness was more associated with pink and less with the colour green. No other significant associations were found by examining the effect of angularity versus curvature between the five different colours.

4.3.1.1.3 Revisiting Kandinsky.

As in Chapter 2, the colour-shape 2AFC paradigm also gave the opportunity to test whether there were any predominant associations between triangles and circles, on the one hand, and yellow and red on the other, in a more constrained task. In Chapter 2, choices for the Kandinsky shapes and colours were defined by a lack of blue choices for triangles and a strong association between blue and squares, but no significant findings to determine whether triangles and circles were more likely to be associated with yellow or red. For the colour red, when individuals were forced to choose between a triangle and circle, 64% chose the triangle, which is a significant deviation from a 50% test proportion when tested using a binomial test (p = .005). For the colour yellow, 56% of individuals chose the triangle instead of a circle, which a binomial test found is not significantly different from 50% (p = .211). This was mirrored by the shape-colour task's choices too, where of the individuals who chose yellow or red for triangles and circles, 64.9% and 64.5% chose red, respectively.

4.3.1.2 Experiment 4B.

Multinomial logistic regression models were run using mblogit in RSpace to determine the effect of painting category on colour choices. In comparison to angular paintings, round paintings were less associated with red than blue (b = -.36, SE = .18, p =.034), green (b = -.40, SE = .18, p = .027), and yellow (b = -.47, SE = .18, p = .008) and thus more associated with blue, green, and yellow than red. In comparison to angular

paintings, mixed paintings were more associated with the colours green (b = .49, SE = .18, p = .006) and yellow (b = .40, SE = .18, p = .022) than red, and thus more associated with yellow and green than red.

Mixed versus curved paintings did not differ in terms of their associations with any pair of comparisons between colours. Thus, it was an angular painting's association with red that stood out as a correspondence, whilst round and mixed paintings were more associated with the colours green and yellow. Round paintings were also more associated with the colour blue than red, but no other differences in associations for blue existed between the paintings. It was also found that when predicting colour choices based on the individual's rated angularity of the painting, there was a significant increase in red colour choices with increasing angularity (b = -.15, SE = .07, p = .042). However, the overall effect of rated angularity on colour choice was not significant based on the model run using the /GENLINMIXED command in SPSS (F(3,1599) = 2.43, p = .064).

4.3.2 Beauty mediation.

4.3.2.1 Experiment 4A.

4.3.2.1.1 Colour-shape 2AFC task.

An LMM found that for colour-shape 2AFC choices, individuals' colour beauty ratings predicted their chosen shape's beauty, such that individuals chose shapes they found

more beautiful for colours they rated higher in terms of beauty as well ($F(1, 3656.61) = 493.66$, $p < .001$, $b = 8.87$, SE = .40, $p < .001$, 95% CI (8.09, 9.66)). In Figure 4.10, it is possible to see, how with increasing colour beauty, mean chosen shape beauty increased as well.

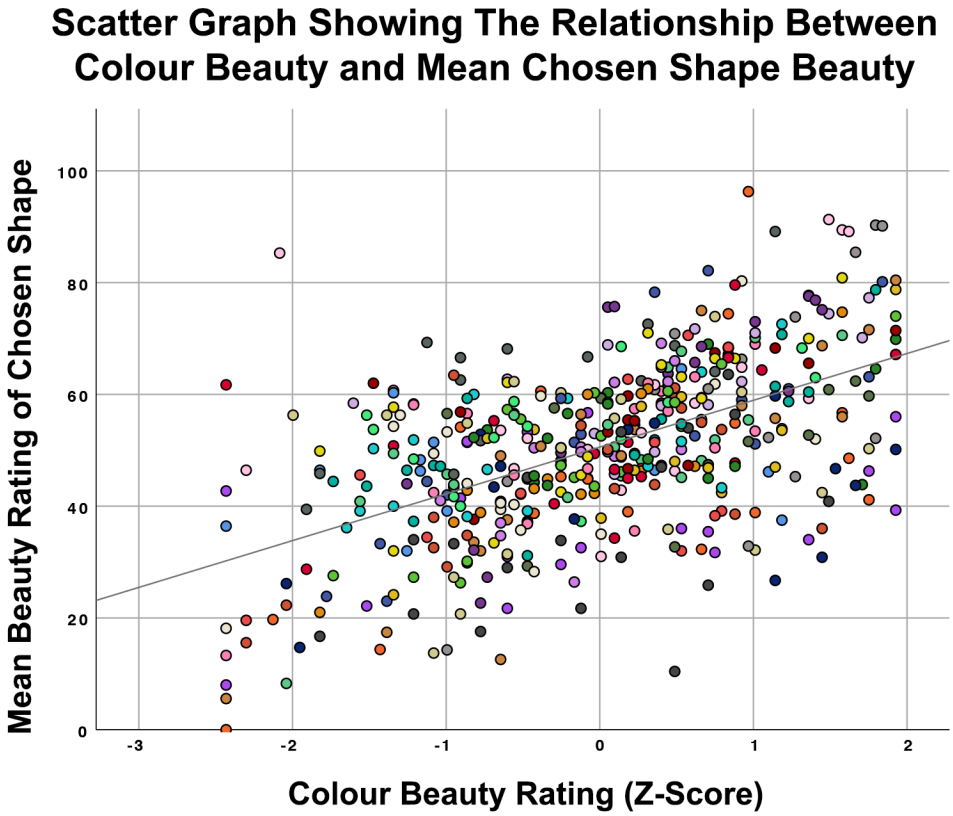


Figure 4.10 Graph showing the beauty mediation effect for the colour-shape 2AFC choice task in Experiment 4A, whereby mean beauty ratings of chosen shapes increase with the presented colour's beauty rating. Colour rating are represented as z-scores and each participant is given a different colour for their datapoints on the graph.

4.3.2.1.2 Shape-colour choice.

An LMM found that for shape-colour choices, shape beauty predicted chosen colour beauty (F(1, 1124.53) = 26.90, $p < .001$), such that individuals chose colours that they found more beautiful for the shapes that they rated as more beautiful (b = 2.91, SE = .56, $p < .001$, 95% CI (1.81, 4.02)).

4.3.2.2 Experiment 4B.

As for Experiment 4A, both beauty ratings averaged across all colours of paintings (F (1, 1602.75) = 33.81, $p < .001$, b = 3.34, SE = .57, $p < .001$, 95% CI (2.21, 4.46))) as well as black and white beauty ratings (F(1, 1588.36) = 16.30, $p < .001$, b = 2,14 SE = .53, $p < .001$, 95% CI (1.10, 3.18)) predicted significant increases in chosen colour beauty judgments. Thus, overall, there was consistent evidence across Experiments 4A and 4B that aesthetic appraisals part mediated and influenced colour-shape associations.

4.3.3 Aesthetic appraisals of shapes and colours.

4.3.3.1 Experiment 4A.

An LMM found that with increasing continuously rated shape angularity, shape beauty ratings decreased significantly (F(1, 1096.52)= 45.16, $p < .001$, b = -4.64, SE = .69, $p < .001$, 95% CI (-5.99, -3.28)). The same effect was found when angularity was tested as a binary variable – round shapes were found significantly more beautiful than

angular ones (b = 9.32, SE = 1.38, p < .001, 95% CI (6.61, 12.03)). Whilst average interest in the arts had no effect on the effect of shape characteristics on beauty ratings, individuals who were higher in openness had higher beauty ratings overall (b = 1.92, SE = .89, p = .034, 95% CI (.15, 3.68)), and showed increasing levels of aesthetic appreciation for angularity with higher openness (b = 2.02, SE = .69, p = .003, 95% CI (.67, 3.37)).

For the shape-colour task, first click, last click, and page submit times were available for analysis. No effect of angularity category was found for any of the dependent variables. Both shape beauty and chosen colour beauty had no significant effects on any of the RT outcomes either when tested in models alone or in tandem. Only for a model containing shape beauty, chosen colour beauty, and their interaction, did the interaction term have a significant effect on last click times (b = -.19, SE = .09, p = .045. 95% CI (-.37, -.00). It was found that when the beauty ratings for shape and the individual's chosen colour were most discrepant (e.g., low beauty shape rating with a chosen colour rated high in beauty, or shape rated as very beautiful with a colour chosen for it that was very low in terms of aesthetic evaluation), times until individual made their last click (and therefore, last choice for their final colour on the task) were significantly higher than for less discrepant matches. This effect was not found for first or page submit times, however.

4.3.3.2 Experiment 4B.

LMMs found no significant difference in beauty ratings of paintings by category (round, mixed, angular) regardless of whether the dependent variable was the black and white painting or an average of all the coloured-in version. Interestingly, and counter to the predictions, both averaged across colours painting beauty (b = 2.04, SE = .43, $p < .001$, 95% CI (1.20, 2.89)) and black and white painting beauty (b = 2.24, SE = .56, $p < .001$, 95% CI (1.15, 3.34)) were instead found to be higher with increased rated angularity of the painting stimuli. Individual differences in openness and average interest in the arts had few effects on the effect of shape appraisals on beauty ratings. Average interest was found to increase beauty ratings of black and white paintings (b = 2.73, SE = 1.26, p = .033, 95% CI (.23, 5.23)) but had no effect on averaged across colours beauty ratings of paintings.

4.3.4 Correspondence congruent beauty effect.

Do individuals rate the colour-shape and shape-colour matches they choose as matching the best, as more beautiful later in the experiment when they are presented with coloured-in shapes and asked to rate them on a scale of 'ugly' to 'beautiful'? In other words, do participants find their correspondent congruent coloured-in shapes more beautiful than their unchosen counterparts?

4.3.4.1 Experiment 4A.

4.3.4.1.1 Colour-shape 2AFC task.

For each colour in the colour-shape 2AFC choice block, the shape the individual chose was determined alongside their beauty rating for that particular combination of coloured-in shape for each of the seven 2AFC colour-shape choices. This can then be compared to the beauty rating of the version of the coloured-in shape in the trial's colour that was not chosen. Running six t-tests (one for each colour and the overall average) corrected for multiple comparisons (Strict Bonferroni corrected test statistic = .008) on this difference measure between the chosen and not chosen coloured-in shape beauty ratings showed that only for the colour pink did individuals choose a shape whose coloured-in that trial's colour version significantly differed from zero ($t(107) = 3.06$, $p < .003$, $d = .29$). This difference was positive (mean difference = 2.99, SD = 10.15) indicating that the pink coloured-in version of the chosen shape was rated as significantly more beautiful than the pink coloured-in version of the not chosen shape.

4.3.4.1.2 Shape-colour choice.

The same procedure was followed to analyse the shape-colour choice data. In this case, twelve t-tests were run (one for each shape and the overall average) and corrected for multiple comparisons (test statistic = .0004). For the circle (mean difference = 7.07,

SD = 18.34, $t(107) = 4.01$, $p < .001$, $d = .39$), round mandala (mean difference = 5.39, SD = 19.27, $t(107) = 2.91$, $p < .001$, $d = .28$), and the overall average (mean difference = 1.91, SD = 6.83, $t(107) = 2.91$, $p < .001$, $d = .28$), individuals chose a colour whose beauty ratings when colouring in the shape, was higher than the average beauty rating of the remaining four possible coloured-in versions of the not chosen colour for that shape.

The results across the two blocks are thus not unanimous about whether correspondence congruent coloured-in shapes are rated as more beautiful. In the colour-shape 2AFC block, this seems to be less the case (except for the colour pink). For the shape-colour block, the overall average was indeed significant and positive in direction, with individuals finding correspondent congruent coloured-in shapes to be more beautiful. Nevertheless, even in the shape-colour block the effect was not consistently found across shapes and, notably, only found for round shapes. The lack of consistent evidence highlights the fact that beauty judgements may determine an individual's colour-shape matches in part but are by no means the only determinant of what is considered a 'best match'. This is, of course, no surprise in light of the results of Chapter 2 where several other perceptual, emotional, and semantic characteristics were also found to mediate colour-shape associations.

4.3.4.2 Experiment 4B.

The same procedure was used as in Experiment 4A to determine whether individuals' correspondence congruent in-colour beauty ratings, were higher than the in-colour beauty ratings of the average beauty rating of the three colours they did not choose for that painting. Therefore, sixteen one-sample t-tests were run, one for every painting that individuals saw and the average difference of all of them (strict Bonferroni corrected test statistic = .003), to test whether the difference between the chosen in-colour beauty rating was significantly different to zero (see Table 4.1 for the results of the t-tests).

Going by a strict Bonferroni correction, only the mixed version of the Soft Hard painting and the overall average of all paintings resulted in significantly more beautiful correspondent congruent in-colour painting ratings than correspondent incongruent ones. Overall, it appears, just as in Experiment 4A, that there is no unequivocal evidence that for each painting individuals chose the in-colour version they found more beautiful than the average beauty of the three not chosen version. The fact all mean differences are positive, as well as the significance of the t-test of the overall average, however, points to a potential trend that future researchers may want to explore further. Indeed, as noted before, it appears that other factors aside from ratings on a scale from ugly-beautiful may be crucial in driving individuals' choices for what colour best matches each painting.

Table 4.1 Graph showing the results for the t-tests conducted to analyse whether a correspondence congruent beauty effect existed for the painting stimuli in Experiment 4B. Positive mean differences indicate that the chosen colour's version of the painting was rated more beautiful than the average not chosen versions, negative mean differences mean the reverse.

Painting	Painting category	*t*	df	*p*	Mean difference	Lower 95% CI	Upper 95% CI
Calmed	**Angular**	1.46	106	.147	2.92	-1.04	6.88
	Mixed	1.18	106	.243	1.90	-1.31	5.12
	Round	1.22	106	.227	1.68	-1.06	4.42
Composition II	**Angular**	.71	106	.482	1.47	-2.65	5.59
	Mixed	.28	106	.781	.55	-3.32	4.41
	Round	1.00	106	.319	1.78	-1.74	5.29
Contact	**Angular**	1.41	106	.162	2.45	-1.00	5.89
	Mixed	.81	106	.419	1.40	-2.01	4.81
	Round	2.67	106	.009	4.66	1.20	8.12
Soft Hard	**Angular**	2.09	106	.039	3.90	.20	7.60
	Mixed	4.63	106	.000	6.88	3.93	9.84
	Round	1.46	106	.148	2.59	-.94	6.11
Stars	**Angular**	2.37	106	.020	3.31	.54	6.08
	Mixed	1.50	106	.137	2.31	-.75	5.37
	Round	2.15	106	.034	3.50	.27	6.74
Average Difference Across Paintings		4.26	106	.000	2.75	1.47	4.03

4.3.5 How coloured-in shape aesthetic appraisals form.

4.3.5.1 Experiment 4A.

An LMM was run that predicted in-colour shape beauty from the fixed effects of colour beauty and shape beauty, with the random effect of participant added as an intercept-only factor. Whilst colour beauty had no significant effect on in-colour beauty ($F(1, 5718.39) = 2.27$, $p = .132$), shape beauty significantly predicted in-colour beauty ($F(1, 5931.72) = 1947.67$, $p < .001$), whereby, in-colour beauty increased significantly with increasing shape beauty ($b = 11.52$, SE = .26, $p < .001$, 95% CI (11.01, 12.04)).

4.3.5.2 Experiment 4B.

An LMM was run that predicted in-colour painting beauty from the fixed effects of colour beauty and black and white painting beauty, with the random effect of participant added as an intercept-only factor. Colour beauty had a small but significant effect on in-colour painting beauty ($F(1, 6407.37) = 4.21$, $p = .040$, $b = .50$, SE = .24, $p = .040$, 95% CI (.02, .97))). Shape beauty, like in Experiment 4A played a far more important role, and significantly predicted in-colour beauty ($F(1, 6402.30) = 2630.48$, $p < .001$), whereby, in-colour beauty increased significantly with increasing black and white painting beauty ($b = 13.38$, SE = .26, $p < .001$, 95% CI (12.89, 13.89)).

4.4 Discussion

For both tasks in Experiment 4A, red was strongly associated with angularity and pink was markedly associated with curvature. For both tasks, green was found to be more associated with angularity than with curvature. This may, in particular, be a function of the kind of green used, which was particularly vibrant and intense. The 2AFC colour-shape task also highlighted that both green and blue were more associated with angularity, and less associated with curvature than both pink and yellow. For Experiment 4B, mixed and curved paintings did not differ significantly in their associations with the four colours of red, green, blue, and yellow in comparison to one another. Angular paintings, however, were found to be more associated with red than all other colours in comparison to round paintings, which were more associated with the colours green, blue and yellow in comparison. Mixed paintings in comparison to angular paintings, were more associated with the colours yellow and green than red, with thus angular paintings being more associated with the colour red than green or yellow.

Overall, there was consistent evidence for a link between angularity and red. One possible explanation for this result is their common association with threat (see for references and discussion in relation to shape, Chapter 3, Section 3.1.3; Elliott & Maier, 2012; Feltman & Elliot, 2011; Humphrey, 1976; Young, Elliot, Feltman, & Ambady, 2013). However, other explanations such as high arousal (devoid of specific negative

associations of threat) could also contribute. Pink too shares common semantic associations with roundness, such as femininity and the female gender (Blazhenkova & Kumar, 2018; Koller, 2008) that could have driven its associations with roundedness in Experiment 4A. Since such affective and semantic associations were not probed directly in this experiment, no determination can be made of what the driving factors were in actuality in this case. Crucially, affective and semantic associations of colours are rarely clear cut: red could arguably also be expected to be associated with curvature through its association with sweetness (Deroy & Valentin, 2011, though consider its association with spiciness too: Shermer & Levitan, 2014) or the concept of love that may bring to mind hearts and elicit an approach stance. Indeed, a recent global survey of entrepreneurs found that red was associated with words such as passion (10.58%), love (10.49%), power (6.63%), anger (5.36%), blood (5.31%), and danger (4.68%; King, 2019). Thus, care should be taken not to put too much weight on post-hoc explanations of such findings, since they are not specifically tested hypotheses.

Nevertheless, it does appear that by reducing number of choices, investigated shape dimensions, and thus changing the task demands, more consistent findings were able to be found across the same shape stimuli of the two tasks in Experiments 4A, as well as similar colour stimuli between Experiments 4A and 4B.

The role of aesthetic evaluations in mediating shape/painting and colour associations was found to be consistent across tasks and Experiments 4A and 4B. Individuals chose

colours they found more beautiful for shapes and paintings they judged as more beautiful. In Experiment 4A, the preference for curvature effect was replicated, such that individual preferred curved shapes over angular shapes. Unlike Cotter *et al.* (2017), but in line with the findings in Chapter 3, increased openness in fact positively moderated liking of angularity, rather than curvature. In contrast, no differences in aesthetic evaluations were found between the curved, mixed, and angular version of paintings. In fact, counter to the preference of curvature effect, a slight increase in beauty evaluations with higher rated angularity of paintings was found. Whilst in Experiment 4A openness was found to have a positive direct effect on shape beauty ratings, it was average interest in the arts that had a positive direct effect on beauty ratings of black and white paintings in Experiment 4B.

The results for the correspondence congruent beauty effect were not unanimous across tasks in Experiment 4A, nor across the two experiments. There was no consistent significant evidence that individuals rated their correspondence congruent coloured-in shape and painting versions as more beautiful than their not chosen counterparts from the matching task. Overall, a significant correspondence congruent beauty effect was found only for: the colour pink, the circle, round mandala, the overall difference (for the shape-colour choice task), the mixed version of the Soft Hard painting, and the overall difference across paintings. The positive results for the averages in both experiments and the fact all mean differences were positive in Experiment 4B speak in favour of a correspondence congruent beauty effect. The more detailed analysis of the

separate shapes and paintings, though, shows that future researchers will need to investigate this finding further before more confident assertions can be made.

Additionally, the subtle interplays that affect aesthetic evaluation that could have been set off by a change in colour, could have unpredictable changes on the beauty judgments of the paintings (Braun & Doerschner, 2019). Ultimately, then, whilst aesthetic evaluations do factor into what colours or shapes are chosen on colour-shape correspondence tasks, they are by no means the only appraisal dimension that drives individual's choices, since otherwise stronger evidence for the correspondence congruent beauty effect should have been found. In regard to fluency theory, this challenges the notion that colour-shape associations reflect a combination of stimuli that can be processed faster because they are intrinsically more associated in our cognitive architecture. However, the fact that highly discrepant matches in terms of their aesthetic evaluations resulted in longer time taken on the task on at least one measure, does indicate that matching stimuli which are less associated semantically, may result in less processing ease.

Finally, as predicted and replicating Sato and Oda's (2014) result, in both Experiments 4A and 4B, for shape and painting stimuli, shape and black and white painting beauty ratings were more influential in determining the aesthetic evaluations of in-colour shapes and paintings than colour ratings. For paintings, colour aesthetic judgements did have a small but significant effect. Indeed, it would be surprising if colour

preferences played no role in aesthetic evaluations of abstract art when judged by a simple ugly-beautiful rating dimension. Rump and Southgate (1967), for example, even noted that older viewers particularly enjoyed abstract paintings due to their colouring. Previous research has generally found that removing colour reduces appeal of paintings for average observers and that individuals prefer brightly coloured paintings (Hekkert & Van Wieringen, 1996; Rump & Southgate, 1967). Although this phenomenon may depend on type of painting: Polzella, Hammar, & Hinkle (2005) found that this effect held true for landscape paintings, but not for portrait paintings.

Interestingly, there was little, if significant ($t(1604) = -2.96$, $p = .003$), difference in mean ratings of each painting across all choices, with black and white versions (mean = 44.34, SD = 25.25) indeed being rated on average lower than the paintings averaged across all colour version (mean = 45.69, SD = 21.63). As such, it may be that colour increases aesthetic appeal of paintings, but that individuals' specific colour preferences are less influential than their specific shape preferences in determining the exact level of aesthetic appeal of a painting. The exact conception of beauty or aesthetic evaluation may also be crucial here: for example, in a study of abstract paintings that focused specifically, on the use of shapes, colours, and textures, Yanulevskaya *et al.* (2012) found that both CIELAB colour space and local shape predictors of where people's eye gaze was focused improved predictions of whether a painting was rated as being either positively or negatively valenced, although colour was a better predictor in comparison to shape features.

Ultimately, it is highly likely and accepted as fact, that colour contributes to our aesthetic and emotional experiences whilst experiencing art. As such the evidence here only highlights that at least in the more clinical context of Experiments 4A and 4B, that individual shape and black and white painting beauty ratings were better in predicting in-coloured shape and painting ratings than colour aesthetic evaluations were.

5 Conclusions: Colour-Shape Correspondences Reconsidered

5.1 Overview of the Findings

Chapter 1 systematically reviewed the colour-shape correspondence research that has been published to date. Some consistent findings were found. For example, the predominance of the association and dissidence correspondences. This finding was also replicated in Chapter 2. Chapter 1 also highlighted some common results in the research field (e.g., an association between warmth and shapes with acute angles, cold colours and shapes with obtuse angles, triangles and yellow, circles and red). But, through looking back at the past literature, Chapters 1 and 3 also demonstrated that there were inconsistencies in the findings that are rarely discussed and problems with the statistical analyses chosen to analyse colour-shape correspondences. Additionally, it remained an open question of whether specific shape characteristics predict certain colour characteristics since only one researcher had systematically varied a larger set of shape stimuli to test this question (Malfatti, 2014). In Chapter 3, this question was answered through the novel (for the field of colour-shape correspondences) statistical analysis methodology of linear mixed models (LMMs) that allowed match-by-match data to be retained by clustering individuals by participant as a random effect. The extent of the variability of colour-shape correspondences, and limited variance

perceptual predictors could explain in chosen colour characteristics, was demonstrated in a set of four experiments.

Such inconsistent results stand in stark contrast to Chapter 2 and 4, where more limited colour and shape stimuli and, thus, restricted choices resulted in more consistent findings. Overall, for the Kandinsky shapes and colours a strong link between blue and the square, and disassociation between the triangle and blue was found in Chapter 2. When homing in on angularity with limited sets of colour and shape stimuli in Chapter 4, the association between red and angularity was highlighted consistently. Crucially though, such associations cannot be taken as generalisable truths – in Chapter 3, whether red was associated with angularity or curvature depended on which set of shape stimuli was presented and did not show consistent replication across experiments using the same stimuli either. Throughout Chapters 2, 3, and 4, the suitability of using affective and semantic appraisals (especially liking, arousal, and aesthetic evaluations), to predict colour-shape correspondences gained strong support. The preference of curvature and symmetry found in and predicted by the previous literature was replicated when shape stimuli were used (but not the painting stimuli of Experiment 4B). However, on some level, these findings are at odds with the lack of consistent predictions in colour characteristics that could be found based on the shape characteristics of angularity, symmetry, and complexity. As such, it is not surprising that individual differences played a role in determining affective shape appraisals.

Finally, in Chapter 4, initial and yet inconsistent evidence was found for a correspondence congruent beauty effect. This finding will have to be tested in the future by other researchers, to see whether those colours and shapes that individuals previously matched together do indeed result in more beautiful ratings of their corresponding coloured-in versions. The bidirectionality of colour-shape correspondences tested using smaller set of stimuli was evidenced in Chapter 4, which is in line with the characterisation of crossmodal correspondences as a bidirectional phenomenon. Finally, in Chapter 4, the importance of shape (vs. colour) aesthetic evaluations in determining beauty judgments of coloured-in versions of paintings and shapes was given support.

5.2 Standing Issues and Limitations

5.2.1 Task issues and stimuli limitations.

5.2.1.1 Can we stay online?

Colour science, understandably, is particularly focused on accurate presentations of colours. How can we understand colour if we cannot make sure the same colour is presented? This has been a crucial focus for most psychophysical perception research, but it is done with particular meticulous effort in colour research. For example, in their review of colour and psychological function research to date, Elliot (2015) states:

> First, although in some research in this area colour properties are controlled for at the spectral level, in most research it (still) is not. Colour control is typically done improperly at the device (rather than the spectral) level, is impossible to implement (e.g., in web-based platform studies), or is ignored altogether. Colour control is admittedly difficult, as it requires technical equipment for colour assessment and presentation, as well as the expertise to use it. Nevertheless, careful colour control is essential if systematic scientific work is to be conducted in this area. Findings from uncontrolled research can be informative in initial explorations of colour hypotheses, but such work is inherently fraught with interpretational ambiguity (Whitfield and Wiltshire, 1990; Elliot and Maier, 2014) that must be subsequently addressed. (p. 5)

For this reason, the hardened colour perception researcher may be hesitant to consider the results of any online experiment conducted to examine colour-shape correspondence research as having any gravity, especially if the question of replicability is central to the research agenda. In the case of Experiments 3A, 3B, and 3C, this is a more valid worry than for Experiment 3D. But even here, the current author would argue that the average colour dimensions used to determine chosen colour characteristics, offer a relative understanding of what colours were chosen (redder vs. greener) and online methodologies do not preclude that colour categorisation by different individuals may likely still be consistent enough across screens. Experiment 3D, however, still showed the same veritable amounts of variation between sets of shapes and between participants even though the same individual evaluated all stimuli sets.

Yet, there is strong evidence from colour preference research that asking individuals to rate their perceptual experience of each colour along dimensions such as red/green, yellow/blue, lightness, and saturation, in fact well captures colour preferences, and

does so markedly better than physiological models based on the weighted average of cone contrasts relative to the background colour with added psychophysical variables of lightness and saturation (Palmer, Schloss, & Sammartino, 2013). Indeed, Palmer and Schloss (2010) even used a weighted average of such subjectively rated perceptual dimensions of colour to predict colour preferences. This highlights that even for Experiments 3A, 3B, and 3C, the online methodology may be less detrimental to the accounting of variance than one may predict. Furthermore, online methodologies do not restrict our ability to evaluate the affective appraisals of individuals, which have been shown in this thesis to be crucial variables in determining and understand colour-shape correspondences.

As such, it is recommended that future researchers consider both individual and average ratings of the perceptual dimensions of colour that relate to dimensions of the Natural Colour System (Hård & Sivik, 1981) as well as the CIELAB colour dimensions (Buckley & Giorgianni, 2016) if they choose to conduct online research. But, in addition to these lines of research, heeding Elliot's (2015) call for carefully controlled stimuli, colour-shape correspondence research needs to similarly use spectrally controlled stimuli. In addition to the statistical guidelines set out previously, researchers must proceed with caution and care in the establishment of a broader, more replicable field of study.

5.2.1.2 Capturing the full gamut of emotions.

Emotions are difficult to conceptualize and throw up various measurement issues (Frijda, 2009; Mulligan & Scherer, 2012; Scherer, 2005). Whilst liking and arousal as appraisals were focused on to give an insight into emotional responses in Chapter 3, future researchers may want to find ways of assessing a broader set of semantic and affective associations (such as those tested in Chapter 2) simultaneously to see how they affect colour-shape correspondences. One such methodology that could be used is based on Euclidean distances that capture the similarity between stimuli across whatever range of dimensions one chooses to evaluate. Indeed, this methodology has been used successfully to account for perceptual predictors of grapheme-colour synaesthesia (e.g., Watson, M.R., *et al.*, 2012), and will be discussed in more detail below. The related dimensions of potency, dominance, or control are often (e.g., Goudbeek & Scherer, 2010; Rodá, Canazza, & De Poli, 2014), as they were here, given less precedence in explorations of emotional mediation. However, it may be prudent for future researchers that want to evaluate the full range of emotions that could play a role in affective appraisals as best as possible to include them. Since they are included in many major emotional appraisal models that attempt to boil down the nuanced complexity of our emotional responses to a few dimensions, it seems pre-emptive to not explore their role further (Fontaine *et al.*, 2007; Mehrabian and Russell, 1974; Osgood, 1960; Osgood, May, & Miron, 1975; Scherer, Dan, Flykt, 2006; for how,

unsurprisingly, more factors determine the appraisal components of emotions and moods in real-world practice, see Ellsworth & Scherer, 2003).

Moreover, Chapter 4 clearly provided a very preliminary look at how colour-shape correspondences intersect with beauty, aesthetics, and art. A more nuanced view of beauty that takes into account the complexity of emotions art can convey and evoke, will be well suited to a more sophisticated study of colour-shape correspondences. Considering a broad set of affective appraisals when assessing the emotional mediation hypothesis (Palmer, Schloss, Xu, & Prado-León, 2013) is well matched with a reflective and nuanced investigation of how colour-shape associations may affect aesthetics and art experiences. Further into the research agenda, researchers may also want to consider emotional measures that go beyond the cognitive appraisal level, and consider biological indicators such as galvanic skin response methodologies, pupil dilation, heart rate measurements, and even facial expressions (for reviews, see Boehner, DePaula, Dourish, & Sengers, 2007; Mauss & Robinson, 2009). This is important in order to determine what level of affective processing colour-shape correspondences can have an influence on and be affected by: does the emotional mediation of colour-shape correspondences extend into the embodied experience of emotion?

5.2.1.3 What about other shape characteristics?

There are other shape perceptual and aesthetic shape characteristics, such as prototypicality, exposure, balance, the golden ratio, and harmony that can affect

appraisals, as well as show individual differences in people's preferences for them (Farkas, 2002; Fechner, 1865, 1871, 1876; Garner, 1974; Green, 1995; Montoya, Horton, Vevea, Citkowicz, & Lauber, 2017; Palmer, 1991; Palmer & Griscom, 2013; Philips, Norman, & Beer, 2010; Shimamura & Palmer, 2012; Veryzer & Hutchinson, 1998). These have not been controlled for explicitly in this study. This may be particularly problematic for the type of polygons which much research makes use of – namely well-known polygons like those found in the geometric shape stimuli set in Chapter 3.

That is not to say, though, that one may not be interested in what colours common and prototypical shapes are associated with. Indeed, it is the first letters of the alphabet that show the strongest consistency between grapheme-colour synaesthetes (e.g., Root *et al.*, 2018; Simner *et al.*, 2005). In fact, this gives an interesting insight into the mechanisms of how colour-shape associations as well as grapheme-colour synaesthesia may arise, suggesting a possible role, for example, for ease of generation and the availability heuristic (Deroy & Spence, 2016; Kahneman & Tversky, 1973; Pollard, 1982; Spence *et al.*, 2015). However, it is important to keep in mind that, therefore, such shapes may differ from less well-known shapes, in terms of what predicts their shape-colour associations, thus, adding to the variability between sets of shape stimuli of what perceptual shape predictors may be associated with particular colours or colour properties.

5.2.2 What makes a colour-shape correspondence?

5.2.2.1 Dealing with the many inconsistencies.

The colour-shape correspondence literature abounds with inconsistencies (as a close reading of Appendix 6.4 soon reveals), even for those effects often heralded as the most replicable and notable. For example, as was noted in Chapter 1, the association between circles and red are commonly found and highlighted by researchers (see references and discussion in Chapter Section 1.2.2; see also Woods, Spence, Butcher, & Deroy, 2013). Yet, in Chapter 4, when forced to choose between a circle and a triangle for the colour yellow, individuals were significantly more likely to choose a triangle over a circle, and one of the most commonly found combinations of associations for the Kandinsky shapes and colours – the association correspondences – involves a yellow circle.

Now, consider that a circle and triangle are at polar opposites on the continuous dimension of curved to angular. In Chapter 3, it was found that redness could be associated with both angularity and roundness, whilst in Chapter 4 it was consistently associated with angularity, in line with previous research associating warmer colours with acute angles (Albertazzi, Da Pos, *et al.*, 2013; Albertazzi, Malfatti, *et al.*, 2015; Chen, N., 2015). It may be that circles and triangles are non-differentially associated with yellow and red (as the results of the experiments reported in Chapter 2 imply). Moreover, it may be that redness has associations with both angularity and roundness,

for example, through threat associations and more positively valenced connections to sexuality and curvature. It is crucial to remember that the above is just one network of such inconsistencies for shapes, shape characteristics, and colours. Additionally, it is an example pertaining to the relationships between those stimuli and stimuli characteristics that have been considered to be the most reliable results in the field.

Many things appear to have an effect on colour-shape correspondences that could lead to such inconsistencies. This requires clarity on how one can conceive of colour-shape correspondences and what aspect of them a specific experiment is investigating. Consider a methodology that investigates one-to-one mappings and does not have enough instances of shapes to actually represent one condition (e.g., angularity vs. curvature), yet makes conclusions about what shape characteristics may predict colour characteristics. Such analysis conflates two notions of colour-shape correspondences, without sufficient statistical testing of the latter. Of course, one-to-one mappings and continuous dimensions are likely to co-exist in how we map shapes to colours, but it is advisable to be clear on what is being investigated in each experimental instance.

So, what can result in inconsistencies and should be considered in conclusions of what kind of colour-shape associations are being investigated? First, how shape and colour are parameterised within both analysis and task design plays a role. Chapter 3 and the associated Appendices (6.10 , 6.12, 6.14) linked to for each analysis demonstrated that whether shape is conceived of as a continuous subjective or categorical objective

variable can result in inconsistencies, albeit with a number of commonalities too. This is not only a question of continuous versus categorical ratings, but also one of whether researchers should rely on subjective phenomenological ratings (as seems particularly pertinent, for example, for complexity – see, for example, Spence & Wang, 2018) or choose 'objective', non-phenomenological methods to categorise shapes.

Second, how colour is conceived of also matters. This can again involve both objective and subjective versions of categorical and continuous measures. The parameterisation determines whether a claim is being made about a specific hue being associated with a certain shape or shape characteristic, whether only polar opposites (white vs. black) are being investigated, or whether an effect holds true when colour is conceived of as a continuous variable within a given colour space. The latter conception results in an additional difficulty, which could have contributed to the weak evidence for perceptual relationships between colour and shape in colour-shape correspondences found in Chapter 3.

To understand this, it can be useful to turn to grapheme-colour synaesthesia again. Here, second-order mappings are frequently found for dimensions that can be thought of linearly, e.g., saturation and lightness, or when colour is conceived of as differences in similarity across a variety of variables. However, the association between absolute hues and features usually found to determine inducer-concurrent relationships (e.g.,

ordinality) are not found (see for example, Watson, M.R., *et al.*, 2012, and references and discussion therein). Hence, M.R. Watson *et al.* (2012) note:

> We prefer to analyse second-order relations among grapheme-colour pairs. Our primary motivation is that strong second-order mappings (with weaker first-order mappings) have often been observed in human perception more generally (e.g., we remember melodies, not absolute pitch, in music; facial configurations, not specific facial features, in vision; and words, not phonemes, in language). A secondary motivation is that second-order analyses allow for the easy investigation of the property of hue. Because luminance and saturation are one-dimensional properties of colours, they can be used in correlations or other linear analyses. Hue requires at least two dimensions, however, in order to be specified (e.g., blue/yellow or red/green), which makes it impossible to compute a simple correlation between hue and any other measures. *Differences* between hues, on the one hand, are one-dimensional, and thus amenable to linear analyses. (p. 212)

Since colour can be conceived of as a circular space (Gilbert *et al.*, 2016), and at the very least, hue needs to be conceptualised along two dimensions (e.g., red/green and yellow/blue), simple linear analyses of colour characteristics are insufficient in capturing colour as a metathetic dimension (see Stevens, 1957, for the distinction between prothetic and metathetic, and Spence, 2019a for a discussion of such characterisations within in the context of colour-related correspondences, finally note that colour combines both properties: lightness, which can be thought of as being more or less making it a prothetic dimension, and hue, which cannot, and is, thus, metathetic).

Analysis that tries to address this issue of hue not being a linear dimension when cast as a first-order characteristic, requires the average colour property to be found for each shape, the average rating in shape properties for each shape to be determined, and

then for all unique pairs of shapes, to then be compared in a difference analysis based on Euclidean distances (see Watson, M.R., *et al.*, 2012, for details of the methodology). Unfortunately, when the exact procedures used by the authors are applied to the data from Experiment 3D[21], shapes which are more similar in rated angularity, symmetry, and complexity, do not result in smaller hue differences as measured in CIELAB or subjectively rated colour dimensions. Nevertheless, future researchers, will surely find inspiration in such difference analyses, which could offer new avenues for examining colour-shape associations that avoid some of the issues of continuous parameters of hue being analysed separately and open up the possibility of looking at second-order mappings of colour and shape.

As such, it may be, that object associations, affective appraisals, and the connotative meanings of shapes and colours, may be more important in colour-shape correspondences than the perceptual features of angularity, symmetry, and complexity (at least as analysed in Chapter 3). But such assertions of mechanisms, whilst well evidenced, do not save us from the fires of inconsistency. It is clear to anyone that colours and shapes can have a multitude of associations and meanings on all three of these levels, that may align or contradict one another. It is likely that individual differences, cultural differences, and even contextual and mood effects influence what

[21] Since Experiment 3D is the experiment most sensitive to individuals' differences in colour perceptions and with the largest power due to the sample size it was chosen for the preliminary analysis here.

associative node is activated most strongly in any given moment. Furthermore, it may be that individuals differ in what they are most tuned in with – is someone who is more interoceptive, more aware of the affective associations, and thus more likely to ignore object associations? Is someone less open to new experiences, more likely to focus on the task as a simple object-to-colour matching challenge? Such questions also feed into how the questions raised in Section 5.2.2.2 below are addressed.

Moreover, it appears that colour-shape correspondences are likely to be affected by other aspects of task design, most notably, the number of choices. It is unlikely to be a coincidence that exceedingly more inconsistent results are found in experiments with eight-six shapes and thirty-six colours, as in Chapter 3, than the more limited stimuli sets of Chapter 2 and 4. Additionally, tasks which require or imply that each shape should only be chosen once (as is often the case for experiments dealing with the Kandinsky shapes and colours), alter task demands which could result in other colour-shape associations than a less restrictive task. Moreover, they may again be different than the results of a 2AFC task, which might point to what colour-shape correspondences exist when dimensions are directly pitted against one another. This is not completely unexpected – Bertamini and Palumba (2016) also found that a 2AFC task (vs. a rating scale task) boosted the preference response for curvature. They suggest that one reason for this may be that the possibility of selecting the middle range is removed. Such a result is particularly relevant in the light of the evidence showing the role affective appraisals such as preference play in colour-shape

correspondences. Indeed, more differentiated results were found for the 2AFC colour-shape task than the shape-colour task in Experiment 4A.

Additionally, evidence of bidirectionality was found in Chapter 4. As the first instance of such support for colour-shape correspondences, it requires replication and investigation to determine whether such task demands may not also alter colour-shape correspondences. Specifically, bidirectionality was only tested using a 2AFC task, not using a task where one colour was presented and an entire set of shape stimuli that differed across a variety of dimensions was presented (in other words, the actual mirror of the standard shape-colour task used in Chapter 3).

Finally, it is difficult based on the research conducted for this thesis, to determine whether inconsistencies may simply be a characteristic that are more likely to arise for intramodal correspondences (vs. crossmodal correspondences) or whether instead there is something about the dimensions of colour or shape, which are having a particular influence on the variation found in the data. Exploration of the former is hampered by the lack of existing research of other intramodal correspondences. There is no particular reason why mappings between colour and shape would be more difficult to form, indeed, topographic map formation and alignment in the mammalian visual system are precisely honed developmental mechanisms (Cang & Feldheim, 2013).

Alternatively, perhaps exactly because alignment of stimuli is already organised within each sense, there is less functional need for intramodal correspondences in comparison

to crossmodal correspondences. These may, for example, serve a useful function in helping to solve the crossmodal binding problem (Ernst, 2007; Spence, 2011). However, it is prudent to note that shape and colour related crossmodal correspondences have been found for a variety of other sensory modalities (e.g., Barbiere, Vidal, & Zellner, 2007; Deroy *et al.*, 2013; Hanson-Vaux *et al.*, 2012; Sidhu & Pexman, 2018; Velasco *et al.*, 2015; Whiteford, Schloss, Helwig, & Palmer, 2018). In addition, the intramodal association between angularity and brightness (Walker, P., 2012a), is well replicated across sensory modalities, and theoretically would be an instance of a colour-shape correspondence.

Thus, maybe it is particularly the challenges presented by the metathetic attributes of colour that are adding to the inconsistent findings. Especially, as more colour options are added to a task, one-to-one mappings are bound to become messier. In addition, if inadequate statistical analyses are used which are not capturing hue as a continuous dimension, further difficulties in finding consistent replicable findings are bound to arise. Ultimately, future progress in understanding intramodal and crossmodal correspondences, their commonalities and differences, and the functions they serve, will be instrumental in determining whether the *intramodal* nature of colour-shape correspondences is adding significant variation and inconsistencies to the findings. In relation to colour and shape as dimensions, the parameterisation and number of choices seem crucial in terms of determining the amount of variation and inconsistencies they may add to the data.

In sum, there are plenty of sources of inconsistencies that can only be surmounted with clarity on what is being tested by an experiment and a critical and honest description in terms of what conclusions can be drawn about colour-shape associations from each study in turn. Since, the focus has been on explicit and direct matching experiments in this thesis, considerations noted in Section 1.2.3.2.3 will not be repeated at length. Briefly, however, inconsistencies or dissociations between implicit and explicit levels are a further burdening complexity for the theory building the field needs to do to conceptualise what colour-shape correspondences are and at which level (which ones) may exist. Ultimately, as a guide, researchers should consider if they are investigating:

- A one-to-one mapping between a shape and a specific colour;
- A mapping between a specific shape and a colour dimension rated continuously or categorically;
- A mapping between a specific colour and shape dimension rated continuously or categorically;
- An association between shape and colour dimensions rated categorically or continuously;
- A mapping or an association that depends on subjective phenomenological characterisations of colour and shape, or objectively defined measures of them.

Additionally, the colour-shape associations that are found should be qualified with clear references to what specific contexts they arose under, such as:

- The number of shapes and colours presented;
- Whether a shape was presented and a colour had to be chosen, or the other way around;
- Whether implied or stated restrictions existed on how many times a shape or colour could be chosen;
- Whether shapes were presented in the colour of choice (or vice versa) during the decision process.

Indeed, it would be illuminating to track a single individual's changes in colour-shape associations as such properties of the task are changed from one block to the next (e.g., by adding more colour choices, or restricting choices to having to use each colour only once). Finally, implicit task experiments of colour-shape correspondences should also consider the use of a broader set of shapes that are explicitly designed to test for the effect of particular shape properties.

5.2.2.2 Dealing with the tension.

Further complexities need to be addressed in order to answer the question of what makes a colour-shape correspondence. The research findings reported here mimic the tension highlighted by Street *et al.* (2016). Colour-shape correspondences, or shape-emotion associations, can be understood through the lens of replicable universal trends that allow us to say things like: curvature is associated with positive valence, angularity is associated with redness, and so on. Indeed, there is an extent to which

such universality is considered central to whether a crossmodal correspondence is considered to exist (Spence, 2011). But such statements are in competition with the mounting evidence that there are individual differences that exist at the participant-level in how individuals react to both the perceptual and affective characteristics of stimuli, such as shapes and colours. For colour-shape correspondences, and crossmodal correspondences more generally, this creates an immediate tension to universal statements of feature-to-feature associations, since there is considerable evidence for emotional and semantic mediation playing a significant role in determining these associations.

This thesis, particularly Chapter 3, has documented the importance of such individual differences in the affective appraisals of shape characteristics, which, in turn, will play a role in what colours are chosen as the strong evidence for emotional mediation of colour-shape correspondences has shown. Wrestling with this at the theoretical level in terms of why certain individual differences may alter appraisals of shapes, but also coming at shape appraisals from both objective and truly phenomenological perspectives (Albertazzi, 2015, 2018; Albertazzi *et al.*, 2017; Albertazzi & Louie, 2016), will be essential in future research of colour-shape correspondences.

Furthermore, the stimuli-dependent nature, lack of replication across experiments, alongside the high levels of individual differences in what perceptual shape characteristics predict which colour-characteristics, has revealed two things: first the

need to test a variety of shape stimuli in order to make generalisable statements about colour-shape correspondences (if they exist). Second, that the chosen perceptual shape predictors used here – angularity, symmetry, and complexity – are an inadequate parameterisation of shape if replicable shape dimension-colour characteristic associations do exist across stimuli (at the very least when shape dimensions are rated at the average-level, and not by each individual separately).

Finally, in comparison to summarising methodologies that average across stimuli items and matches, analysis that protects information at the match-by-match level can reveal that there is more variation in responses. Indeed, the increasing use of models such as LMMs in psychology and neuroscience (Magezi, 2015) that preserve such details will allow us to truly wrestle with questions raised for our conception of intramodal and crossmodal correspondences as universally held associations.

Much like there are cut-offs for intra-individual consistency in colour-grapheme associations for diagnosing synaesthesia (Eagleman *et al.*, 2007), correspondence researchers have to consider the balance between universal replicable trends and variation between individuals. This could be variation in terms of individual differences in appraisals of stimuli as well as associations between shapes and colours. This is crucial to consider for determining when an association between two features or dimensions can be considered an intramodal or crossmodal correspondence, and when it is simply a personal instantiation of an association (and whether that matters).

Questions like these are crystallised in applied fields – for example, product design for supermarkets – where miniscule changes in behaviour can have larger monetary effects if they hold true for enough of the population (Gregory Simmonds, personal communication, 25th October 2018). However, for the, arguable, lack in concrete theory of the cognitive architecture, or tests thereof, of most crossmodal correspondences or colour-shape correspondences, the question of what is a meaningful association, at what level of analysis, and with what permittable amount of individual variation, is a crucial tension that future researchers and theorists need to resolve.

5.2.2.3 Underlying mechanisms and networks.

5.2.2.3.1 Existing accounts of intramodal and crossmodal correspondences.

The above complexities raised in Sections 5.2.2.1 and 5.2.2.2, of course, also come to bear on the putative mechanisms that are hypothesised to underlie and give rise to colour-shape correspondences (and other intramodal and crossmodal correspondences). As discussed in Chapter 1, Section 1.1.4, mutually not exclusive mechanisms, such as statistical, structural, affective, and semantic ones, may underlie the existence of correspondences (Parise & Spence, 2013; Spence, 2011, 2018).

Within this network of putative mechanisms, some popular polarity-based accounts have been put forward. Proctor and Cho (2006), for example, highlight the importance

and evidence for binary representations, based on a review of a host of tasks based on binary dimensions. The authors suggest that speeded classification results can be accounted for simply by the stimulus and response alternative being coded either as positive or negative polarity, across several dimensions, thus leaving out the need for both perceptual and conceptual mechanisms to account for stimulus-response mappings.

Laura and Peter Walker's work (Walker, P., 2012a, 2012b; Walker, P., & Walker, L., 2012: Walker, L., & Walker, P., 2016; Walker, L., *et al.*, 2012) suggests that crossmodal correspondences depend on a network of bidirectional polar dimensions (e.g., light/dark, light/heavy, thin/thick, small/big), which are cross-activated by sensory stimuli across auditory, tactile, and visual domains. Their work suggests why and provides evidence for the fact that angularity is associated with brightness, hardness, and high pitch, size is associated with brightness, and low pitch is associated with the opposite polar dimensions of high pitch's associations, such as heaviness, darkness, and low elevation (see Figure 5.1 for a figure of the aligned dimensions; e.g., Parise & Spence, 2009, 2012; Walker, P., 2012a, 2016; Walker, P., *et al.*, 2015; Walker, P., Scallon, & Francis, 2017). The authors' highlight that such associations are likely driven by semantic mechanisms (Walker, P., *et al.*, 2012), grounded in connotative meanings we learn linguistically over time (this incidentally would be an account that uses both semantic and statistical mechanisms).

As P. Walker (2012a) describes: "The connotative meaning of any kind of stimulus is what it suggests, implies, or invokes, rather than what it explicitly or directly denotes" (p. 1792). In P. Walker's (2012a) account, the resulting connotative meanings are what allow a tune not to be bright but to feel bright, etc., since no claim of actual representation of a stimulus being represented as such is being made. This is interesting in particular when compared to the notion of qualia from philosophy – the 'what it is likeness' of an experience – that speaks directly to the phenomenology of our conscious experiences (for example, when in his seminal paper, Nagel, 1974, asks, what it is like to be a bat; Dennett, 1988). The importance of this 'invoked' experience was also picked up on early in psychology: Köhler in 1914 (pp. 181-182) notes that the association between pitch and lightness he experiences is not just a metaphorical one, but one that one can truly 'feel', so to speak. High pitch is not simply strung together with the separate thought of lightness, rather it is experienced as the feeling of lightness. Indeed, I believe it is often this further notion of the associated qualia – the invoked experience – that truly fascinates us in the context of intramodal and crossmodal correspondences.

Thus, the question is whether a specific connotative meaning is 'invoked' as a qualitative experience by a different feature and, if so, developing a solution for this that is not circular as P. Walker's (2012a) account arguably is (i.e. a connotative meaning is invoked because they have been shown to be associated in previous research, we learn these associations linguistically, and, thus, associations across a block of these

connotative meanings are seen in a different experimental context). Why features share connotative meanings, why should they be found in our metaphors, or be learnable by cross-use in our language, needs to be explained. Note that Proctor and Cho's (2006) coding of all dimensions along a particular polar dimension gets around this circularity better yet requires the reduction of all related feature dimensions across intramodal and crossmodal phenomena to polar dimensions of positive versus negative. This would offer a particularly simple and parsimonious account, whose ease of processing would be particularly attractive from a coding and evolutionary perspective. Nevertheless, it may be particularly complex for metathetic (vs. prothetic) dimensions, such as colour to code all responses as positive and negative.

The recoding of features along a positive-negative dimension cannot be divorced completely from the notion of valence. Yet, valence for many stimuli surely has to be contextual, and for some it is difficult to say why a particular polar dimension of a feature should be associated with approach and another with avoidance. Additionally, such an approach reduces the complexity of affective responses to an important aspect of our emotional responses and encoding, that is yet impoverished in view of most research on the function, affective space, and experience of emotion and affective appraisals (e.g., Fontaine *et al.*, 2007; Nummenmaa, Hari, Hietanen, & Glerean, 2018; Posner, Russell, & Peterson, 2005; Russell, 1980; Tellegen, Watson, & Clark, 1999).

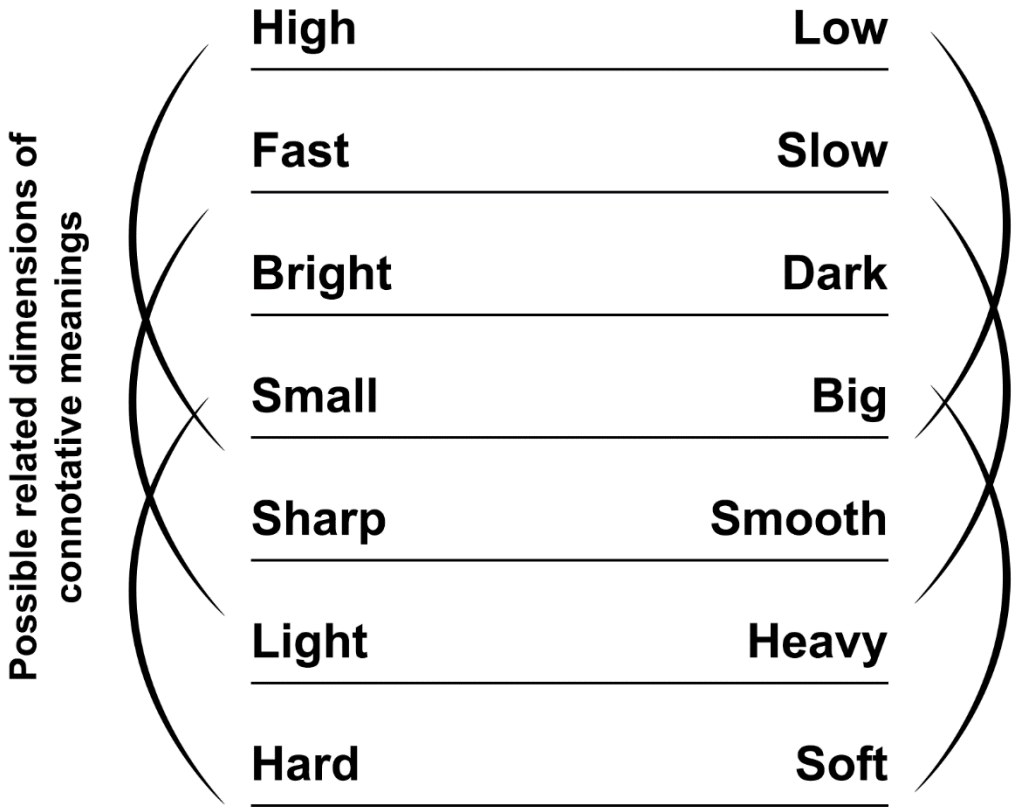


Figure 5.1 Figure showing the suggested aligned connotative meanings that could result in the different dimensions low and high pitch are aligned with according to P. Walker (2012a). P. Walker (2012a) derived the aligned connotative meanings from the work of Karwoski et al. (1942) and demonstrates in this particular paper the association of angularity with high pitch, brightness, and hardness.

Some of these associations highlighted in Figure 5.1 are likely to have sources in our physical environment – such as elevation and pitch (Parise *et al.*, 2014) and size and pitch (Evan & Treisman, 2010; Parise & Spence, 2013; Parise, 2016; Spence, 2011) – which could not only, in turn, strengthen such associations, but also be the grounding sources of the associations suggested by the Walkers and their colleagues. Such an account depending on physical realities, at least, is clear about the causal start of such associations.

It may turn out that crossmodal and intramodal correspondences are not unitary phenomena, each in their own right, or both together. But explanations that can only eke out a putative mechanism for a small number of features, are lengths away from an integrative theory of correspondences and capturing the cognitive network that could underlie them. The Walkers' account works well across auditory, visual, and tactile dimensions. But it struggles to consider other aspects of colour beyond lightness – such as hue – which have been found to have crossmodal correspondence effects with senses such as taste, olfaction, music, and, intramodal ones potentially, as investigated here, with shape (e.g., Gilbert, Martin, & Kemp, 1996; Schifferstein & Tanudjaja, 2004; Spence, 2019a; Spence *et al.*, 2015).

Indeed, as Parise (2016) notes, there may well be a large putative associative network of interconnected sensory features, far beyond what is usually assumed. Indeed, even when asking colleagues from the field of crossmodal correspondences to suggest features they considered to not share correspondences, which were then tested on 62 naïve individuals, 15 out of 28 of the pairs were shown to have consistent associations (see Figure 5.2, for the original results from Parise, 2016).

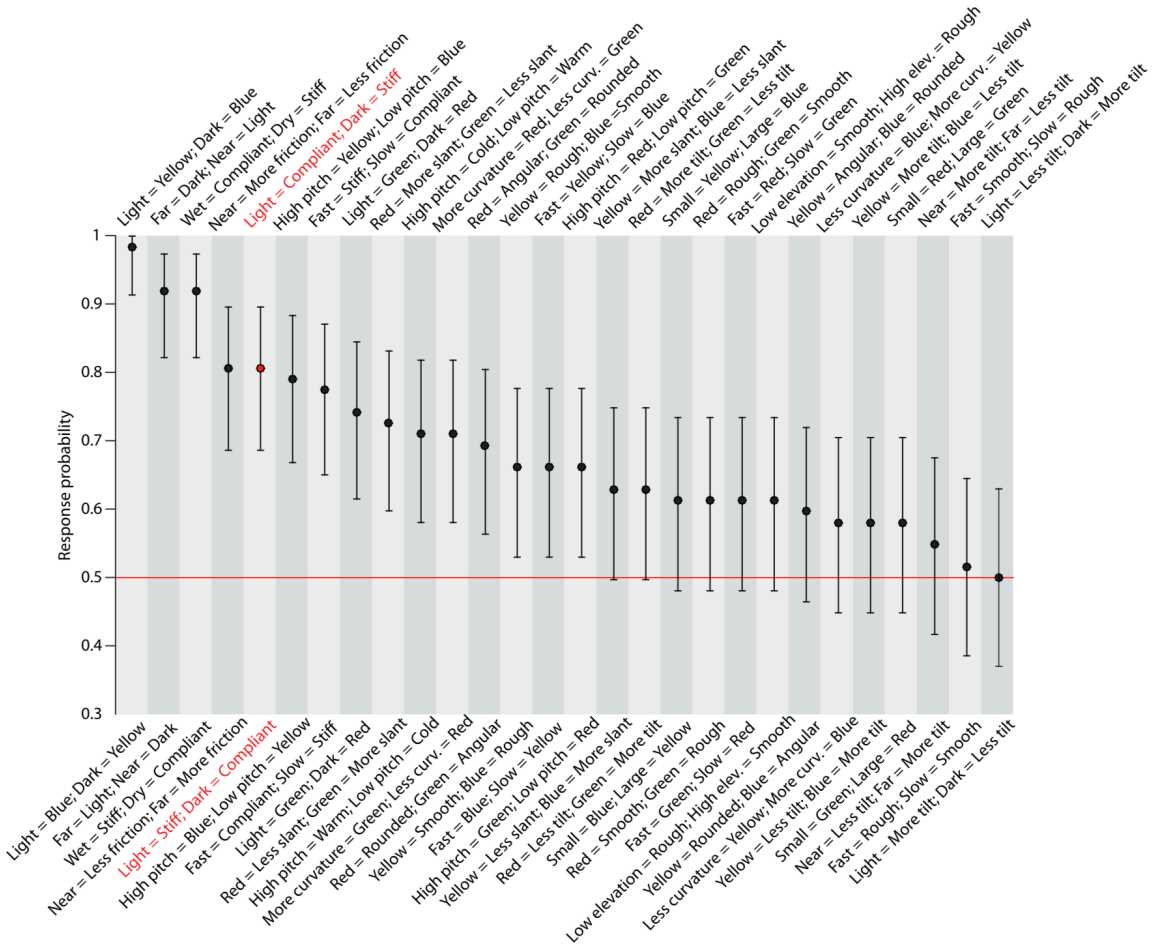


Figure 5.2 Graph from Parise (2016) replicated here with permission of the author. Error bars represent 95% confidence intervals.

Furthermore, it seems unlikely that the underlying network includes only binary polar dimensions (light or dark) rather than polar dimensions that can take into account levels of difference as well as relativity in continuous way (light to dark). The reasons for this are manifold, but a few are: first, crossmodal correspondence effects have been shown to be relative not absolute (for a review for pitch-related correspondences, see Spence, 2019c). Second, it is functionally important to be able process extents and levels of sensory, affective, and semantic features. It is, as ever, useful to remember

that our cognitive and perceptual systems need to help us survive and thrive in an ecologically valid environment, which likely does not consist of only binary tasks, like those Proctor and Cho's (2006) account leans on exclusively. Third, some sensory features are not easily represented as binaries: Colour processing may be dependent on colour opponent cortical processing, as noted previously, of yellow/blue and red/green, but hue, and colour more broadly, is not a one variable feature. Either intramodal and crossmodal correspondences depend on a system built on polar dimensions alone, or colour-shape correspondences such as the one found between pink and roundedness, need to be accounted for in a way that does not rely on binary features. In some ways, such a question is related to the theoretical challenge of how correspondences are conceptualised – suggesting binary polar dimensions is akin (though not identical) to creating one-to-one mappings.

Finally, and crucially, cortical organisational principles do not have to depend solely on ON-OFF connections between representations, but node to node strengths or, potentially, coded distances across a network of features can be interpreted as continuous and dynamically changing measures of association strength. There may be important tipping points there (e.g., when processing of two sensory features is so associated that they can reduce RTs in implicit paradigms, when a system will under threat interpret something in the blink of an eye as safe or not). Nevertheless, it seems short sighted to put too much emphasis on reinterpreting all sensory features as positive or negative as Proctor and Cho (2006) suggest, when it is far more likely that

a dynamic, complex, associative network that is constantly adjusting node weights could account for intramodal and crossmodal correspondences.

To make progress in terms of conceptualising intramodal and crossmodal correspondences and to link these with potential models of representation at both the neuronal and computational level, it is this author's suggestion to integrate the field with the areas of subjective similarity and representational geometry – two concepts which are sides of the same coin.

5.2.2.3.2 Subjective similarity and representational geometry.

At the heart of these concepts lies the fundamental notion of representation (Dennett, 1987), which offers a tractable response to the problems of cognition and consciousness within the context of the biological reality of the brain, by offering the building blocks of cognitive information processing. A representation, as Kriegeskorte and Kievit (2013) point out, can be anything from a sensory experience (e.g., an odour, taste, or colour), a semantic or affective interpretation of that experience, as well goals, actions, and the initiation of motor reactions. Thus, making it an explanatory account ideally suited to the conceptual analysis of intramodal and crossmodal correspondences. Crucially, populations of neurons in functional areas are considered to encode such information in neuronal population codes (Averbeck, Latham, & Pouget, 2006). The notion of representational geometry is summed up neatly by Kriegeskorte and Kievit

(2013), who offer an excellent review of the topic for the interested reader, which will be leaned on heavily here:

> We can think of a brain region's representation as a multidimensional space. The dimensions of the space correspond to the neurons, and a point corresponds to an activity pattern (i.e., each neuron's activity provides the coordinate value for one of the dimensions). A visually perceived object, for example, will correspond to a point in the representational space of a given visual area. The set of all possible objects (or pieces of mental content) corresponds to a vast set of points in the space. It is the geometry of these points that defines the nature of the representation. . . .
>
> To characterize the geometry of a representation, we can compare the brain-activity patterns representing a set of stimuli (or, more generally, experimental conditions) to each other. The dissimilarity of two patterns corresponds to the distance between their points in the representational space. Having measured these distances, we can construct a matrix, the representational dissimilarity matrix (RDM), in which we can look up the representational distance (or dissimilarity) for each pair of stimuli. . . . Intuitively, the RDM tells us which distinctions between stimuli the population code honors and which distinctions it disregards. (p. 401)

Both behavioural, cognitive, and neural paradigms have now been used to examine this notion of representational geometry (see Kriegeskorte & Kievit, 2013, and references therein), where similarity or dissimilarity between two representations can give us a handle on their subjective similarity, the categories inherent in our cognitive architecture, which may divide or unite them, as well their location along continuous dimensions. Indeed, the notion of representational geometry and its phenomenological counterpart of subjective similarity have been contentious topics of debate in psychology for several decades, especially in terms of the complexities that arise in the parameterisation of similarity (Goodman, 1972; Pothos, Busemeyer & Trueblood, 2013;

Tversky, 1977). Tversky (1977), for example, famously demonstrated that formalising similarity at the cognitive level of interpretation as a simple measure of linear distance is insufficient. However, the field of similarity has been concerned predominately with the exactly those features and perceptual systems most crucial to colour-shape correspondences, such as the representation of shape (e.g., Edelman, 1998).

As Kriegeskorte and Kievit (2013) review in more detail, representational geometry at the neural level has been shown to be key in understanding the visual system in humans (but also monkeys in some cases) from low-level to higher-level processing areas, and to be superior to single-cell interpretations in some cases (Hegdé & Van Essen, 2007). Representational geometry has been shown to be a successful interpretation of representations of symbols and visual patterns (Hegdé & Van Essen, 2007), natural textures (e.g., Groen, Ghebreab, Lamme, & Scholte, 2012a, 2012b), colour (e.g., Brouwer & Heeger, 2009), 2D and 3D shapes (e.g., Drucker & Aguirre, 2009; Haushofer, Livingstone, & Kanwisher, 2008; Op de Beeck, Wagemans, & Vogels, 2001; Yamane, Carlson, Bowman, Wang, & Connor, 2008), animate versus inanimate categories (Looser, Guntupalli, & Wheatley, 2012; Mahon, Anzellotti, Schwarzbach, Zampini, & Caramazza, 2009; Mormann *et al.*, 2011), human/non-animals and manmade/natural objects categories (Mur *et al.*, 2013), properties of natural scenes (e.g., Kravitz, Peng, & Baker, 2011; Walther, Beck, Fei-Fei, 2012; Walther, Caddigan, Fei-Fei, & Beck, 2009; Walther, Chai, Caddigan, Beck, & Fei-Fei, 2011), faces (Freiwald & Tsao, 2010; Kanwisher, McDermott, & Chun, 1997; Kietzmann, Swisher,

König, & Tong, 2012), facial expressions (Peelen, Atkinson, & Vuilleumier, 2010; Said, Moore, Engell, Todorov, & Haxby, 2010), perceived emotions, and even similarities between visual mental imagery and actual visual perception (e.g., Cichy, Heinzle, & Haynes, 2012; Stokes, Thompson, Cusack, & Duncan, 2009). Such evidence highlights how:

> Studies of the geometry of visual representations have impressively documented the stage-wise transformation of the retinal image from low-level representations of local physical features to high-level holistic representations of objects, faces, and scenes that better reflect perceptual qualities, emphasizing behaviorally important categories and semantic dimensions and deemphasizing accidental and behaviorally irrelevant variation of the visual input. (Kriegeskorte & Kievit, 2013, p.408)

It is clear that from the perspective of colour-shape correspondences, in particular, the evidence for representational geometry at the behavioural and neural level, makes it an ideal candidate for a theoretical and computational account of associations between colours and shapes. Importantly, though, representational geometry and subjective similarity have also been found to be applicable to other senses, such as auditory and olfactory senses (Chang *et al.*, 2010; Giordano, McAdams, Zatorre, Kriegeskorte, & Belin, 2012; Howard, Plailly, Grueschow, Haynes, & Gottfried, 2009). Further it appears to extend to other levels and functions of cognition, such as memory, typicality, stimulus and response generalisation, categorisation, discrimination, attentional mechanisms, problem-solving, as well as action and motor control (Davis, Xue, Love, Preston, & Poldrack, 2014; Davis & Poldrack, 2013; Duncan & Humphreys,

1989; Edelman, 1998; Goldstone, 1994; Jiang, Lee, Asaad, & Remington, 2016; Kriegeskorte & Kievit, 2013; Kriegeskorte, Mur, & Bandettini, 2008; Novick, 1988; Polyn, Natu, Cohen, & Norman, 2005; Schurger, Pereira, Treisman, & Cohen, 2010; Shepard, 1958, 1987; Xue *et al.*, 2010; Yassa & Stark, 2011).

Moreover, representational geometry can account for general trends across populations: evidence shows that, for example, visual representations are generally shared across individuals (Haxby *et al.*, 2011; Raizada & Connolly, 2012; Shinkareva, Malave, Just, & Mitchell, 2012). However, there is also evidence that representational geometry can capture crucial individual differences: Charest, Kievit, Schmitz, Deca, & Kriegeskorte (2014), for example, found evidence that individual's unique semantic categorisation of objects and, as such their subjective perceived similarity, was predicted by the dissimilarity in representational geometries of neural activity patterns of each individual. There is also evidence that the space of affective representations can also be captured using representational similarity analysis (Nummenmaa *et al.*, 2018). Moreover, it has been found that associative learning of exemplar-shock combinations, increases similarity of neural patterns, and that such neural patterns predict the later expression of such fear memories (Visser, Scholte, Beemsterboer, & Kindt, 2013; Visser, Scholte, & Kindt, 2011). Such evidence indicates that the emotional mediation of correspondences could also be captured by a representational geometry account of similarity.

What is particularly fascinating is that representational geometry accounts still have to deal with many of the same standing questions which a model of intramodal or crossmodal correspondences would face (for an extended list, see Box 3 in Kriegeskorte and Kievit, 2013). The question of how individual differences can affect unique responses mirrors our discussion and investigation above of how differences between individuals may affect shape and colour appraisals, the experience of the matching task, and further, colour-shape correspondences themselves. The question of whether certain mental health conditions or impairments could result in atypical representational geometries, is just as instrumental in understanding how the associative network of correspondences and feature appraisals may be affected by, for example, autistic or alexithymic traits. The question of whether feature-based similarity models can help us interpret neuronal codes in the same way that a geometric model of similarity judgments can, would be crucial in understanding the relationships between correspondences and feature-based perceptual predictor causal mechanisms. Finally, the question of how such transformations of representational geometry and similarity occur between levels is as crucial for our model of intramodal and crossmodal correspondences that appear to be influenced by perceptual, affective, and semantic mechanisms at various levels of cognitive processing.

Other similarities exist beyond this: Spence (2015), for example, suggested that crossmodal correspondences could be thought of as akin to crossmodal grouping by similarity. In addition, the focus on similarity as well as the second-order nature (see

Shepard & Chipman, 1970), that avoids first-order correspondence mapping, is similar to the methodology seen in M.R. Watson *et al.* (2012) noted above, and thus, may explain why this level of analysis is more fruitful in some case for the field of grapheme-colour synaesthesia. Most importantly perhaps, representational geometry allows for a dynamic associative system, which, as discussed below, is necessary for an integrative account of intramodal and crossmodal correspondences.

Yet, operationalising subjective similarity of stimuli is difficult, and requires enormous effort and number of ratings to compare stimuli with one another. Even when such research is conducted for shape stimuli, for example, by Li, Liang, Lee, and Barense (in press), it is unclear whether this would be useful for colour-shape correspondences, since capturing subjective similarity between shapes that truly cover a reasonable number of ways shapes can vary would be immensely difficult. Indeed, Li *et al.*'s (in press) attempt to create circular shape space of subjective visual similarity is an interesting and commendable starting point. However, it is, in its current form, wholly unsuited to understanding shape with the level of complexity colour-shape correspondence researchers would be interested in, since the shapes only vary along so few dimensions of shape characteristics.

Here lies the rub: accepting that similarity is a coding and organising principle of the cortex that is likely to influence correspondences does not reveal along what dimensions our cognitive architecture is comparing stimuli along, be they sensory, perceptual,

emotional, or semantic. Thus, creating the stimuli that capture subjective similarity is immensely difficult (even disregarding the unwieldy number of comparisons required to even map out a relatively small stimulus space, though see Kriegeskorte & Mur, 2012, and Li *et al.*, in press, for advances and developments in methods of eliciting similarity and dissimilarity judgments). It follows that making conclusions beyond subjective similarity in stimuli that vary in features X, Y, Z, does not leave us with many more insights that traditional notions of what perceptual or affective mechanisms predict and mediate colour-shape correspondences before further research.

Not that such traditional notions leave us with uninteresting findings about what features predict affective reactions and connotations across sensory modalities: Sievers, Lee, Haslett, and Wheatley (2019), for example, show that emotional arousal is signalled and perceived consistently on the basis of a low-level feature multisensory-code – the spectral centroid – in auditory stimuli like sounds and speech, shapes, and even body movements. In fact, all current research on what causal mechanisms have been shown to influence intramodal and crossmodal correspondences are indicative of what level of complexity is needed to create an all-encompassing blueprint for a dynamic associative network and process that can be applied across all intramodal and crossmodal correspondences.

5.2.2.3.3 A dynamic representational geometry associative model of intramodal and crossmodal correspondences.

It can feel like even the most excellent of reviews of what causes may exist for correspondences (e.g., Sidhu & Pexman, 2018), make it feel like these are simple phenomena we can find neat explanations for. Even hardened statistical regularities detectable in the environment (e.g., elevation-pitch, size-pitch), are adapted and held alongside new information that we are associatively learning all the time, even between these features. Even elegant explanations as those associating a variety of polar dimensions such as lightness, weight, pitch, and size, that work beautifully across sensory dimensions (e.g., Walker, P., 2012a), can at best only be a small beam of a torchlight at what must be going on 'under the hood', so to speak, of intramodal and crossmodal correspondences. Determining whether crossmodal correspondences that rest on a continuous dimension of similarity are the same or different to one to one mappings of colour and shape (and how they relate to one another), is a challenge before the potential transitivity and interconnection between correspondences that has been suggested to exist in some cases is considered (e.g., Walker, P., 2012a; Walker, P., & Walker, L., 2012; Walker, P., 2016; and yet not others, see, for discussion of the issue, Deroy *et al.*, 2013) and how these stimuli maps or maps of similarity are connected, compared or superimposed.

The question of what correspondence wins out in our explicit or implicit paradigms, is likely to be dependent on statistical, structural, affective, and semantic mechanisms which are not mutually exclusive. However, in addition, they need to derive from a system that can dynamically integrate these notions, at any given point, under specific goal or motivational states (e.g., under time pressure in an IAT paradigm or under lengthy creative reflection when choosing the perfect colour for a painting's feature). As such, below is presented, not an answer to what network or networks underlie intramodal and crossmodal correspondences based on tested hypotheses. Rather it is, for some, the echo of a lingering nightmare, and for others, a call to arms to truly consider what we mean when we speak of intramodal and crossmodal correspondences.

Ultimately, subjective similarity and representational geometry are key potential explanatory mechanisms for an integrative framework of intramodal and crossmodal correspondences. They are not panaceas to our causal mechanism woes nor are they likely to be the only coding mechanisms we need to understand concerning the representation of correspondences and perception more generally. Much work lies ahead in determining the architecture, key dimensions, peculiarities of comparing similarity (e.g., Kriegeskorte & Mur, 2012; Tversky, 1977), and how perceptual features (e.g., angularity, complexity, symmetry, balance, the central spectroid, etc.) are combined with both affective (valence, arousal, potency, etc.) and semantic connotative meanings and compared across modalities and levels of representation. Since extensive work has been done looking at representational geometry at the neural

level, such an account serves as a starting point for verifying intramodal and crossmodal correspondences using a new methodology, at a different level of analysis. Indeed, on some level, it offers a learning tool for which representations of features may be crucial for a correspondence when explicit, implicit, and neural paradigms from both the fields of representational geometry and crossmodal correspondences are combined (e.g., Kriegeskorte & Kievit, 2013; Kriegeskorte & Mur, 2012; Kriegeskorte *et al.*, 2008; Parise, 2016; Spence, 2011).

Moreover, as the name implies, it is a concept that can capture both phenomenological notions of how we perceive the world subjectively, and also capture individual differences in responses at the computational level of representation. As such, in sum, representational geometry may well play a vital role in how crossmodal and intramodal correspondences are instantiated and evaluated. To be clear, subjective similarity and representational geometry represent the current state of representations within our cognition architecture that is dynamically learned by means of a variety of inputs, such as the statistical regularities in the environment, our reactions to the environment, as well as the monitoring of our embodied responses to our internal and external environment. In the context of cognition and the blueprint for a dynamic representational geometry associative account of intramodal and crossmodal correspondences, the representational geometry of dissimilarities between representations serves as a principle of comparison across internal layers of our cognitive architecture.

Table 5.1 builds a multi-layered cake of complexity of the inputs, internal levels of cognitive architecture, outputs, and the vertical linkages that exist between them which must be considered, at least in passing, and arguably in detail, when the causal mechanisms of correspondences are considered. Its structure is, on some level, invariant to which principles of cortical organisation and form of representation we are referring to when a sensory feature, an emotion, or semantic concept is mentioned. However, associative learning mechanisms, the explanatory account of representational geometry and subjective similarity, as well as the required predictive functionality of our perceptual, emotional, and symbolic systems are likely to be fundamental in the structure and instantiation of the hypothesised model. Nevertheless, here, they present nothing more or less, than hypotheses that need to be tested. The cognitive architecture that is suggested, the instantiations of each level, the encoding information, the causes, the results, encoding factors, and activating factors, are based on research findings, psychological theories, and an encompassing view of the field of intramodal and crossmodal correspondences, to the current author's best knowledge based on the literature referenced throughout this thesis (see Section 7). Such a structure attempts to account for the possibility of transitivity, multiple influences on each probing of a crossmodal and intramodal correspondence, as well as universal trends and individual differences.

Furthermore, the suggested network of association and activation of sensory features and their connectome of affective and semantic nodes highlights, why colour-shape

correspondences may be the source of so much variation. Shape and colour represent so much in our world. As visually dominant creatures (under most conditions at least; see, for a review, Witten & Knudsen, 2005; Botvinick & Cohen, 1998; Hartcher-O'Brien, Levitan, & Spence, 2010; Pavani, Spence, & Driver, 2000; though also consider, Alais & Burr, 2004; Hecht & Reiner, 2009; Morein-Zamir, Soto-Faraco, & Kingstone, 2003), shape and colour are what literally give form to our (visual) reality. They are resplendent with a multitude of associations and information at each input level. This is likely to be reflected in a less differentiated structure at the cognitive level, with high levels of inter-individual variation that could be caused by individual differences in representational geometries at the affective and semantic level for shape and colour features, context effects, as well as task demands. Thus, it may require restricted task demands with well-chosen stimuli such that statistical regularities are more cohesive at the affective and semantic level, which in turn reveal polar ends of *activation patterns*[22] of these affective and semantic networks. Only then may it be possible to find replicable sensory feature-sensory feature colour-shape associations across experiments. Finally, the vertical linkages make clear that such a system cannot be interpreted bottom-up or top-down but needs to be treated as a dynamic system with constant realignments and interplays between levels. It has not only internal

[22] This is at odds with the notion of simply activating a polar dimension or several polar dimensions on one cognitive level (e.g., affective), but rather leaves space for summing of activations within and across all levels of representational geometry of features and functional areas.

feedback loops and but also some which cross the boundary of the entity of the individual.

Table 5.1 A table representing a putative underlying network for the existence of intramodal and crossmodal correspondences.

CAUSES	STRUCTURES AND INSTANTIATIONS	VERTICAL LINKAGES	ENCODING FACTORS	RESULTS
INPUT LEVEL				
Statistical regularities in the physical environment				
- Physics - Biology - Evolution - Human-mediated reinforcement (we might create things which are more congruent, and thus re-create such statistical regularities in the environment).	- Elevation–pitch - Elevation–lightness - Pitch–size - Angularity–darkness/contrast - Objects–colour - Taste–colour.	- Current state of cognitive architecture directs attentions and creates expectation states in perceiving regularities.	- Feature sensitive cognitive and neural systems - Associative learning principles - Encoding information (e.g., current context, motivational state, goal state) - Individual differences in perceptions, reaction, and cognitive representations.	- Associative links: Changes in weights of and distances between nodes in cognitive architecture level.
Statistical regularities in reactions to physical environment and experience of stimuli				
- Innate reactions - Learned reactions - Embodied cognition and perception of physiological	- Sharp angles–threat, alertness, pain - Red–alertness, sweetness, pain, threat - Softness–pleasure - Roughness–pain, displeasure	- Current state of cognitive architecture directs attentions and creates expectation states in	- Motivational states - Cognitive load - Task framing - Feature sensitive cognitive and neural systems	- Associative links: Changes in weights of and distances between nodes in cognitive

emotional states.	- Objects–conceptual categories (e.g., curved nudes–sexuality) - Objects-emotional appraisals (e.g., gun–threat) - Facial expressions signal emotions and intent - Semantic activations by sensory stimulus (e.g., short small sound, activates short and small conceptual associations) - Physiological state when perceiving or creating sensory stimulus.	perceiving regularities.	- Associative learning principles - Encoding information (e.g., current context, motivational state, goal state) - Symbolic representation system - Individual differences in perceptions, reaction, and cognitive representations.	architecture level.
Affective and semantic human-mediated reinforcement				
- Language-use - Art e.g., Literature, poetry, music - Creativity, innovation, exploration, curiosity, - Need to create art - Need to express ourselves.	- Emotion-emotion, semantic-semantic, emotion-semantic, and sensory/percept/object–emotion/semantic links - Learned metaphors and analogies.	- Cognitive architecture structures and their implicit, explicit, and phenomenological outputs across human development.	- Motivational states - Cognitive load - Task framing - Feature sensitive cognitive and neural systems - Associative learning principles - Encoding information (e.g., current context, motivational state, goal state) - Symbolic representation system - Individual differences in perceptions, reaction, and cognitive representations.	- Associative links: Changes in weights of and distances between nodes in cognitive architecture level.

COGNITIVE ARCHITECTURE				
CAUSES	**STRUCTURES AND INSTANTIATIONS**	**VERTICAL LINKAGES**	**ENCODING & ACTIVATING FACTORS**	**RESULTS**
Dynamic affective network that links emotions-emotions and emotions-features/objects				
- Functional links between sensory processing areas and affective responses - Functional links between affective and sensory representations.	- Emotions arranged with strong links across key affective responses (e.g., liking, arousal) - Sensory features are linked to affective appraisals and emotional reactions more broadly such as embodied effects (strong effect) - Memories of physical instantiations (e.g., objects) linked to affective responses (e.g., a scent – safety, sexual arousal, positive or negative valence).	- Sensory features linked to sensory features associated with the same emotion (weaker effect).	- Cortical organisational principles (e.g., aligning of stimuli maps) - Encoding information (e.g., current context, motivational state, goal state) - Bayesian principles of prediction - Individual differences in perceptions, reaction, and cognitive representations.	- Effects at all output levels based on node strengths and/or representational distance (includes effects of categorisation, generalisation, typicality, and hierarchies).
Dynamic semantic network that builds conceptual knowledge network that links features, objects, and conceptual information				
-Underlying symbolic and semantic processing system with links to sensory representations.	- Memory system of our semantic architecture that learns hierarchies, categories, exemplars, prototypes and their association for objects and semantic meanings (e.g., soft-gentle-careful) - Sensory features linked to semantic label or meaning (strong) - Memories of physical instantiations (e.g., objects) linked to	- Sensory features linked to sensory features associated with the same semantic association (weaker effect).	- Cortical organisational principles (e.g., aligning of stimuli maps) - Encoding information (e.g., current context, motivational state, goal state) - Bayesian principles of prediction	- Effects at all output levels based on node strengths and/or representational distance (includes effects of categorisation, generalisation, typicality and hierarchies).

	semantic categories and meanings (e.g., book-knowledge, muscle-strong, velvet-soft).		- Individual differences in perceptions, reaction, and cognitive representations.	
Dynamic links between sensory features and perceptual processing areas				
- Innate and dynamic associative network that can access sensory, affective, and semantic representations - Functional links between sensory processing areas - Functional links to motor sequence and action control representations.	- Replicated effects of crossmodal and intramodal correspondences (e.g., sound symbolism Bouba/Kiki effect).	- Emotion-emotion, emotion-semantic, and semantic-semantic associations strengthened between those sensory features that are linked.	- Cortical organisational principles (e.g., aligning of stimuli maps) - Encoding information (e.g., current context, motivational state, goal state) - Bayesian principles of prediction - Individual differences in perceptions, reaction, and cognitive representations.	- Effects at all output levels based on node strengths and/or representational distance (includes effects of categorisation, generalisation, typicality and hierarchies).
OUPUT LEVEL				
CAUSES	**STRUCTURES AND INSTANTIATIONS**	**VERTICAL LINKAGES**	**ACTIVATING FACTORS**	**RESULTS**
Implicit: Predictive and Perceptual Effects				
- Representational distance of functional links created across all levels of cognitive architecture levels.	- Faster RTs to congruent stimuli in implicit paradigms - Activation of varied structures aspects of affective states, including embodied experiences of emotion through increased activation of these through isolated	- Strong vertical linkage with both to the phenomenological and explicit output levels. - Predictions, whether met or not within certain contextual,	- Context - Goal states - Motivational state - Task demands - Mood - Personality and other individual differences	- Creation of expectation states and priming of moods - Use of predictive information from all cognitive levels to help with multisensory

	associated presented stimuli (e.g., colour) or congruent stimuli (e.g., coloured shape).	motivational, or goal states can in turn adjust cognitive architecture levels accordingly for future predictions.	- Meta-cognitive (e.g., what would others answer, confidence) - Expectation effects - Individual differences in perceptions, reaction, and cognitive representations.	integration and sense-making - Ease of generation - Motor sequences and actions.
Explicit: Behavioural				
- Subjective similarity across cognitive architecture levels based on representational distance.	- Direct matching behaviour - Explicit behaviour congruent with semantic or affective states as a result of increased activation of them through presentation of sensory stimuli in isolation, or in congruent combinations.	- Output at the implicit and phenomenological levels - Expectation effects created by current state of cognitive architecture. - Feedback mechanisms to cognitive architecture levels that can strengthen or weaken links, especially if behaviour is particularly salient, memorable, or successful within task demands - Feedback into affective and semantic human-mediated reinforcement level - Feedback into encoding contexts of new linkages if, for example, a	- Context - Goal states - Motivational state - Task demands - Mood - Personality and other individual differences - Meta-cognitive (e.g., what would others answer, confidence) - Expectation effects - Individual differences in perceptions, reaction, and cognitive representations.	- Act of creating multisensory linkages in language and art, as listed below for the phenomenological level. - Motor sequences and actions.

		particular emotional state is induced.		
Phenomenological: Experience, and affective/semantic state induction				
- Subjective similarity across cognitive architecture levels based on representational distance.	- Connotative links between sensory features (e.g., this tune 'feels' bright) - Phenomenological matches between sensory features - Changes in feelings or mood based on co-activation of sensory features (e.g., congruency–harmonious feeling, incongruency–on edge, two sensory features with strong positive valence – stronger affective responses that can be experienced at various levels of emotional response).	- Expectation effects created by current state of cognitive architecture. - Feedback mechanisms to cognitive architecture levels that can strengthen or weaken links, especially if phenomenological experience is particularly salient - Feedback into affective and semantic human-mediated reinforcement - Feedback into encoding contexts of new linkages if, for example, a mood is induced.	- Context - Goal states - Motivational state - Task demands - Mood - Personality and other individual differences - Meta-cognitive (e.g., what would others answer, confidence) - Expectation effects - Individual differences in perceptions, reaction, and cognitive representations.	- Richness in multisensory experience - Intuitiveness and confidence in matching tasks between sensory features Ability to create, understand, and emotionally react to: - Metaphor, similes, etc. - Music, poetry, and other artistic pursuits. - Cross-sensory influences and experiences of food and drink.

So, how would such multi-layered and complex dynamic representational geometry associative model of colour-shape correspondences function? A variety of inputs – such as, from the environment as well our internal responses to it – offer statistical inputs for our associative network that can change the location of representations within a

multidimensional space within each cognitive layer, but also, by association, through vertical linkages between them. When similarity is summed across associations of colours and shapes – be they affective, semantic connotation, semantic categories, or specific object – as a measure of dissimilarity or similarity in representational geometry, this would offer a measure of likelihood that a particular shape and colour are elicited in an explicit matching task. Furthermore, as noted above, the system of representation geometry would similarly be able to account for the location of representations and their associations along continuous dimensions. Moreover, it may be that such a system could account for differentiation of correspondences (e.g., between the explicit and implicit level), in terms of distance of similarity across the suggested levels, but also potentially, with putative further associations with motor sequences and action control that are learned or innate for specific sensory features or affective response that are similarly represented further apart or closer together in a multidimensional representational space.

5.3 Final Thoughts

The dreaded questions are: Do colour-shape correspondences exist, and if so, what are they? As has been made clear, the conceptualisation of what makes a correspondence can be crucial here. This is tightly linked with both the importance and leeway chosen to be given to individual differences and variation, our choice of level of analysis, as

well as how both colour and shape are conceived of and parameterised. This thesis has shown that surprisingly consistent associations can be found when stimuli sets and task demands are restricted like in Chapter 2 and Chapter 4. But, similarly, Chapters 1 and 3 highlighted the dirty underbelly of colour-shape correspondence research, and the inconsistencies that are often too easy to ignore in introductions and analyses when our focus lies simply on confirming trends rather than squaring them with the messy data, outliers, and falsifications that the research to date confronts us with. This does not mean the hypothetical colour-shape correspondence baby needs to be thrown out with the bathwater. Rather, it requires us to awaken to the complexities of colour-shape associations, refine our theories in the light of these subtleties, and test these new demarcated hypotheses more carefully (consider, for example, Earp & Trafimow, 2015; Popper, 1959).

As such, colour-shape correspondences may exist, but the exact associations and whether you are able to replicate them will depend strongly on a variety of variables, from number of choices and task demands to your choice of statistical analysis and parameterisation of colour and shape. It is simply, as of yet, not possible to make statements about colour-shape correspondences backed up by replicable findings about how perceptual predictors systematically affect associations like is possible, for example, for sound symbolism effects like Bouba-Kiki (Chen, Y.-C., *et al.*, 2016; Cuskley *et al.*, 2017; Fort, Martin & Peperkamp, 2015; Nielsen & Rendall, 2011, 2013;

Sidhu & Pexman, 2018; Turoman & Styles, 2017; for context of the Bouba-Kiki effect, see Köhler, 1947; Ramachandran & Hubbard, 2001b).

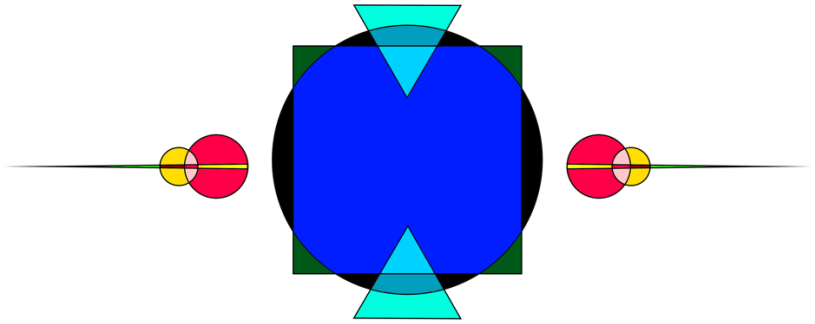
What is clear is that colour-shape correspondences are not solely an object-association driven phenomenon, but also affected by a range of interconnected associations that individuals use to match colours and shapes so they are more congruent in terms of their affective appraisals (e.g., liking and arousal), aesthetic judgements (e.g., beauty), and a host of other semantic and linguistic associations. The associative learning over a lifetime, from an early age, potentially aided by innate processes and structures (such as identifying threat and symmetry quickly and efficiently), likely result in a complex network of interconnections between perceptual features and dimensions.

Whether sensory and structural associations exist at the physical neural, coding, and functional level, in addition to the instantiation of this putative associative network, is as yet of unclear for colour-shape correspondences (as it is for intramodal and crossmodal correspondences at large). The research is still limited, as well as mixed, over the effect colour-shape correspondences can have on sensory processing (see Spence, 2011 for how such processing benefits of crossmodal congruency form the bedrock of theorising about other correspondences). The use of natural scene statistic and neuroimaging studies have aided in our understanding of other crossmodal correspondences (e.g., Parise *et al.*, 2014; Revill, Namy, DeFife, & Nygaard, 2014), and may yet do so for colour-shape correspondences. Especially in regard to deciphering

the difficulty perceptual predictors alone have in predicting colour characteristics, natural scene statistics may offer a useful insight into the sources of our associative learning at the fine-grained feature level. But it will be crucial for neuroimaging and implicit studies to be starkly aware of the individual differences and variation that exist in colour-shape correspondences, especially as a function of stimuli and task demands. Thus, caution is urged, for example, to not only probe implicit associations for assumed colour-shape correspondences, but rather to also test them on associations established for each individual separately.

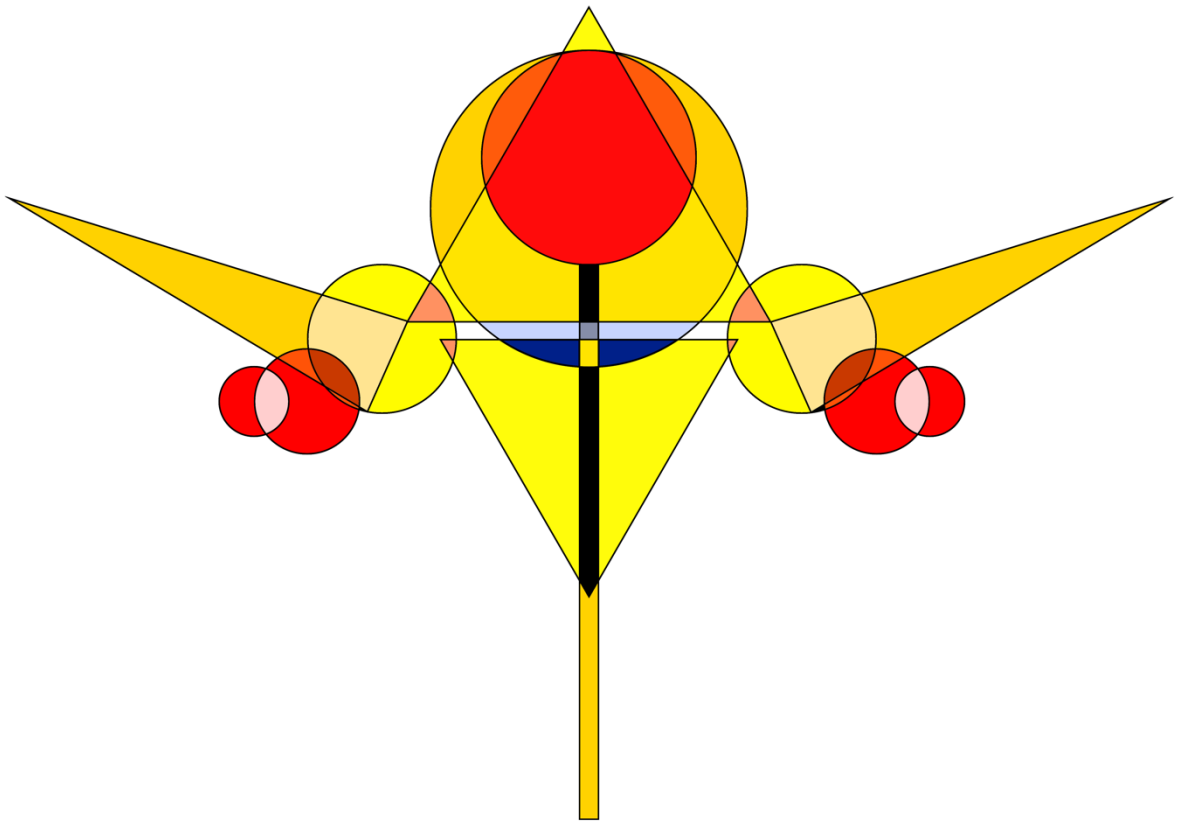
The success of the affective, semantic, and linguistic mechanistic accounts of colour-shape correspondences and other crossmodal correspondences (e.g., Malfatti, 2014; Martino & Marks, 1999; Palmer, Schloss, Xu, & Prado-León, 2013; Schifferstein & Tanudjaja, 2004; Velasco *et al.*, 2015; Walker, P., 2012a; Wang *et al.*, 2016, though see Woods *et al.*, 2013), leaves open questions of exactly how this network is instantiated – a non-trivial problem as discussed and hopefully illuminated, at least partially, in 5.2.2.3 above through presenting a dynamic representational geometry associative model of correspondences. But this is important work for future researchers and theorists: How this connectome of sensory, perceptual, affective, semantic, conceptual, and linguistic associations functions is crucial to understanding the nature of intramodal and crossmodal correspondences. Not only this, but it is likely to be a defining feature of our cognitive architecture for understanding and determining the richness, complexity and multisensory interplays that make up our personal

phenomenological experience and ways of processing the endless array of stimuli that bombard our senses. It is this deeply interconnected phenomenological network that helps gives rise to the creativity, art, metaphor, and poetry that we can create and then share to connect and empathically communicate with others about experiences. Such correspondences and associations help us besiege and overcome the theoretical and felt isolation of the solipsism of our consciousness and perception, thus not only enriching our own lives but helping us to better convey the kaleidoscope of experiences that stimulate our senses and perceptions.



"What is essential in the sensuous-perceptible is not that which separates the senses from one another, but that which unites them; unites them among themselves; unites them with the entire (even with the non-sensuous) experience in ourselves; and with all the external world that there is to be experienced."

Von Hornbostel, The Unity of the Senses, 1927/1950, p. 214



6 Appendix

6.1 Original 1923 Kandinsky Questionnaire

Although the original questionnaire cannot be replicated here due to copyright reasons, it does appear that the Bauhaus-Archiv Berlin does still hold at least one original filled-out version of the questionnaire. Only around three to five filled-out completed copies of the original exist today it appears from online and book research and the one translated below is the only version that I have seen used in academic books and papers (e.g., Gage, 1993).

A full verbatim translation of the entire document is offered below as this is rarely provided. The survey states:

> Specialty (job): ___ Gender: ___ Nationality: ___. The workshop for wall-painting in the national Bauhaus Weimar asks for completion of the following questions for the experimental purposes of the workshop. 1. Fill out the three drawn shapes with three colours – yellow, red, and blue – such that each shape is completely filled by one colour. 2. If possible give an explanation for these choices. Explanation: ___.

It should also be noted that unlike shown in Kandinsky (1923/1994, p.850), the shapes are shown with triangle and square in the top row, to the left and right, respectively, and the circle below and in the middle of the two (see Figure 2.1 for a close simile of the arrangement).

One questionnaire, depicted in Gage (1993)[23], is filled-out by a student called Alfred Arndt who "explains that he has chosen yellow triangle for its flame-like nature, a red square for its solid yet attacking defensiveness, and a blue circle for its intensely closed, inward-looking quality" (Gage, 1993, p. 261). Whilst hard to decipher the job title written down is more likely to be "Lehrer" meaning teacher. The best guess at the content of Arndt's justification departs only slightly from Gage's parsing of the meaning and is as follows:

> Das Blau der Kreis: harmonische Geschlossenheit[24], inbrünstige Sammlung. Das Gelb das Dreieick: Unruhe, wie eine nach oben lodernde Flamme. Rot das Quadrat: Stechend, breite wuchtige Phalanx zur Abwehr bereit." This can be translated as: "The blue the circle: harmonious coherence , ardent collection[25]. The yellow the triangle: Restlessness, like the upwards flare of a flame. Red the square: Piercing, wide powerful phalanx[26] ready to defend. (All translations courtesy of the current author)

[23] This particular questionnaire can be found here: http://www.jitter-magazin.de/wp/wp-content/uploads/2014/06/9_Fragebogen_Wandmalerei_1923_Bildnachweis-Bauhaus-Archiv-Berlin_600.jpg (Retrieved 23rd September 2019).

[24] Geschlossenheit can also be construed as the state of being closed.

[25] This most likely refers to collection in the sense of the state of being collected or composure. ("collection, n.". OED Online. December 2015. Oxford University Press. http://www.oed.com/view/Entry/36275?rskey=6uPdS8&result=1 (accessed February 12, 2016).)

[26] A phalanx is a rectangularly-shaped infantry formation, where individuals are heavily armoured and carry weapons such as spears.

6.2 Dissenting Opinions to Kandinsky's Correspondences and References to Lupton and Miller's Findings

Jacobsen and Wolsdorff (2007) cite Lupton & Miller (1993) saying that six out of eight respondents did not reproduce Kandinsky's three correspondences, whilst the two who did, gave differing explanations for their choices. The version of this book held by the Bodleian Library of the University of Oxford (Lupton & Miller, 1993), however, simply states that a few of the responses are reproduced here, whilst offering no total sample size. Further, of the seven reproduced in this edition, none reproduce Kandinsky, but two offer the assignment endorsed by Hölzel and Popova (namely, yellow triangle, blue square, and red circle). These two offer very similar explanations for their choices, except in the case of the yellow triangle. If this is, in fact, a mistake, it should be noted other authors have accidentally used the information mentioned by Jacobsen and Wolsdorff (2007) in their own work (e.g., Dadam, 2010, Kharkhurin, 2012). Dumitrescu (2011) also seems to be working from a version where two respondents reproduced Hölzel's and Popova's suggested correspondences and none responded with the Kandinsky correspondences. He, however, cites the book as Lupton (2000). Other authors, meanwhile, rarely detail the results. Finally, in order to avoid future confusion, it should be noted that the titles of this work vary but most likely simply refer to different editions (year and translation) of the book, e.g., *The ABC's of design: The Bauhaus and design theory* and *Dreieck, Quadrat, Kreis: Bauhaus und Design-*

Theorie heute [Triangle, square, circle: Bauhaus and design theory today] and *The ABCs of [triangle, square, circle]: The Bauhaus and design theory.*

6.3 Duplicate Places of Publication

Table 6.1 Table showing where which experiments and their results are published in duplicate in full or part for the systematic review conducted in Chapter 1.

Article and experiment	Duplicate places of full or partial publication and experiment
Albertazzi, Da Pos, *et al.* (2013) – Experiment 1	Malfatti (2014) – Experiment 1
Albertazzi, Da Pos, *et al.* (2013) – Experiment 2	Malfatti (2014) – Experiment 2
Albertazzi, Malfatti, Canal, & Micciolo, 2015 – Experiment 1	Malfatti (2014) – Experiment 3
N. Chen, Tanaka, Matsuyoshi, & Watanabe (2015a) – Experiment 1	N. Chen (2015) – Experiment 1
N. Chen, Tanaka, Matsuyoshi, & Watanabe (2015a) – Experiment 2	N. Chen (2015) – Experiment 2
N. Chen, Tanaka, Namatame, & Watanabe (2016) – Experiment 1	N. Chen (2015) – Experiment 5; N. Chen, Tanaka, Matsuyoshi, Nagamori, Namatame, & Watanabe (2014)
N. Chen, Tanaka, Namatame, & Watanabe (2016) – Experiment 2	N. Chen (2015) – Experiment 6
N. Chen, Tanaka, & Watanabe (2015) – Experiment 1	N. Chen (2015) – Experiment 3
N. Chen, Tanaka, & Watanabe (2015) – Experiment 2	N. Chen (2015) – Experiment 4
Dadam, Albertazzi, Da Pos, Canal, and Micciolo (2012)	Dadam (2010) – Chapter 4, Task 1
Dreksler & Spence (2019) – Experiment 1	Chapter 3, Experiment 3A
Dreksler & Spence (2019) – Experiment 2	Chapter 3, Experiment 3B

Dreksler & Spence (2019) – Experiment 3	Chapter 3, Experiment 3C
Hantzsch (1935)	Frieling (1968/1990, p. 172)
Holmes & Zanker (2013)	Holmes & Zanker (2008) poster abstract presented at the ECVP

6.4 Direct Matching Experiments (Systematic Review 1A)

Table 6.2 A table of all experiments for the Systematic Review 1A that probe colour-shape correspondences in a direct and explicit manner, e.g., matching experiments, including additional studies that explore emotional mediation effects. The table details, sample size, sample information, the type of colour and shape stimuli used, relevant controls, procedural details, main findings, and main colour-shape associations found.

DIRECT STUDIES					
Albertazzi, Da Pos, *et al.* (2013) – Experiment 1					
	N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
	60	Students from the University of Trento, Italy	12 geometric shapes[a]	40 hue NCS colour wheel[b]	Conducted in laboratory with constant lighting conditions (130-250 lux, 3400K, halogen lamp). Hue circle was presented at four different orientations (0°, 90°, 180°, and 270°) across two sessions 4-6 weeks apart.
Presentation	Shapes were presented on separate cardboard sheet one at a time. Participants chose colour on the hue circle.				
Main findings	A significant association between colour and shape was found for both sessions, with a log-linear model finding no significant difference in the pattern of association between sessions. Residual analysis[c] of the full contingency table revealed positive and negative associations between certain shapes and colour categories (see next row). A correspondence analysis found two factors, interpreted as warmth and lightness, that accounted for 38.6% (session 1) –39.0% (session) and 35.8% (session 1) – 34.4% (session 2), respectively.				
Colour-shape associations	**Circle** – yellow (+), red (+), blue/green (–) **Cone** – blue (–) **Hexagon** – red/blue (+)				

	Oval – green (–) **Parallelogram** – yellow (–), yellow/red (+), red (–), blue (+), blue/green (+) **Pyramid** – yellow (+), red (–) **Square** – yellow (–), red (+), blue (+), blue/green (–) **Trapezium** – yellow (–) **Triangle** – yellow (+) No associations for the rhombus and truncated cone.

Albertazzi, Da Pos, *et al.* (2013) – Experiment 2

N	Sample information	Shape stimuli	Colour stimuli	Controls
70	Students from the University of Trento, Italy	Circle, square, triangle, rhombus	40 hue NCS colour wheel[b]	Conducted in a laboratory with constant lighting (1 lux). Subjective hue categorizations were determined and compared in the analysis to the experimenter's division of the hue circle. Shapes were presented in different sizes (large shapes with same perimeter, small shapes with same area) and at different orientations. The hue circle orientation was varied randomly.

Presentation	Shapes and colours were presented on a laptop screen. Shapes were presented in the center of the wheel of hue circles on a white background and turned the chosen colour upon a participant clicking a colour.
Main findings	A Chi-square analysis of the full contingency table revealed a significant association between colour and shape. Log-linear models found that the area/perimeter, size, and orientation of shapes had no effect on this association, regardless of whether hues were

	categorized by the experimenter or the participant's subjective hue categorizations. The four shapes were plotted on the two factorial axes of Experiment 1 (see next row) and had similar locations on these when subjective unique hues were used in the analysis. The triangle and circle were found to be warm shapes. The rhombus was located on the cooler end of the first factor axis. The square was found to be on the dark end of the second factor axis, with the circle being located mid-way between the zero point and the darker square. Both the triangle and rhombus were not located far from the zero point of the second factor axis, and the square was close to the zero point on the first factor axis.
Colour-shape associations	**Triangle** – warm **Circle** – warm **Rhombus** – cool **Square** – dark

Albertazzi, Malfatti, Canal, & Micciolo (2015)

N	Sample information	Shape stimuli	Colour stimuli	Controls
56	Students from the University of Trento, Italy	6 angles: 22.5°, 45°, 90°, 135°, 157.5°, 180°	40 hue NCS colour wheel[b]	Conducted in a laboratory with constant lighting (1 lux). Angles were presented at 8 orientations (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°). The hue circle orientation was varied randomly. Analysis was conducted with participants' subjective unique hue categorization choices.

Presentation	Shapes and colours were presented on a laptop screen viewed through a black cylinder that reduced screen reflections. Angles were presented in the center of the wheel of hue circles on white and black backgrounds and turned the chosen colour upon a participant clicking a colour.
Main findings	A Chi-square analysis of the full contingency table found a significant association between colour and angle for the white and black backgrounds. Residual analysis of the white and black background revealed specific associations (see next row). On a

	white and black background, acute angles were found to be positively associated with warm colours and negatively associated with cool colours[d], whilst the reverse trend was found for obtuse angles. On a white background, the highest positive residuals for a right angle were a green and an orange hue, and the highest negative residual was a dark bluish green hue. A straight line was most strongly positively associated with the green hue, and most negatively associated with a slightly more yellow green tone. On a black background, the highest positive residuals for a right angle were a slightly yellow green and a purple hue, and the highest negative residual was a sea green hue. A straight line was most strongly positively associated with the sea green hue.
Colour-shape associations	<u>White background:</u> **Acute angles** – warm (+), cold (–) **Obtuse angles** – warm (–), cold (+) **Right angle** – green (+), orange (+), dark blueish (–) **Straight line** – green (+), yellow green (–) <u>Black background:</u> **Acute angles** – warm (+), cold (–) **Obtuse angles** – warm (–), cold (+) **Right angle** – yellow green (+), purple (+), sea green (–) **Straight line** – sea green (+)

Blazhenkova & Kumar (2018) – Experiments 1 and 2

N	Sample information	Shape stimuli	Colour stimuli	Controls
1 – 197, 2 – 113	Students from Sabanci University in Istanbul, Turkey	1 – 26 pairs of shapes consisting of curved and angular version, 2 – 8 pairs of curved & angular shapes	Red, green	N/A

Presentation	Experiment 1: In a computerized forced choice task conducted online wherever the participant chose, participants were presented with 26 pairs of angular and curved shapes and had to choose between two verbal labels on 8 sensory dimensions, by dragging each shape to the box of the verbal label they felt best matched it. In regard to colour, participants could choose between red and green.

	Experiment 2: Eight shape pairs were presented on laminated pages. Participants were presented with the actual experiences of different sensory dimensions and had to match each of the pairs of experience with the shape that felt more like it. In the case of colour, participants had to match a red and green paper to the angular and curved shape pairs.
Main findings	The prevalent association was curved/green and red/angular. On average across shapes, 78.3% of individuals chose the prevalent association.
Colour-shape associations	**Curved** – Green **Angular** – Red

Campbell (1942)

N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
122	N/A	12 designs: Rectangular, curved, and angular version of 2 duple and 2 triple rhythm repeating patterns	Black-red, blue-green, blue-yellow, green-red, blue-yellow, green-yellow	It appears care was taken to make sure the lighting conditions were kept as constant as possible throughout the experiment. The experimenters note that a previously unnoticed but later corrected small unevenness in the laying of the colours made them decide to split participant groups in their own analysis.

Presentation	This experiment proceeded in two parts and with an undeterminable variation in participants between subsections therein. Simplified though, using paper stimuli participants were asked to choose the design they felt was the most fitting for the colour combinations (choose design instruction), and in turn, were asked to choose which colour combination best fit the presented rectangular, angular and curved design they were presented with (choose colour instruction)
Main findings	The authors conclude that the shape (rectangular, angular, curved) had a significant effect on colour choices, but less so the rhythm of the design (duple, triple).

Colour-shape associations	N/A

N. Chen, Tanaka, Matsuyoshi, & Watanabe (2015a) – Experiment 1

N	Sample information	Shape stimuli	Colour stimuli	Controls
128	Japanese	12 geometric shapes[a]	40 hue NCS colour wheel[b]	Experiment presented on same hardware and in same room for all participants. Orientation of colour circle was pseudo-random; shape presentation was random. Participants were non-synesthetic with normal or corrected-to-normal visual acuity and colour vision (no details of how this was checked).

Presentation	Shapes and colours were presented on a laptop screen. Shapes were presented in the center of the wheel of hue circles from which participants had to choose one for the shape presented.
Main findings	No effect on colour found based on shape rotation and choice (each shape was seen twice). Significant main effect of colour. Significant interaction effect found for size X colour and shape X colour. Post hoc Chi-square analysis tests showed significant differences in colour choices for all shapes when each shape was analyzed separately in a Chi-square analysis. Some colours found to be more associated with certain shapes using Ryan's method of multiple comparisons (Hsu, 1996, see next row). Correspondence analysis found two factors that explained 89.30% of variance colour-shape associations between the 12 shapes and 8 colour groups.
Colour-shape associations	**Circle** – yellow, yellow/red, red **Triangle** – yellow **Rhombus** – yellow **Hexagon** – blue

	Trapezium – blue **Oval** – yellow, yellow/red, red **Cone** – yellow **Pyramid** – yellow, blue **Truncated cone** – yellow, blue No associations for the truncated pyramid, parallelogram, and square

N. Chen, Tanaka, Matsuyoshi, & Watanabe (2015a) – Experiment 2

N	Sample information	Shape stimuli	Colour stimuli	Controls
22	Japanese	12 geometric shapes[a]	40 hue NCS colour wheel[b]	Experiment presented on same computer apparatus and in same room for all participants, which in turn were both the same as in Experiment 1.

Presentation	On a computerized task, participants rated the shapes and colours on a variety of affective and semantic dimensions.
Main findings	Ratings of the colours and shapes on the dimensions of cold/warm, light/heavy, and sharp/round, revealed that the first factor was explained by the warmth ratings of colours and shapes whilst the second factor was associated with the roundness of the shape and heaviness of the colour. When applying the rating data to Experiment 1 matching results (row above), choice frequency of warm colours certain warm colours (yellow-red, red) was positively correlated with the warmth rating shapes, whilst the choice frequency of colder colours (blue, green, green-yellow) was negatively correlated with shape warmth ratings. Heaviness and roundedness ratings of colours and shapes were not found to predict choice frequencies.
Colour-shape associations	N/A

N. Chen, Tanaka, Namatame, & Watanabe (2015)

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	16	College students with hearing threshold level over 60db referred to as deaf by authors	12 geometric shapes[a]	40 hue NCS colour wheel[b]	Experiment presented on same computer apparatus and in same room for all participants, which in turn both were the same as in N. Chen, Tanaka, Matsuyoshi, & Watanabe (2015a). Shape rotation and size was varied for each of the shapes.
Presentation	Shapes and colours were presented on a laptop screen. Shapes were presented in the center of the wheel of hue circles from which participants had one for the shape presented. Participants were re-tested on the same task 6 months later.				
Main findings	A log-linear analysis revealed that there was a three-way interaction between shape, colour and session and a significant interaction between shape and colour. Colour choices differed significantly between sessions for the parallelogram, cone, and truncated cone based on separate Chi-square analyses conducted for each shape between sessions. All other shapes showed no significant differences between sessions. Post hoc comparisons and multiple comparisons using Chi-square tests and Ryan's method (Hsu, 1996) for the shapes that did not show significant differences between sessions, revealed significant differences in colour choices for all shapes. Certain colour-shape associations were found more commonly based on multiple comparisons analysis (see next row), which were similar to those found in Chen, Tanaka, Matsuyoshi, & Watanabe (2015a).				
Colour-shape associations	**Circle** – Red **Triangle** – Yellow **Rhombus** – Yellow **Hexagon** – Blue **Oval** – Yellow **Pyramid** – Yellow				

N. Chen, Tanaka, Namatame, & Watanabe (2016) – Experiment 1

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	186	91 Japanese college students with hearing thresholds above 69db, 95 hearing Japanese college students.	Circle, square, triangle	Red, blue, yellow, green	Shape and colour wheel rotation were counterbalanced across participants
Presentation	Shapes were presented on the left size of an A4 page and a wheel of the colours was presented on the right side of the page.				
Main findings	Log linear analyses revealed no significant effects of group (deaf /hearing), group X colour, and group X colour X shape. A significant main effect of colour and significant interaction effect of colour X shape was found. Post hoc Chi-square analyses showed significant differences in colour choices for all three shapes when analyzed separately. Significant associations were found between certain shapes and specific colour categories using Ryan's method of multiple comparisons (see next row).				
Colour-shape associations	**Circle** – red **Triangle** – yellow **Square** – blue, green				

N. Chen, Tanaka, & Watanabe (2015) – Experiment 1

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	38	Japanese college students	Circle, square, triangle	Red, blue, yellow	Participants had normal or corrected to normal visual acuity and normal motor functions (it is not mentioned how this was tested). The experiment was conducted in a dimly lit laboratory (1 lux on wall) with the same computer set up for all participants.

Presentation	Participants completed 3 IAT experiments that tested Kandinsky's correspondences versus their opposite (IAT 1: blue/circle, red/square vs. red/circle, blue/square; IAT 2: blue/circle, yellow/triangle vs. blue/triangle, yellow/circle; IAT 3: yellow/triangle, red/square; red/triangle, yellow/square). After completion, participants completed a paper questionnaire with the shapes and colours presented in two rows and were match a colour to each shape by drawing three lines.
Main findings	For IAT 1, *D* scores indicated an association opposite to Kandinsky's and rather for a red circle and blue square in line with the dissident correspondences (mean *D* score = -.26). For IAT 2, *D* scores were distributed around the midpoint and showed no significant association toward the Kandinsky congruent nor incongruent pairings (mean *D* score = .06). For IAT 3, the *D* scores indicated an association congruent with Kandinsky (yellow triangle, red square; mean *D* score = .38). Bonferroni corrected t-tests of the reactions times for each IAT found the same trend in results. Participants chose the dissident correspondences (red circle, blue square, yellow triangle) and Kandinsky correspondences (blue circle, red square, yellow triangle) the most often (36.84% each). The authors suggest that the preponderance of individuals matching colours in line with the Kandinsky correspondences could have been influenced by increased exposure to these pairings during the IAT task. Those who made Kandinsky congruent matches in the explicit questionnaire did not exhibit faster responses to such matchings in the IAT. Those who made dissident correspondences congruent matches in the explicit questionnaire showed faster responses for these pairings in IAT 1 and 3.
Colour-shape associations	Implicit: **Triangle** – yellow **Square** – red, blue **Circle** – red Explicit: **Dissident correspondences** (red circle, blue square, yellow triangle) **Kandinsky correspondences** (blue circle, red square, yellow triangle)

N. Chen, Tanaka, & Watanabe (2015) – Experiment 2

N	Sample information	Shape stimuli	Colour stimuli	Controls
24	N/A	Circle, square, triangle	Red, blue, yellow	Participants had normal or corrected to normal visual acuity (it is not mentioned how this was tested). The experiment was

					conducted in a dimly lit laboratory (1 lux on wall) with the same computer set up for all participants.
Presentation	Participants completed 3 IAT experiments that tested this dissident correspondences (or Japanese associations) versus their opposite (IAT 1: red/circle, blue/square vs. blue/circle, red/square; IAT 2: red/circle, yellow/triangle vs. yellow/circle, red/triangle; IAT 3: yellow/triangle, blue/square; blue/triangle, yellow/square)				
Main findings	For all three IATs, the positive *D* scores and faster mean RTs for the dissident correspondent congruent pairings, indicated that participants associated red with a circle, blue with a square, and yellow with a triangle. Relevant D scores were not reported in the article but sent to the first author privately by the first author of the article (IAT 1: mean *D* score = .35 SE = .11; IAT 2: mean *D* score = .31 SE = .1; IAT 3: mean *D* score = .33 SE = .09). In the explicit questionnaire, more than half of participants chose the dissident correspondences (54.16%), which as for Experiment 1 could have been influenced by the pairings presented during the IAT. For participants with dissident correspondent congruent explicit matches, IAT 1 and IAT 2 showed significant congruency effects. For participants with explicit matches which were incongruent with the dissident correspondences, none of the IATs showed significant association effects.				
Colour-shape associations	**Dissident correspondences** (red circle, blue square, yellow triangle)				

Dadam, Albertazzi, Da Pos, Canal, & Micciolo (2012)

	N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
	60	Undergraduate and post-graduate students, half of which were recruited from the University of Trento, Italy.	32 achromatic natural shapes taken from Haeckel's (1904/2004) *Art Forms in Nature*	40 hue NCS colour wheel[b]	Laboratory had constant controlled lighting (<10 lux on the table).
Presentation	Figures were presented in the center of the screen surrounded be the hue circle. Participants had to choose the colour which 'naturally matched' the shape and were asked to avoid making associations with past experiences. Participants could change their choice until they were satisfied.				

Main findings	A full contingency table Chi-square analysis found a significant association between the shapes and colour categories ($V = .15$). Specific associations between shape characteristics[e] and colours were probed using a Chi-square analysis, although residuals were not reported (see next row for results). Shape showed a significant association with warmth (Cramér's phi = .07).
Colour-shape associations	**Rounded** – red, cold (–)/warm (+) **Elongated** – blue to green, cold (+)/warm (–) **Holed** – green to yellow **Non-holed** – red, cold (–)/warm (+) **Flat** – red, green

Chapter 2 – Experiment 2A

N	Sample information	Shape stimuli	Colour stimuli	Controls
31	Participants were predominantly European and from the UK.	Circle, square, triangle	Red, blue, yellow	Participants were generally unaware of Kandinsky's correspondence theory or were unable to replicate Kandinsky's assignments and statistical tests verified that knowledge of these areas did not affect colour choices. Felt tip pen order was randomized. Participants were given a description of synaesthesia and asked to respond whether they experienced anything similar. Experiment occurred in same dimly lit room for all participants.

Presentation	Participants filled out a translated version of the 1923 Kandinsky questionnaire using a pen and coloured felt tip pens. They then rated how intuitive their matches felt. Participants rated all shapes and colours on a variety of perceptual, affective and semantic dimensions and filled out a series of psychometrics on creativity including the Biographical Inventory of Creative Behaviors (Batey, 2007).
Main findings	The association between colour and shape was found to be significant in a Chi-square analysis. Chi-square analysis revealed that the Kandinsky (29.0%) and association (35.5%) correspondences were most commonly chosen. Adjusted residual analysis results of the full contingency table of one-to-one colour-shape matches are noted in the next row and can be compared to the results of two other methods of analysis. Affective mediation results are discussed in Chapter 2.
Colour-shape associations	**Dissident correspondences** (red circle, blue square, yellow triangle) **Kandinsky correspondences** (blue circle, red square, yellow triangle) Chi-square analysis (full-crosstabulation): **Circle** – red (–) **Square** – blue (+), yellow (–) **Triangle** – blue (–) Chi-square analysis (each shape separately): No significant Chi-square statistic for any shape. Multinomial logistic regression analysis: **Square** – blue (+), red (+) **Triangle** – blue (–)

Chapter 2 – Experiment 2B

N	Sample information	Shape stimuli	Colour stimuli	Controls
94	Cross-cultural sample with the majority of individuals being European or North American	Circle, square, triangle	Red, blue, yellow	Participants were generally unaware of Kandinsky's correspondence theory or were unable to replicate Kandinsky's assignments and statistical tests verified that

					knowledge of these areas did not affect colour choices. Shape order and configuration and colour order were randomized.
Presentation	Participants were presented with all three shapes above the colours on an online platform and had to choose the colour they felt best matched. The shapes were presented either in a straight line or in a triangle as in the original 1923 Kandinsky questionnaire. Participants rated all shapes and colours on a variety of perceptual, affective and semantic dimensions and filled out a series of psychometrics on creativity including the Biographical Inventory of Creative Behaviors (Batey, 2007).				
Main findings	The association between colour and shape was found to be significant in a Chi-square analysis. Chi-square analysis revealed that the dissident (26.8%) and association (26.8%) correspondences were most commonly chosen. Adjusted residual analysis results of the full contingency table of one-to-one colour-shape matches are noted in the next row and can be compared to the results of two other methods of analysis. There was no significant effect of shape configuration on colour choices. Affective mediation results are discussed in Chapter 2.				
Colour-shape associations	**Association correspondences** (yellow circle, blue square, red triangle) **Dissident correspondences** (red circle, blue square, yellow triangle) Chi-square analysis (full-crosstabulation): **Circle** – blue (–), yellow (+) **Square** – blue (+), red (–), yellow (–) **Triangle** – blue (–), red (+) Chi-square analysis (each shape separately): **Square** – blue (+), yellow (–) Multinomial logistic regression analysis: **Square** – blue (+), red (+) **Triangle** – blue (–)				

Chapter 2 – Experiment 2C

	N	Sample information	Shape stimuli	Colour stimuli	Controls

	200	Cross-cultural sample with the majority of individuals being European or North American	Circle, square, triangle	Red, blue, yellow	Participants were unaware of Kandinsky's correspondence theory and were unable to replicate Kandinsky's assignments.
Presentation	On an online platform, participants were presented with one shape with the three colours being shown in a quasi-random order below. They were asked to choose the colour that they felt best matched the shape.				
Main findings	The association between colour and shape was found to be significant in a Chi-square analysis. Chi-square analysis revealed that the dissident (24.7%), combination 6 (blue triangle, red triangle, yellow circle, 20.6%) and Kandinsky (18.6%) correspondences were most commonly chosen. Adjusted residual analysis results of the full contingency table of one-to-one colour-shape matches are noted in the next row and can be compared to the results of two other methods of analysis.				
Colour-shape associations	Chi-square analysis (full-crosstabulation): **Square** – blue (+), yellow (–) **Triangle** – blue (–), yellow (+) Chi-square analysis (each shape separately): **Square** –yellow (–) Multinomial logistic regression analysis: **Square** – blue (+), red (+) **Triangle** – blue (–)				

Dreksler & Spence (2019) – Experiment 1, 2, and 3

N	Sample information	Shape stimuli	Colour stimuli	Controls
1 – 64, 2 – 68. 3 – 75	Cross-cultural samples.	Experiment 1: 58 geometric shapes varying in roundedness, symmetry and complexity.	36 colours of different hues each with a light,	Participants were asked to complete the experiment in a quiet, normally lit room free from distractions and to set their monitors to a lightness that

			Experiment 2: 16 mandala/snowflake shapes varying in roundedness, symmetry and complexity. Experiment 3: 12 radial frequency pattern shapes varying in roundedness, symmetry and complexity	saturated and dark version.	allowed them to differentiate the colour stimuli from one another. Participants were excluded if they reported having non-corrected vision issues (self-reported) or indicated they experienced some type of synesthesia that was relevant to colour or shape, and if they failed the colour vision test. Participants were excluded if responses indicated gamed or unaware responding.
Presentation	Participants were presented with each shape on an online platform on a gray background and had to choose the colour they felt past matched it and rated how intuitive they felt this match was. Participants had to rate the valence and arousal of all shapes and colours. Finally, they completed a series of psychometrics (Big Five Inventory, 20-item Toronto Alexithymia Scale, Vividness of Visual Imagery Questionnaire, Autism Spectrum Quotient) and filled out questions on their age, gender, experience of synesthesia, and cultural background, and completed the City University web-based colour vision test.				
Main findings	The aim of this set of experiments was to identify whether there are any shape characteristics than are consistently found to be related to certain colours, colour categories or colour dimensions. Whilst each experiment found significant results with small effect sizes for the association between colour and shape, none of these specific associations were replicated across the three stimuli sets. Furthermore, the use of different statistical approaches to explore these associations showed that they could lead to inconsistent results between them as well. However, on the point of emotional mediation, more consistent results were found, whereby, to varying degrees, the liking and arousal ratings of shapes correlated with the liking and arousal ratings of colours that were chosen for these shapes. Sometimes this included correlations that crossed these boundaries, such as more liked colours also being chosen for shapes which were rated as more arousing, although this was unsurprising since the liking and arousal for a stimulus were often strongly correlated. Affective mediation results are discussed in more detail Chapter 3.				
Colour-shape associations	<u>Experiment 1:</u> **Pointedness** – Green (–) **Complexity** – Yellow (+), blue (–), darkness (+), warmth (+)				

	Symmetry – Green (–), darkness (+) Experiment 2: **Pointedness** – darkness (+) Experiment 3: **Pointedness** – Green (+), red (–) **Complexity** – yellow (+), lightness (+)

Dumitrescu (2003)

N	Sample information	Shape stimuli	Colour stimuli	Controls
686	N/A	Set 1: Circle, square, triangle. Set 2: Hexagon, half hexagon-half circle, half circle-half-square. Set 3: Circle, ellipse, triangle, square, pentagon, hexagon.	Set 1: Red, blue, yellow. Set 2: Orange, green, violet, red, yellow, blue, brown, white, grey, black. Set 3: Red, orange, yellow, green, blue, violet.	N/A

Presentation	Set 1: It is unclear whether the questionnaire was presented on a computer or other means and much of the procedure for this experiment remains unclear. Participants were presented with the circle, triangle, and square along the top row. Red, yellow, and blue were presented on the left in a descending manner. They then saw all 6 possible combinations of the three Kandinsky shapes and colours and had to choose one.

	Set 2: Participants were presented with 9 shapes[f] and had to fill out columns 1 and 3 as they had done in first part of the experiment, and then had to choose colours for the second row shapes which were constructed as a sort of median shape between the shape to its left and right. Set 3: Participants were presented with the shapes along the top row (in the order stated here), with all the colours (in the order stated here) presented in a descending manner on the left side and had to match them to one another.
Main findings	Since throughout the article Dumitrescu (2003) mainly reports percentages of shape-colour matches, frequencies were calculated from these and re-analysed to align with prevailing statistical analyses in the field. Chi-square analyses revealed that all three shape-colour sets tested in the experiments showed significant associations between colours and shapes (effect sizes can be found in Table 1.2 and Table 1.3). Results of the adjusted residual analyses (-2 or below for a negative association, 2 or above for a positive association) can be seen in the next row.
Colour-shape associations	<u>Set 1:</u> **Circle** – Blue (–), red (+) **Square** – Blue (+), red (–), yellow (–) **Triangle** – Blue (–), yellow (+) <u>Set 2:</u> **Hexagon** – Violet (+), blue (–), grey (–) **Half hexagon-half circle** – Orange (+), violet (–) **Half circle-half square** – Orange (–), grey (+) <u>Set 3:</u> **Circle** – Red (+), orange (–), yellow (+), green (–), blue (–), violet (–) **Ellipse** – Red (–), orange (+), yellow (–), green (–), blue (+), violet (+) **Triangle** – Red (+), orange (–), yellow (+), blue (–), violet (–) **Square** – Red (–), orange (+), yellow (–), green (–), blue (+), violet (+) **Pentagon** – Orange (–), green (+), blue (–), violet (–) **Hexagon** – Red (–), yellow (–), green (–), blue (+), violet (+)

Dumitrescu (2011)

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	615	N/A	Circle, triangle, square, sphere, tetrahedron, cube	Red, blue, yellow	The participants did not have artistic training, nor did they know of Kandinsky's original questionnaire.
Presentation	Participants were presented with the 2D and 3D shapes in all possible colour combinations. Participants were then required to mark each shape with a number from 1-5 to indicate how 'inappropriate' to 'perfect' they considered this combination.				
Main findings	The author only reports the percentage of individuals who chose the highest mark (5) that indicates a perfect combination for each shape as well as the mean score for each colour-shape combination. The highest mean mark for each shape is as follows: circle-red, triangle-red, square-blue, sphere-red, tetrahedron-yellow, cube-blue. This same pattern is reflected in the distribution of the highest marks given for the colour-shape combinations.				
Colour-shape associations	**Shapes based on circle** – red **Shapes based on square** - blue				

Hantzsch (1935)

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	Unknown although likely 182 based on title of doctoral dissertation	Pupils from the years 5 to 13	Circle, square, triangle, ellipse, rectangle, cube, pyramid, sphere	13 colours including reds, yellows, blues, violet, brown, green	N/A
Presentation	Participants were asked to use the coloured pencils to fill in the shapes.				
Main findings	Only the predominant colours chosen were reported by Frieling (1968/1990): yellow colours for the triangle (30% of colours chosen) and pyramid (38%), red colours for the square (36%) and cube (37%), and blue colours for the circle (21%) and sphere (28%).				

Colour-shape associations	**Triangle** – yellow **Pyramid** – yellow **Square** – red **Cube** – red **Circle** – blue **Sphere** – blue

Jacobsen (2002)

N	Sample information	Shape stimuli	Colour stimuli	Controls
200	Non-artist university and junior college students, Leipzig, Germany	Circle, square, triangle	Red, blue, yellow	Conducted in experimental room with ceiling neon lamp and daylight filtered through grey window shades. Pens were presented in a randomized order. Participants had not received formal art or design training nor were they aware of Kandinsky's correspondence theory nor did they report an impairment in colour vision.

Presentation	Questionnaire resembling Kandinsky's was printed on a sheet of A4 paper. Participants matched the shapes and colours by colouring in the shapes with felt tip pens, offered a rationale for their choices, and filled out personal information. Participants either were asked simply to match the shapes and colours or, in the aesthetic condition, were instructed to produce the most beautiful and aesthetically pleasing assignment. An average 4.8 months later 58 participants were re-tested using the same procedure.
Main findings	There was no significant difference in the distributions of assignments between the two different instruction conditions. Across the two sessions, participants' choices were reasonably stable as measured using contingency measures (Cramér's $V = .52$) and was more stable for those who predicted their choices would be stable (Cramér's $V = .62$).

	The most frequent colour-shape combination was the association correspondences (red triangle, blue square, yellow circle). Only 5% chose the Kandinsky correspondences and 15.5% choice the dissident correspondences. Participants' often made reference to their experience in their rationale. 56% of individuals who had chosen the association correspondences made reference to both a traffic sign/warning sign being triangular and the sun in their rationale, although this rationale was twice as common in the normal non-aesthetic instruction condition. 62% of participants in the first testing session reported that a fundamental relation between colour and shape was possible, regardless of the instruction condition they had been assigned to.
Colour-shape associations	**Association correspondences**: red/triangle, blue/square, yellow/circle. Support for **Combinations 2, 3 (dissident correspondences), and 6** to a lesser degree.

Jacobsen & Wolsdorff (2007)

	N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
	74	Visitors of conference on art education, all had or were receiving professional training in the visual arts	Circle, square, triangle	Red, blue, yellow	Only one participant reported being familiar with Kandinsky's correspondence theory and assignment.
Presentation	N/A				
Main findings	The art educators' responses differed significantly from the layman sample tested in Jacobsen (2002). The most common choice, with 50% of participants choosing it, was the dissident correspondences (yellow/triangle, blue/square, red/circle). 21.6% chose the association correspondences and 14.9% chose the Kandinsky correspondences. There was no effect of gender or age group on the distribution of choices.				
Colour-shape associations	Strongest support for the **dissident correspondences** (red circle, blue square, yellow triangle) Support for the **Kandinsky correspondences** (blue circle, red square, yellow triangle) and **association correspondences** (yellow circle, blue square, red triangle) to a lesser degree.				

Kharkhurin (2012) – Experiment 1

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	284	56 were further tested with colour-form priming task, non-artist students at the American University of Sharjah, United Arab Emirates	Circle, square, triangle	Red, blue, yellow	None of participants reported familiarity with Kandinsky's correspondence theory. Priming test was administered 30 days after explicit questionnaire, and both were presented on the same computer screen for all participants.
Presentation	On a web-based survey, each shape was presented in three colours on a white screen and participants had to choose which felt right to them and offer the criteria and explanation for their choice. The priming test was presented on an in-lab monitor and required individuals to respond yes/no for each block for a target shape. A coloured screen was presented for 1000ms after the fixation cross and before and just before the shape was presented.				
Main findings	Kharkhurin (2012) only report a consistent preference for a blue square, although it is unclear whether this is a result found when analysing each shape separately or when performing a Chi-square residual analysis on the entire contingency table. Re-analysis using Chi-square procedures of the reported frequencies reveals that the former analysis was probably conducted (see next row). 90.20% of individuals reported pragmatic object associations affected their colour choices, whilst 9.80% reported on perceptual properties (e.g., 'circles feel yellow').				
Colour-shape associations	<u>Shape-by-shape Chi-square analysis</u> (assumes equal frequency of colour choices across shapes, residuals of -2 and below, and 2 and above are reported) **Circle**: χ^2 (2, $N = 284$) = 4.94, $p = .084$ **Square**: χ^2 (2, $N = 284$) = 60.77, $p < .001$. Residual for blue = 51.3, residual for yellow = -55.7. **Triangle**: χ^2 (2, $N = 284$) = 3.39, $p = .184$ <u>Full contingency table Chi-square analysis</u> (expected observations are based on total instances of colour choice across all shapes) adjusted residuals of -2 and below, and 2 and above are reported) χ^2 (4, $N = 852$) = 53.25, $p < .001$				

	Circle – blue (–), yellow (+) **Square** – blue (+), yellow (–) **Triangle** – yellow (+)

Kharkhurin (2012) – Experiment 2

N	Sample information	Shape stimuli	Colour stimuli	Controls
60	Non-artist students at the American University of Sharjah, United Arab Emirates	Circle, square, triangle	Red, blue, yellow, green, white, black	Test was administered on the same computer screen for all participants.

Presentation	First a colour-form recognition test was completed on a computer: participants were presented with coloured shapes of all possible combinations of the stimuli on a grey background and had to respond to whether the target colour or shape was present or not. After completion participants saw each screen, each filled with one of the three shapes in 6 different colours and were asked to pick the drawing that feels 'right' to them.
Main findings	For the recognition task, the author reports a significant effect of condition (congruent with Kandinsky's associations, incongruent with Kandinsky's associations, and control: green, white, black) for accuracy ($F(2, 118) = 3.76$, $p < .05$, $\eta_p^2 = .06$) but only a "marginally significant" (p. 177) one for RT ($F(2, 118) = 2.99$, $p = .05$, $\eta_p^2 = .05$). Post hoc analysis revealed significantly and marginally significantly faster RTs to congruent and incongruent conditions versus the control, but no significant difference between the congruent and incongruent conditions. Since no standard deviations were reported, effect sizes could not be calculated. For the explicit colour-form survey, the authors report that there is no significant preference for any colour-form combination. Based on a re-analysis of the data, it is clear that here the analysis used was a full contingency table Chi-square crosstabulation. This non-significant finding holds true for a shape-by-shape Chi-square re-analysis as well.
Colour-shape associations	<u>Shape-by-shape Chi-square analysis</u> (assumes equal frequency of colour choices across shapes, residuals of -2 and below, and 2 and above are reported) **Circle**: $\chi 2$ (5, $N = 60$) = 4.60, $p = .467$ **Square**: $\chi 2$ (5, $N = 60$) = 7.20, $p = .206$ **Triangle**: $\chi 2$ (5, $N = 60$) = 6.40, $p = .269$

	Full contingency table Chi-square analysis (expected observations are based on total instances of colour choice across all shapes) adjusted residuals of -2 and below, and 2 and above are reported) χ^2 (10, $N = 180$) = 9.83, $p = .456$

Lindauer (1973)

N	Sample information	Shape stimuli	Colour stimuli	Controls
118[g]	Undergraduates, predominately women. Had heard brief lecture on imagery before test.	Shapes were categorized according to shape (round, curvy, straight), size (big, moderate, small), direction (horizontal, up), extensiveness (large, moderate, small), intensity of boundary lines (light, medium, dark)	Red, blue, green, yellow	The order of the characteristics on the checklist were different between participants.

Presentation	Monochromatic filter slides (Welch Scientific Company No. 3662) were projected onto a large screen at front of the room of a general psychology class. Participants were asked to imagine a form to each colour and then indicated the characteristics of the imagined form on a checklist of the 5 shape characteristics. Participants rated how difficult they found the task which was taken as a proxy measure of ease of imagery.
Main findings	It is difficult to determine exactly what statistical analyses were conducted, but the author reports the qualitative results of a significant Chi-square analyses "of the number of [participants] who chose on descriptive category of a colour's form significantly more than any other" (pp. 165-166). These results are detailed in the next row. No significant results were found for red and shape, and yellow and size. Assignment of choices for about half of colour-form categories showed differences depending on reported sex and ease of imagery.
Colour-shape associations	**Red** – Moderate size, horizontal direction, large extensiveness, dark boundary line intensity. **Yellow** – Straight lines, up direction, moderate extensiveness, light boundary line intensity.

	Blue – Curvy lines, big size, horizontal direction, large extensiveness, dark intensity of boundary lines. **Green** – Straight lines, moderate size, horizontal direction, large extensiveness, medium intensity of boundary lines.

Malfatti (2014) – Experiment 4

N	Sample information	Shape stimuli	Colour stimuli	Controls
44	Students at the University of California, Berkeley	44 open line shapes[hi]	37 colours of the Berkeley Colour Project[ij]	Participants were tested and excluded if a positive result was attained for defective colour vision (Dvorine Pseudo-Isochromatic Plates) and synaesthesia (online Synesthesia Battery at www.synaesthete.org by Eagleman *et al.*, 2007). Shapes were presented at two orientations (0°, 180°).

Presentation	The experiment was conducted on a computer monitor where shape stimuli were presented to the right of the 37 BCP colours on a grey background in a dark room. Participants chose the three colours they felt most and least matched each shape. Additionally, participants rated the shapes and colours on emotional and semantic dimensions[k] and noted what object and associated colour each shape reminded them of.
Main findings	No effect of shape orientation on colours chosen was found. Separate repeated measure ANOVAs found that more intersections were associated with redder, more saturated colours. Angular (vs. curved) lines were associated with darker, redder, yellower, and more saturated colours. Symmetry was not found to affect colour choice dimensions. Stepwise multiple linear regressions were conducted for both the geometric and perceptual shape information. Pointedness and closure were positively associated with saturation and redness for both geometric and perceptual models. Pointedness was associated with darker colours, and to a lesser degree yellowness, in both models. An average of 49% of variance in colour dimensions was explained by geometric models (range: 10% – 73%), and 53% was explained by perceptual models (range: 14% – 74%). Participants self-reported that 31% of colour choices were affected by object associations. Emotional mediation results indicated large correlations between the emotional associations of shapes and the colours chosen to best match with them and

	emotional associations accounted for considerable variance in colour choices, though this reduced to very limited additional variance explained when perceptual models were first taken into account.
Colour-shape associations	**Angular shape** – darkness, red, yellow, saturation **Shapes with intersections** – red, saturation **Pointedness** – saturation, red, darkness, yellow **Closure** – saturation, red

Malfatti (2014) – Experiment 5

N	Sample information	Shape stimuli	Colour stimuli	Controls
44	Students at the University of California, Berkeley	45 closed geometric shapes[hi]	37 colours of the Berkeley Colour Project (BCP)[ij]	Participants were tested and excluded if a positive result was attained for defective colour vision (Dvorine Pseudo-Isochromatic Plates) and synaesthesia (online Synesthesia Battery at www.synaesthete.org by Eagleman, *et al.*, 2007). Shapes were presented at two orientations (0°, 180°).

Presentation	The experiment was conducted on a computer monitor where shape stimuli were presented to the right of the 37 BCP colours on a grey background in a dark room. Participant chose the three colours they felt most and least matched each shape. Additionally, participants rated the shapes and colours on emotional and semantic dimensions[k] and noted what object and associated colour each shape reminded them of.
Main findings	No effect of shape orientation on colours chosen was found. Separate repeated measure ANOVAs found that more symmetrical shapes were associated more saturated and redder colours. More convex shapes were associated with lighter colours. Pointier shapes were associated with more saturated and lighter colours. Several interaction effects were found (saturation: concavities X pointedness; lightness: symmetry axes X pointedness, concavities X pointedness, symmetry axis X concavities X pointedness; redness: symmetry axes X pointedness; yellowness: concavities X pointedness). Stepwise multiple linear regressions were conducted for both the geometric and

	perceptual shape information. Pointedness and symmetry-axes were positively associated with saturation and redness for both geometric and perceptual models. In geometric models, pointedness and concavities were associated with darker colours and more symmetrical shapes with lighter colours. In perceptual models, only complexity was associated with lightness, whereby by more complex shapes were associated with darker colours. No variance in yellowness was explained by perceptual or geometric models. An average of 27% of variance in colour dimensions was explained by geometric models (range: 0% – 39%), and 26% was explained by perceptual models (range: 0% – 43%). Emotional mediation results indicated large correlations between the emotional associations of shapes and the colours chosen to best match with them and emotional associations accounted for considerable variance in colour choices, with some additional variance explained when perceptual models were first taken into account.
Colour-shape associations	**Symmetry** – saturation, red, lightness **Convexity/Concavities** – lightness/darkness **Pointedness** – saturation, lightness (0 concavities), darkness (1 or more concavities, overall in stepwise multiple linear regressions), red **Complexity** – darkness

Sakuta & Gyoba (2006) – Recognition test

N	Sample information	Shape stimuli	Colour stimuli	Controls
20	Undergraduate and graduate students from Tohoku University who were native Japanese speakers	24 target & 24 distracter shapes	24 target & 24 distracter colours	Order of stimulus presentation changed in each session.

Presentation	Participants had to memorize 48 colour-form pairs presented on a computer screen. They then were presented with one form as a recognition cue and had to choose the colour it had been paired with in the study phase from 3 colours (one target, two distractors). Participants then rated the colour-form pairs again for how the "impressions of colour and form matched each other" (fitness rating, p. 200).
Main findings	There were significant main effects of semantic differential factors (activity, potency, evaluation), colour properties, and form properties as well as significant interaction effects (factors X colour, colour X form, factor X colour X form). For the semantic differential rated dimensions of activity and potency, colours and forms that were congruent in their rating on these scales (vs. incongruent) showed higher recognition performance. For the dimension of evaluation, incongruent colour-form pars resulted in

	higher recognition performance than congruent pairs. Fitness ratings were higher for colour-form pairs that were congruent (vs. incongruent) in their ratings on the activity and potency dimensions. The reverse was true for the evaluation dimension.
Colour-shape associations	N/A

Welsh (1974) – Experiment 1

N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
110	Students from advanced psychology courses	Square, rectangle, triangle, hexagon, circle, oval, diamond, convex lens, concave lens, semicircle, 'hourglass', trapezoid	Red, orange, yellow, green, blue, purple, brown, gold, silver, white, grey, black	N/A

Presentation	Participants were presented with a sheet divided into twelve areas labelled with the twelve colours. They were asked to draw a geometric form or shape that would be most appropriate for the colour.
Main findings	The three studies by Welsh (1974) set out to verify only whether individuals chose the colour-shape combinations set out by Birren (1955) and Dreyfuss (1972). As such, only the frequencies of the following colour-shape combinations were reported: square/red, rectangle/orange, triangle/yellow, hexagon/green, circle/blue, oval/purple, diamond/brown, convex lens/gold, concave lens/silver, semicircle/white, 'hourglass'/grey, trapezoid/black. When the colour was given, only thirteen out of 110 participants chose of the studied twelve shapes, with five drawing a triangle for yellow. For the colour orange, 60% of participants drew circles or circular shapes, which were often depicting fruit or included rays like a sun. For the colour brown 42.7% drew thin, elongated forms, which the authors potentially attribute anal stage of the then still popular Freudian development theory. 50% of participants drew a rectangle for black, potentially reminiscent, the authors suggest, of a blackboard.
Colour-shape associations	**Orange** – Circular shapes **Brown** – Elongated thin shapes **Black** – rectangle

Welsh (1974) – Experiment 2

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	100[1]	Students from advanced psychology courses	Square, rectangle, triangle, hexagon, circle, oval, diamond, convex lens, concave lens, semicircle, 'hourglass', trapezoid	Red, orange, yellow, green, blue, purple, brown, gold, silver, white, grey, black	N/A
Presentation	Participants were given a sheet with the twelve shapes. They were asked to write the name of colour underneath which they felt best matched the shape.				
Main findings	When the form was given and participants could freely choose any colour, seventy-four participants chose yellow for the triangle, twenty chose red for the square, and twenty chose blue for the circle. The authors postulate that the preponderance of the yellow/triangle association is based on the association with the yellow yield sign, with some participants even labelling it as such. The authors also report that 22% of participants chose white for the square and that the majority of individuals chose red for the hexagon (77%). The authors postulate that this is due to the association to an octagonal red stop sign. For the oval, the most common chose was blue (22%). For the circle, both yellow and blue were chosen by 18% of participants.				
Colour-shape associations	**Triangle** – yellow **Square** – white **Hexagon** – red **Oval** – blue **Circle** – yellow, blue				

Welsh (1974) – Experiment 3

	N	Sample information	Shape stimuli	Colour stimuli	Controls

	34	Students from advanced psychology courses	Square, rectangle, triangle, hexagon, circle, oval, diamond, convex lens, concave lens, semicircle, 'hourglass', trapezoid	Red, orange, yellow, green, blue, purple, brown, gold, silver, white, grey, black	N/A
Presentation	Participants were given a sheet with the twelve shapes. They were asked to write the name of colour underneath which they felt best matched the shape but were asked to restrict themselves to the listed twelve colours.				
Main findings	When participants were restricted by the colours, they could choose for the shapes 61.8% chose yellow for the triangle and 17.6% of participants chose grey for the 'hourglass' shape. All other postulated combinations were chosen by three participants or less. The author concludes from the three studies in Welsh (1974) that colour and form can be explained based on past experience rather than symbolic association, though they do not rule out the possibility that it is, or that this may be affected by individual differences such as personality.				
Colour-shape associations	**Triangle** – yellow '**Hourglass'** – grey				

[a] The 12 geometric shapes referred to are a circle, square, triangle, parallelogram, rhombus, hexagon, trapezoid, oval, cone, pyramid, truncated cone, and truncated pyramid and can be found in N. Chen (2015, Figure 1, p. 13).

[b] The 40 hue NCS colour wheel refers to 40 circles of different hues arranged in a circle in reference to the Natural Colour System (NCS) Atlas and can be found in Malfatti (2014, Figure 2.2, p. 19). For analysis studies using this hue circle collapse the 40 colours in 8 categories: red, blue, yellow, green, blue/green, green/yellow, yellow/red, red/blue, except in Albertazzi, Malfatti, *et al.* (2015) where each of the 40 hues is included separately in the analyses.

[c] Residual analysis considers z scores above 2 and below -2 as indicative of a significant association between two variables that is above and below in frequency, respectively, than what would be expected from chance.

[d] Warm and cool colours here refer to an equal division of the hue circle into two halves that can be seen in Malfatti (2014, Figure 2.13, p. 40)

[e] Shapes were divided into 8 groups based on their categories along 4 variables: shape (elongated/rounded), margins (non-spicules/spicules), texture (non-holed/holed), 3-dimensionality

(flat/thick). These characteristics were in part based on the categorizations of the same figures made by D'Arcy Thompson (Thompson, 1961).

[f] These shapes can be seen in Dumitrescu (2003, Figure 1, p. 4).

[g] An inconsistency exists in the number of participants reported – the abstract notes 118 whilst the article mentions 188.

[h] The open and closed shapes of Malfatti's (2014) Experiment 4 and 5, respectively, can be found in Malfatti (2014, Figure 3.1, p. 51), and both sets varied in number of generating points, pointedness, and symmetry axes. Open shapes also varied in the number of intersections, and closed shapes varied in the number of concavities. These variations were both objectively geometrically determined by the experimenter but also perceptually measured by having two other groups of participants rate the shapes on the following dimensions: closed/open, pointy/smooth, symmetrical/asymmetrical, complex/simple, concave/convex.

[i] A Shape-Colour Association (SCA) score was calculated that subtracted the weighted average of the three colour choices for each colour dimensions least associated with each shape from the weighted average of three colours chosen to be most associated with each shape. This score was calculated for each of the colour dimensions noted in[j].

[j] The Berkeley Colour Project colours can be seen in Malfatti (2014, Figure 3.2, p. 52) and were perceptually rated by 48 separate participants on the dimensions light/dark, saturated/unsaturated, redness/greenness, yellowness/blueness (Palmer & Schloss, 2010).

[k] A Colour-Emotion Association (CEA) score was calculated in the same way as the SCA score for the dimensions of happiness, agitation, angriness, activity, strength, harmfulness, and preference.

[l] There are internal inconsistencies about the number of participants in this study – the abstract notes the number as 100, whilst the only other mention of the sample size in a result table notes it as 110. Later percentages in the article assume a sample size of 100.

6.5 Indirect Matching Experiments (Systematic Review 1A)

Table 6.3 A table of all the indirect studies for the Systematic Review 1A that explore colour-shape correspondences using implicit task paradigms. The table details, sample size, sample information, the type of colour and shape stimuli used, relevant controls, procedural details, main findings, and main colour-shape associations found.

INDIRECT STUDIES					
N. Chen, Matsuyoshi, & Watanabe (submitted) – Experiment 1					
	N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
	29	Japanese college students	Circle, square, & triangle	Red, blue, & yellow	All participants had normal or corrected to normal visual acuity (how this was tested is not mentioned) and motor functions. Experiment was conducted in a dimly lit room on the same computer apparatus for all participants.
Presentation	Participants completed a computerized go/no-go task where they had to determine whether a coloured shape corresponded with the target verbal label presented. Verbal labels were the three shapes and three colours. Go trials were categorized as congruent when they aligned with the dissident correspondences and incongruent when they did not. Target absent No-Go trials were those that did not include an iteration of the presented target label.				
Main findings	No significant differences in error rates were found between congruent and incongruent 'go' trials. However, RTs were significantly faster for congruent conditions versus incongruent conditions for colour and shape target verbal labels (Two-way ANOVA $\eta_p^2 = .25$; paired sample t-tests for colour target: $d = .49$, shape target: $d = .73$). In particular, colour-shape associations appeared to improve recognition speed for circle ($d = .50$), triangle ($d = .52$), and red ($d = .53$) targets. A circle target improved recognition for red and vice versa. A yellow target improved recognition efficiency for a triangle but not vice versa. There were no improvements in recognition efficiency resulting for blue or square.				

Colour-shape associations	**Circle** – Red **Triangle** – Yellow

N. Chen, Matsuyoshi, & Watanabe (submitted) – Experiment 2

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	29	N/A	Circle, square, & triangle	Red, blue, & yellow	All participants had normal or corrected to normal visual acuity (how this was tested is not mentioned) and motor functions. Experiment was conducted in a dimly lit room on the same computer apparatus for all participants.
Presentation	Participants completed a computerized go/no-go task where they had to determine whether a coloured shape corresponded with the target spoken verbal label presented. Spoken verbal labels were the three shapes and three colours. Go trials were categorized as congruent when they aligned with the dissident correspondences and incongruent when they did not. Target absent No-Go trials were those that did not include an iteration of the heard target label.				
Main findings	No significant differences in error rates were found between congruent and incongruent 'go' trials. However, RTs were significantly faster for congruent conditions versus incongruent conditions for shape targets and to a marginally significant degree for colour targets (Two-way ANOVA $\eta_p^2 = .48$; paired sample t-tests for colour target: $d = .43$, shape target: $d = .95$). In particular, colour-shape associations appeared to improve recognition speed for circle ($d = .53$), triangle ($d = .47$), and red ($d = .50$) targets. A circle target improved recognition for red and vice versa. A yellow target improved recognition efficiency for a triangle but not vice versa. There were no improvements in recognition efficiency resulting for blue or square. There was no significant main effect of task (Experiment 1 vs. Experiment 2) indicating that whether the target was a visual word or spoken word had no effect on recognition efficiency ($\eta_p^2 = .017$, $p = .33$), nor did task interact with condition ($\eta_p^2 = .001$, $p = .84$).				
Colour-shape associations	**Circle** – Red **Triangle** – Yellow				

N. Chen, Tanaka, Namatame, & Watanabe (2016) – Experiment 2					
	N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
	20	Hard of hearing students (hearing threshold over 60dB) from the Tsukuba University of Technology, Japan. Results were compared to a hearing sample in Experiment 2 in N. Chen, Tanaka, & Watanabe (2015).	Circle, square, triangle	Red, blue, yellow	All participants had normal or corrected to normal vision and colour vision (how this was tested is not noted). Experiment was conducted in a dimly lit laboratory using same computer screen for all participants.
Presentation	Participants completed 3 IAT experiments that tested the dissident correspondences (or Japanese associations) versus their opposite (IAT 1: red/circle, blue/square vs. blue/circle, red/square; IAT 2: red/circle, yellow/triangle vs. yellow/circle, red/triangle; IAT 3: yellow/triangle, blue/square; blue/triangle, yellow/square)				
Main findings	No significant differences in RTs were found across congruent and incongruent conditions in IAT 1 (mean D score = .06, 95% CI[−.18 .31]), IAT 2 (mean D score = .21, 95% CI[−.06 .48]), and IAT 3 (mean D score = .11, 95% CI[−.11 .33]), which is at odds with the findings for the same experimental procedure conducted with hearing participants in N. Chen, Tanaka, and Watanabe (2015). This suggests that deaf participants may have exhibited less strong colour-shape associations for the dissident correspondences as measured by the IAT.				
Colour-shape associations	None				

N. Chen, Tanaka, & Watanabe (2015) – Experiment 1					
	N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**

	38	Japanese college students	Circle, square, triangle	Red, blue, yellow	Participants had normal or corrected to normal visual acuity (it is not mentioned how this was tested) and normal motor function. The experiment was conducted in a dimly lit laboratory (1 lux on wall) with the same computer set up.
Presentation	Participants completed 3 IAT experiments testing Kandinsky's correspondences versus their opposite (IAT 1: blue/circle, red/square vs. red/circle, blue/square; IAT 2: blue/circle, yellow/triangle vs. blue/triangle, yellow/circle; IAT 3: yellow/triangle, red/square; red/triangle, yellow/square). After completion, the participants completed a paper questionnaire with the shapes and colours presented in two rows and were instructed to match a colour to each shape by drawing three lines.				
Main findings	For IAT 1, *D* scores indicated an association opposite to Kandinsky's and rather for a red circle and blue square in line with the dissident correspondences (mean *D* score = -.26). For IAT 2, *D* scores were distributed around the midpoint and showed no significant association toward the Kandinsky congruent nor incongruent pairings (mean *D* score = .06). For IAT 3, the *D* scores indicated an association congruent with Kandinsky (yellow triangle, red square; mean *D* score = .38). Bonferroni corrected t-tests of the RTs for each IAT found the same trend in results. Participants chose the dissident correspondences (red circle, blue square, yellow triangle) and Kandinsky correspondences (blue circle, red square, yellow triangle) the most often (36.84% each). The authors suggest that the preponderance of individuals matching colours in line with the Kandinsky correspondences could have been influenced by increased exposure to these pairings during the IAT task. Those who made Kandinsky congruent matches in the explicit questionnaire did not exhibit faster responses to such matchings in the IAT. Those who made dissident correspondences congruent matches in the explicit questionnaire showed faster responses for these pairings in IAT 1 and 3.				
Colour-shape associations	Implicit: **Triangle** – yellow **Square** – red, blue **Circle** – red Explicit: **Dissident correspondences** (red circle, blue square, yellow triangle) **Kandinsky correspondences** (blue circle, red square, yellow triangle)				

N. Chen, Tanaka, & Watanabe (2015) – Experiment 2

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	24	N/A	Circle, square, triangle	Red, blue, yellow	Participants had normal or corrected to normal visual acuity (it is not mentioned how this was tested). The experiment was conducted in a dimly lit laboratory (1 lux on wall) with the same computer set up.
Presentation	Participants completed 3 IAT experiments that tested this dissident correspondences (or Japanese associations) versus their opposite (IAT 1: red/circle, blue/square vs. blue/circle, red/square; IAT 2: red/circle, yellow/triangle vs. yellow/circle, red/triangle; IAT 3: yellow/triangle, blue/square; blue/triangle, yellow/square)				
Main findings	For all three IATs, the positive D scores and faster mean RTs for the dissident correspondent congruent pairings, indicated that participants associated red with a circle, blue with a square, and yellow with a triangle. Relevant D scores were not reported in the article but sent to the first author privately by the first author of the article (IAT1: mean D score = .35 SE = .11; IAT 2: mean D score = .31 SE = .1; IAT 3: mean D score = .33 SE = .09). In the explicit questionnaire, more than half of participants chose the dissident correspondences (54.16%), which, as for Experiment 1, could have been influenced by the pairings presented during the IAT. For participants with dissident correspondent congruent explicit matches, IAT 1 and IAT showed significant congruency effects. For participants with explicit matches which were incongruent with the dissident correspondences, none of the IATs showed significant association effects.				
Colour-shape associations	**Dissident correspondences** (red circle, blue square, yellow triangle)				

N. Chen & Watanabe (submitted) – Experiment 1

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	18	Japanese undergraduates	Circle, square, triangle	Red, blue, yellow	All participants had normal or corrected to

					normal visual acuity (how this was tested is not mentioned). Experiment was conducted in a dimly lit room on the same computer apparatus for all participants.
Presentation	Participants viewed two same or different letters at the centre of the screen with two different coloured shapes to the left or right of the letters. Participants had to report whether the two letters were the same or different, the colour of one of the coloured shapes, and their level of confidence in their colour choice. Response outcomes were threefold: hit (whether colour was correct), illusory conjunction (reporting the colour of the distractor) and a feature error (reporting colour not present).				
Main findings	Participants either saw pairs congruent with the dissident correspondence or incongruent pairs which were the 6 possible congruent coloured shape pairs with their colours switched. Participants made more illusory conjunctions binding errors in incongruent conditions than congruent conditions ($d = 1.06$). Participants made significantly more hits in congruent versus incongruent trials ($d = 1.02$). There was no significant difference in feature errors between conditions.				
Colour-shape associations	**Dissident correspondences** (red circle, blue square, yellow triangle)				

N. Chen & Watanabe (submitted) – Experiment 2

	N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
	48	Japanese undergraduates from Waseda University.	Circle, square, triangle	Red, blue, yellow	All participants had normal or corrected to normal visual acuity (how this was tested is not mentioned). Experiment was conducted in a dimly lit room on the same computer apparatus for all participants.
Presentation	In a search array of 4, 8, or 16 distractors of coloured shapes, participants indicated whether the target was present or not. Targets were present in 50% of the trials. Distractors were either congruent or incongruent with the dissident				

	correspondences. Targets were a yellow circle and square, blue circle & triangle, and red triangle and square.
Main findings	On target absent trials ($\eta_p^2 = .05$) and large ($\eta_p^2 = .06$) distractor set sizes (16), visual search was more efficient (faster RTs) when coloured shape distractors were congruent rather than incongruent with the colour-shape associations the authors suggest are common in Japanese individuals (dissident correspondences).The search slope was significantly larger for incongruent versus congruent distractors ($d = .35$, $\eta_p^2 = .11$). Overall, visual search was faster when distractors were congruent with the dissident correspondences.
Colour-shape associations	**Dissident correspondences** (red circle, blue square, yellow triangle)

Holmes & Zanker (2013)

	N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
	6	Psychology students at Royal Holloway University of London	Circle, square, & triangle	Red, orange, yellow, green, cyan, blue, & magenta	Shapes were presented at different orientations. The same computer set-up was used for all participants.
Presentation	Using eye-tracking technology and a gaze driven evolutionary algorithm participants were instructed to look at the most aesthetically pleasing target shape out of a wheel of choices made up of circles, triangles, and squares presented in seven different colours. Shapes were presented either in separate populations or in a mixed population of the shapes.				
Main findings	When the colour palette was restricted to Kandinsky's three colours, they found a robust preference for the yellow triangle. They found this effect to be disrupted, however, when shapes were presented in the 7 different colours. When individuals were presented with the three instances of the same shape coloured in red, yellow, or blue, there was a "slight trend" (Holmes & Zanker, 2013, p. 5) for yellow circles to be chosen over blue circles, a strong trend for yellow triangles to be increasingly chosen as red choices decreased, and no consistent trend for squares. When shapes were presented as a mixed population, there was an increase in red and yellow for the circle, and an increase in yellow for the triangle, and a modest increase in red and substantial increase in blue for the square. In the single shape condition, the orientation of the triangle did not seem to affect the colours it was associated with.				
Colour-shape associations	**Triangle** – yellow **Circle** – yellow, red				

	Square – blue, red

Kharkhurin (2012) – Experiment 1				
N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
284	56 were further tested with colour-form priming task, non-artist students at the American University of Sharjah, United Arab Emirates	Circle, square, triangle	Red, blue, yellow	None of the participants reported familiarity with Kandinsky's correspondence theory. Priming test was administered 30 days after explicit questionnaire & on the same computer screen for all participants. Counterbalanced response keys were used for the priming test. The priming experiment screen was presented in the three colours, but also in white and black as a control.
Presentation	On a web-based survey, each shape was presented in three colours on a white screen and participants had to choose which felt right to them and offer the criteria and explanation for their choice. The priming test was presented on an in-lab monitor and required individuals to respond yes/no for each block for a target shape. A coloured screen was presented for 1000ms after the fixation cross just before the shape was presented.			
Main findings	Kharkhurin (2012) only reports a consistent preference for a blue square, although it is unclear whether this is a result found when analysing each shape separately or when performing a Chi-square residual analysis on the entire contingency table. Re-analysis using Chi-square procedures of the reported frequencies reveals that the former analysis was probably conducted (see next row). 90.20% of individuals reported pragmatic object associations affected their colour choices, whilst 9.80% reported on perceptual properties (e.g., 'circles feel yellow'). For the priming task, the author reports a significant effect of condition (congruent with Kandinsky's associations, incongruent with Kandinsky's associations, and control: white or black priming screens) on RTs ($F(2, 110) = 5.14$, $p < .01$, $\chi^2 = .09$, $\eta_p^2 = .085$) but not accuracy. Post-hoc analysis revealed faster RTs to congruent and incongruent conditions versus the control, but no significant difference between the congruent and incongruent conditions.			

Colour-shape associations	Shape-by-shape Chi-square analysis (assumes equal frequency of colour choices across shapes, residuals of -2 and below, and 2 and above are reported) **Circle**: χ^2 (2, N = 284) = 4.94, p = .084 **Square**: χ^2 (2, N = 284) = 60.77, p < .001. Residual for blue = 51.3, residual for yellow = -55.7. **Triangle**: χ^2 (2, N = 284) = 3.39, p = .184 Full contingency table Chi-square analysis (expected observations are based on total instances of colour choice across all shapes) adjusted residuals of -2 and below, and 2 and above are reported) χ^2 (4, N = 852) = 53.25, p < .001 **Circle** – blue (–), yellow (+) **Square** – blue (+), yellow (–) **Triangle** – yellow (+)

Kharkhurin (2012) – Experiment 2

N	Sample information	Shape stimuli	Colour stimuli	Controls
60	Non-artist students at the American University of Sharjah, United Arab Emirates	Circle, square, & triangle	Red, blue, yellow, green, white, & black	Test was administered on the same computer screen for all participants. Counterbalanced response keys were used on the recognition test

Presentation	First a colour-form recognition test was completed on a computer: participants were presented with coloured shapes of all possible combinations of the stimuli on a grey background and responded to whether the target colour or shape was present or not. After completion, the participants saw each screen, each filled with one of the three shapes in 6 different colours and were asked to pick the drawing that feels 'right' to them.
Main findings	For the recognition task, the author reports a significant effect of condition (congruent with Kandinsky's associations, incongruent with Kandinsky's associations, and control: green, white, black) for accuracy (F(2, 118) = 3.76, p < .05, η_p^2= .06) but only a "marginally significant" (p. 177) one for RT (F(2, 118) = 2.99, p = .05, η_p^2 = .05). Post hoc analysis revealed significantly and marginally

	significantly faster RTs to congruent and incongruent conditions versus the control, but no significant difference between the congruent and incongruent conditions. Since no standard deviations were reported, effect sizes could not be calculated. For the explicit colour-form survey, the authors report that there is no significant preference for any colour-form combination. Based on a re-analysis of the data, it is clear that here the analysis used was a full contingency table Chi-square crosstabulation. This non-significant finding holds true for a shape-by-shape Chi-square re-analysis as well.
Colour-shape associations	<u>Shape-by-shape Chi-square analysis</u> (assumes equal frequency of colour choices across shapes, residuals of -2 and below, and 2 and above are reported) **Circle**: χ^2 (5, $N = 60$) = 4.60, $p = .467$ **Square**: χ^2 (5, $N = 60$) = 7.20, $p = .206$ **Triangle**: χ^2 (5, $N = 60$) = 6.40, $p = .269$ <u>Full contingency table Chi-square analysis</u> Expected observations are based on total instances of colour choice across all shapes and adjusted residuals of -2 and below, and 2 and above are reported (χ^2 (10, $N = 180$) = 9.83, $p = .456$)

Makin & Wuerger (2013)

N	Sample information	Shape stimuli	Colour stimuli	Controls
36		Circle, square, triangle	Red, blue, yellow	Participants had normal or corrected to normal vision. Male participants were tested for colour blindness using Ishihara plates. Participants were unaware of the Kandinsky correspondence theory and/or did not know the proposed colour-shape combinations.

Presentation	Participants completed 3 IAT experiments that tested Kandinsky's correspondences versus their opposite (IAT 1: blue/circle, yellow/triangle vs. blue/triangle,

	yellow/circle; IAT 2: blue/circle, red/square vs. red/circle, blue/square; IAT 3: yellow/triangle, red/square; red/triangle, yellow/square)
Main findings	No support found for Kandinsky's correspondences. IAT 1 (mean *D* score = -.08, SD = .346.) and IAT 2 (mean *D* score = -.04, SD = .351) showed no significant difference in RTs. The authors describe a marginally significant effect in the direction of Kandinsky's correspondences for IAT 3 (mean *D* Score = .13, SD = .383) that indicates a tendency towards associating yellow with a triangle and red with a square, but also emphasize that this *D* score is very low in contrast to comparable IATs and would likely be eliminated after correcting for multiple comparisons. Authors believe that low power is unlikely to have resulted in null results.
Colour-shape associations	None (triangle/yellow, red/square to small degree)

Sakuta & Gyoba (2006) – Experiment 'recognition test'

N	Sample information	Shape stimuli	Colour stimuli	Controls
20	Undergraduate and graduate who were native Japanese speakers	24 target and 24 distracter shapes	24 target and 24 distracter colours	Stimuli presentation order was changed in each session.

Presentation	Participants had to memorize 48 colour-form pairs presented on a computer screen. They were then presented with one form as a recognition cue and had to choose the colour it had been paired with in the study phase from 3 colours (one target, two distractors). Participants then rated the colour-form pairs again for how the "impressions of colour and form matched each other" (fitness rating, p. 200).
Main findings	There were significant main effects of semantic differential factors (activity, potency, and evaluation), colour properties, and form properties as well as significant interaction effects (factors X colour, colour X form, factor X colour X form). For the semantic differential rated dimensions of activity and potency, colours and forms that were congruent in their rating on these scales (vs. incongruent) showed higher recognition performance. For the dimension of evaluation, incongruent colour-form pairs resulted in higher recognition performance than congruent pairs. Fitness ratings were higher for colour-form pairs that were congruent (vs. incongruent) in their ratings on the activity and potency dimensions. The reverse was true for the evaluation dimension. Although F values and degrees of freedom were reported it was not possible to differentiate which test belonged to which comparison, thus making it difficult to report partial eta squared effect sizes for each of the above tests. Parameters were between .047-.221 for the recognition

	performance tests of activity and potency, and between .030-.319 for the fitness comparisons of activity and potency.
Colour-shape associations	N/A

Spector & Maurer (2008) - Experiment 1, 2, 3

N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
1 – 50, 2 – 50, 3 - 40	1 (20 toddlers, 20 older children 10 adults), 2 (20 toddlers, 20 older children, 10 adults), 3 (40 toddlers)	X, O, A, G made out of transparent plexiglass.	Box coloured either half red, half green or half black, half white.	Experimenter was unaware which side of box stimulus was placed (except in Experiment 1). Validity trials were used to see whether participants were engaging with the task.

Presentation	Experiments 1 and 2: Each letter stimulus was placed in one side of a box, with each side coloured a different colour (black/white box/ or green/red box). Participants were shown the letter they were to search for (A/G for green/red box, X/O for the black/white box) whilst it was spoken out loud. Experiment 3: Each letter stimulus was placed in one side of a box, with each side coloured a different colour (black/white box/ or green/red box). Half of participants were shown the letter with no verbal label they were to search for, whilst half were only given a verbal letter but not shown the label (A/G for green/red box, X/O for the black/white box)
Main findings	Since the systematic review is focused on shapes rather than graphemes, only the results relevant to toddlers, none of which could identify all the letters presented to them correctly, will be presented here. Across all three experiments, toddlers were more likely to look for the stimulus in the expected direction (X-black, O-white, Experiment 1: Cohen's $d = 1.49$, Experiment 2: Cohen's $d = 2.27$, Experiment 3: Cohen's $d = 1.21$). This effect was extinguished to a random choice when the toddler only heard the sound of the letter without seeing it. For the red/green box, toddlers appeared to choose the sides to look for the letters A and G randomly.
Colour-shape associations	**X** – Black **O** – White

Spector & Maurer (2011) - Experiment 1

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	10	Toddlers	A, G, O, X	Black, white, green, and red each used to colour half of box always combining a chromatic with an achromatic colour (4 combinations)	Validity trials were used to see whether participants were engaging with the task.
Presentation	Each letter stimulus was placed in one side of a box, with each side coloured a different colour. Participants were looked for the letter in the box.				
Main findings	Preliterate toddlers were more likely to look for the O in the white sections and the X in the black section (Cohen's $d = 1.17$). Preliterate toddlers chose randomly for the letters A and G.				
Colour-shape associations	**O** – white **X** – black				

Spector & Maurer (2011) - Experiment 2

	N	Sample information	Shape stimuli	Colour stimuli	Controls
	50	20 toddlers, 20 older children, 10 adults	I, Z, B, Y	Blue, yellow, white, &black	Validity trials were used to see whether participants were engaging with the task.
Presentation	Participants looked for the I and Z in the black/white box and B and Y in the blue/yellow box.				
Main findings	All participants were more likely to look for the I in the white section and the Z in the black section, even the preliterate toddlers (for toddlers: Cohen's $d = 1.22$). For the B and Y letters, only older children and adults chose in the expected direction (blue/B, yellow/Y), toddlers responded randomly.				

Colour-shape associations	**I** – white **Z** – black

Spector & Maurer (2011) - Experiment 3

N	Sample information	Shape stimuli	Colour stimuli	Controls
40	Toddlers	I, Z	Black, white	Validity trials were used to see whether participants were engaging with the task.

Presentation	Half participants shown the letter with no verbal label they were to search for, whilst remainder were only given a verbal letter but not shown the label
Main findings	Preliterate toddlers were more likely to look for the stimulus in the expected direction (Z-black, I-white, Cohen's $d = 1.35$). This effect was extinguished to a random choice when the toddler only heard the sound of the letter without seeing it.
Colour-shape associations	**I** – white **Z** – black

Spector & Maurer (2011) - Experiment 4

N	Sample information	Shape stimuli	Colour stimuli	Controls
60	20 toddlers, 20 older children, 20 adults	Rounded and angular nonsense shaped	Black, white	One pair of angular/rounded shapes was matched on contour perimeter and another pair was matched for surface area. Validity trials were used to see whether participants were engaging with the task.

Presentation	Participants were asked to look for the shapes in half black, half white boxes.

Main findings	All participants – toddlers, older children, and adults – were more likely to look for the jagged angular shapes in the black sections, and for the rounded shapes in the white sections, as the authors predicted (for toddlers: Cohen's $d = .84$). They suggested that the existence in toddlers and preponderance into adulthood of the association of O and I with white and X and Z with black may be driven by the angularity of the shapes, which could in turn, the authors suggest, originate in experiences with the world, valence judgments (e.g., white/good, black/bad), or even natural biases that enable the learning of valence of judgments to bootstrap on such feature associations.
Colour-shape associations	**Angular/jagged** – black **Rounded** – white

Spector & Maurer (2011) - Experiment 5

N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
60	20 toddlers, 20 older children, 20 adults	E, M, C, T	Green, red, yellow, blue, black, white	Validity trials were used to see whether participants were engaging with the task.

Presentation	Participants had to search for the E and M in the red/green and black/white box and for the C and T in the yellow/blue and black/white box.
Main findings	The expected pairings based on the past literature the authors reviewed were E/green, M/red, C/yellow, and T/blue, and were chosen since they had no *prima facie* literary basis. For the C/T pair all participants chose in the expected direction (for toddlers: Cohen's $d = .96$). For the E/M pair only adults chose in the expected direction. Choices were random for all letters for the black/white boxes. The C/yellow pairing was stronger (toddlers Cohen's $d = .87$) across participants than the T/blue pairing.
Colour-shape associations	**C** - yellow

Spector & Maurer (2011) - Experiment 6

N	**Sample information**	**Shape stimuli**	**Colour stimuli**	**Controls**
20	Toddlers	E, M, C, T	Green, red, yellow, blue	Validity trials were used to see whether

					participants were engaging with the task.
Presentation	Participants had to search for E and M in the red/green box and C and T in the yellow/blue box.				
Main findings	Toddlers were more likely to look, as predicted, for C in the yellow section and T in the blue section (toddlers: Cohen's $d = .80$). Choices were random for searches for E and M in the red/green box. Individual analysis revealed that the effect for the C/T pair was driven only by toddlers associating C with yellow (toddlers: Cohen's $d = .75$).				
Colour-shape associations	**C** - yellow				

6.6 Instructions

The below table can be used by as a reference in regard to what instructions have been used in the past in order to highlight both commonalities and differences for future researchers. They can additionally be compared to the summary of the corresponding results in Appendix 6.4.

Table 6.4 Table showing a variety of the instruction used in colour-shape correspondence direct matching experiments. Instructions are either direct quotes of what was said to the participants (Q) or a description quoted straight from the article (D).

Experiment	Instructions	Quote of actual instruction (Q) or description taken straight from article (D)
Albertazzi, Da Pos *et al.* (2013; Experiment 1)	"You are about to take part in an experiment on the relationship between shape and color. You will be presented with a series of drawings, one at a time, representing a geometric shape. For each shape, you are asked to choose a color from the circle that you see as the one most naturally related to the shape, and to indicate your choice to the researcher, who will make a note of it and of the time it took to reach your decision. However, in your reply, please let accuracy take precedence over promptness." (p. 39)	Q
	"Before the experiment began, participants were expressly told to avoid making associations between the shapes presented and any past experience of those shapes, or similar ones, in certain colours (for instance, triangles or circles with a certain color used in road signs). In addition, when explaining the above instructions, the experimenter carefully avoided mentioning the use of color categories (e.g., red, green, blue, etc.)." (p. 39)	D

Albertazzi, Da Pos, *et al.* (2013, Experiment 2)	"You are about to take part in an experiment on the relationship between shape and color. You will be presented with a series of shapes, one at a time, representing a geometric figure. For each shape you are asked to choose a color from the circle that you see most naturally related to the shape, and double click to make your choice. You are allowed to change the color until you are satisfied with the result." (p. 42)	Q
Albertazzi, Malfatti, *et al.* (2015)	"At the centre of the screen you will see, one at a time, a series of 'angles' (figures formed by two intersecting lines) with different orientations. On the basis SOLELY of the impression produced by the width of the angle, colour the two lines that form the angle with the colour that you perceive as most closely matched with it. Take care NOT TO FAVOUR the colour or colours of the Hue Circle close to the edges of the figure in each presentation. You should not make associations between angle and colour on the basis of past experience. To perform the task, click on the colour that you associate with the angle. You can repeat your choice until you are satisfied with the result. When you are satisfied, click on the vertex of the coloured angle to confirm your choice definitively and go on to the next test. N.B.: once you have confirmed your choice, you cannot go back on it. Press the SPACE BAR to proceed." (p. 85)	Q
Campbell (1942)	"The Os sat facing the couch and gave their judgments orally to the experimenter. The instructions given orally to the Os were: "You will be shown a series of designs in different color-combinations. Disregard, as much as possible, your liking for both the designs and the colours. In the first group, the black and red, choose the design which seem to you to be the most fitting to the color-combination. Do likewise for each color-combination group." This choice will be referred to as Design Choice. When these judgements had been made, the following directions were read for the second part of the experiment: "Now that the judgments on the color groups have been made, I would like a similar judgment on the design groups. This time choose the color-combination which seems to you to be most fitting to the rectangular design, then the curve design, then the angle design." This choice will be referred to as Colour Choice." (p. 312)	D / Q
N. Chen, Tanaka, Matsuyoshi, &	"Participants seated in front of a computer-monitor and instructed to intuitively choose one color from the 40-color	D

Watanabe (2015a; Experiment 1)	patch [sic] that most naturally matches the centrally presented shape via a mouse click." (p. 102)	
N. Chen, Tanaka, Namatame, & Watanabe (2016; Experiment 1)	"The participants were instructed to choose the color that best matched each shape from the four-color wheel." (p. 3)	D
	"The participants were told not to make associations between the figure shown and past experiences, in order to avoid situations like that of Jacobsen's (2002) experiment, in which participants assigned yellow to the circle because of association with the sun, and red to the triangle because of association with road traffic signs. Participants were asked to avoid giving a colour to a figure because "it seems to be something," and although some of them said that it was very difficult not to do so, the abstract character of the figures in most of the cases made such similarities associations impossible.	
Dadam, Albertazzi, Da Pos, Canal, & Micciolo (2012)	Instructions given to participants.—"You are going to see a set of images, one at a time. Each image is presented with a coloured circle around it. Your task is choose, among the colours in the circle, the one which naturally best matches that image. To choose a colour, left click on it with the mouse. The image will change to the colour that you have chosen. If you click, again with the left mouse button, on another colour, the image's colour will change. You can change colours as many times as you want. When you have decided which colour is the best match with the image, click on the image with the right mouse button. Your answer will be re- corded, and a new image will be presented. There is no time limit. Take all the time you need for your choice. There are no wrong answers. Just express your perception, relating colour to image." (pp. 368-369)	D / Q
Chapter 2, Experiment 2A	"Participants were presented with a circle, square, and triangle at the top of the page. After filling in their occupation, gender, and nationality, as in the original Kandinsky questionnaire, the questionnaire asked participants to fill in "the 3 drawn shapes with 3 colours – yellow, red, and blue – and such that each shape is completely filled by one of the colours" and "If possible give an explanation for these choices." Below these statements, there was space to write an explanation for the colour-shape matches made."	D / Q

Chapter 2, Experiment 2B	"Looking at the above three shapes and three colours, pick what colour best matches each shape. Please try to answer as intuitively as possible. Try not to base your answer on past experiences of the world, but rather what feels right to you. There are no right or wrong answers but please avoid answering randomly."	Q
Chapter 2, Experiment 2C	"In this study you will be shown shapes and asked to match them with colours. Your answers should be based on your gut instincts - try to answer as intuitively as possible. Try to avoid basing your answer on past experiences, rather go with what simply feels right to you. There are no right or wrong answers. Avoid answering randomly." "Which of the three colours best matches the shape shown?"	Q
Dreksler & Spence (2019, Experiments 1-3)	" "For each shape please choose the colour that you think best matches it. There are no right or wrong answers. Please answer as intuitively as possible." For each shape, the participant chose one of the 36 colours and rated how intuitive they found their preceding match on a scale of 'I chose completely randomly' to 'This match feels very right.' " (p. 10)	D / Q
Dumitrescu (2003)	"Participants were asked to select the most proper combination of figure – color" (p. 3) "The respondents were asked to fill the median figures with the colours they though as being most appropriate" (pp. 3-4)	D
Dumitrescu (2011)	"subjects who were asked to assess the appropriateness of shape-colour combination by marking each shape with a number from 1 to 5. ("1" corresponds to the most inappropriate combination and "5" to the perfect combination.)" (p. 1042)	D
Jacobsen (2002)	"They were instructed to assign the three colours to the three figures on the paper in a one-to-one manner by completely coloring the forms and to provide a rationale for their assignment choices, if they could provide one. In the Aesthetic-correspondence condition, participants were also instructed to produce the most beautiful, the aesthetically most pleasing, assignment (for the use of the word "beautiful" in an aesthetic preference instruction, see Jacobsen & Höfel, 2001; Jacobsen & Schröger, unpublished)." (pp. 906-907)	D

Jacobsen & Wolsdorff (2007)	"asked to assign the three basic colours to the three basic forms under the Aesthetic- Correspondence instruction (see above)" (p. 24) "... an augmented instruction by additionally asking for the most beautiful assignment of colours to forms." (p. 21)	D
Kharkhurin (2012, Experiment 1)	"On three respective white screens participants were asked to select a form (triangle, square, or circle) coloured in yellow, red, and blue that feels "right" to them as well as to list the criteria and present the explanation for their choice" (p. 173)	D
Kharkhurin (2012, Experiment 2)	"Participants were instructed to indicate their preference by using the mouse click on the drawing that feels "right" to them." (p. 177)	D
Holmes & Zanker (2013)	"Participants were presented with samples of eight coloured shapes and instructed to look for the most aesthetically pleasing shape, the specific target, circle, square or triangle being indicated via an onscreen instruction at the start of each 10-generation run." (p. 4)	D
Lindauer (1973)	"Ss were asked to image a form to each color, if they could, and to do this as spontaneously and immediately as possible (to reduce the possibility of associations rather than images being given)." (p. 165)	D
Malfatti (2014, Experiments 4 and 5)	"During this experiment you will see a series of 44 lines (or 45 shapes), one at a time, with the set of colours below. For each line [or shape] you will be asked to choose the three colours from the set that are MOST consistent with the line [or shape]. Click on the most consistent color first, then the next most consistent, and so on. Then, you will be prompted to click on the three colours that are LEAST consistent with the line [or shape]. Again, click on the color that is least consistent first, then click on the next least consistent, and so on. Make your selection by clicking on the coloured sample. Each time you make your selection, it will disappear. If you have any questions, please ask them now, otherwise, you may click to begin!" (p. 53) "Here is an overview of the lines [or shapes] you will be asked to judge. Please take a moment to look at all the lines [or shapes]. When you are ready, please click to begin the experiment". (pp. 53-54)	Q
Malfatti (2014, Experiments 4 and 5)	"A note at the bottom of the screen reported the written instructions for the ongoing display to avoid confusion during the execution of task, i.e. "Please select the three colours that are MOST consistent with the line [or shape].	Q / D

	Please, select the one that is most consistent first, then select the one that is next most consistent and so on" ('Most Consistent' condition/display), or "Please select the three colours that are LEAST consistent with the line [or shape]. Please, select the one that is least consistent first, then select the one that is next least consistent and so on" ('Least Consistent' condition/display)." (p. 54)	
Welsh (1974)	"Study I Ss were given a sheet divided into twelve areas with the names of the twelve colours placed in the lower part of each area. Instructions were: Studies in color symbolism and empirical aesthetics have suggested that there may be an association between color and visual form. To help in this research you are asked to draw or sketch for each color listed below a geometric form or shape that seems to be appropriate or to go "go" with that color Study II Ss were given a sheet with the twelve forms depicted in Figure 1 which was covered by a sheet of instructions as follows: Studies in color symbolism and empirical aesthetics have suggested that there may be an association between color and visual form. That is, certain colours seem to be appropriate for particular shapes. On the attached sheet are twelve different geometric figures. You are asked to write underneath each one the name of the color you think seems to "go" best with that form. Study III Ss were given the sheet of forms with instructions modified by adding to the last sentence of the Study II cover sheet the words, "...using the twelve colours listed below." The names of the colours were arranged alphabetically and at the bottom another sentence was added, "Please use just the colours on this list and use each color only once in matching the colours and the forms." (p. 12)	D/ Q

6.7 Creativity Trait Measure

Rate yourself as truthfully as possible for the below statements on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree).

- I consider myself to be creative
- I have many wild ideas
- Little can emotionally move me more than music
- I come up with a lot of ideas or solutions other people have never thought of
- I have a talent for at least one visual art
- I don't really care how something looks, function is more important (R)
- I am very musical
- I rarely have original ideas (R)
- I consider myself to be an artist
- I often feel like associations between ideas, concepts or images form easily in my mind
- When writing creatively, scientifically, or at work I often feel stuck about what to put down on paper (R)
- I experience very strong feelings when I look at art
- Colours have a noticeable effect on my mood
- I find thinking about outlandish impossible ideas exhausting and useless (R)
- I notice very quickly how aesthetic something is

- The way things are designed is generally (e.g., websites, household items, clothing) very important to me

Items marked (R) were reversed scored.

6.8 CIELAB Values of Colour Stimuli

Table 6.5 A table of the CIELAB values of all colour stimuli used in Experiments 2B, 2C, 3A, 3B, 3C, 3D, and 4A. Note that all colours are the same across experiments if they reappear. The only small deviation is in Experiment 2B-2C where the lightness value of the saturated blue is 30 instead of 29 as in the other experiments. The difference is immensely difficult to detect even on high quality retina display screens.

	L* value (dark/light)	A* axis (green/red)	B* axis (blue/yellow)
Experiment 2B-2C			
Saturated blue	30	68	-112
Saturated red	54	81	70
Saturated yellow	98	-16	93
Experiment 3A-3D			
Light red	64	59	32
Saturated red	54	81	70
Dark red	32	55	47
Light orange	76	31	46
Saturated orange	63	57	73
Dark orange	39	38	50
Light yellow	97	-12	69
Saturated yellow	98	-16	93
Dark yellow	62	-10	64
Light green	92	-48	62
Saturated green	89	-68	83
Dark green	56	-46	57
Light aquamarine	91	-48	2
Saturated aquamarine	90	-61	9

Dark aquamarine	56	-41	6
Light sky	94	-31	-10
Saturated sky	91	-51	-15
Dark sky	57	-34	-11
Light blue	50	35	-78
Saturated blue	29	68	-112
Dark blue	15	47	-77
Light purple	57	51	-66
Purple	37	73	-99
Dark purple	21	51	-66
Light pink	67	69	-34
Saturated pink	58	89	-36
Dark pink	35	61	-26
Light brown	49	17	32
Saturated brown	41	31	51
Dark brown	27	22	38
White	100	0	0
Light grey	82	0	0
Grey	63	0	0
Dark grey	43	0	0
Darkest grey	21	0	0
Black	0	0	0

EXPERIMENT 4A

Saturated red	54	81	70
Saturated yellow	98	-16	93
Saturated green	89	-68	83

Saturated blue	29	68	-112
Saturated pink	58	89	-36

6.9 Chi-square analyses for Experiments 3A, 3B, 3C, and 3D

As discussed in Chapter 1 and Chapter 3, one of the most common ways that many colour-shape correspondence studies have evaluated whether there are significant colour-shape associations is through Chi-square analyses of the categorical factors of shape and colour categories. Whilst it has been detailed in depth above why these are unsatisfactory methods of analysis, they are helpful for other researchers to have a first-hand look at the data (and allow researchers conducting systematic reviews and meta-analyses, as seen in Chapter 1, to further analyse the data). The results will be presented here for this purpose for the interested reader. In order to avoid cell counts that may be too small during Chi-square analyses, the thirty-six colours were grouped into twelve triplets by colour hue as described in Figure 3.4 (red, orange, yellow, green, aquamarine, sky, blue, purple, pink, brown, white/grey, grey/black). Pearson Chi-square analyses were conducted on the cross-tabulated data to determine whether colour and shape were significantly associated for each stimuli set in Experiments 3A, 3B, 3C, and 3D. Colour and shape revealed significant associations for geometric shapes in both Experiments 3A ($\chi 2$ (627) = 1052.22, $p < .001$, Cramér's $V = .16$) and 3D ($\chi 2$ (627) = 5312.56, $p < .001$, Cramér's $V = .12$). For mandala shapes, significant associations were only found in Experiment 3D ($\chi 2$ (165) = 1679.08, $p < .001$, Cramér's $V = .13$). For RF shapes, significant associations between colours and shapes were found in both Experiments 3C ($\chi 2$ (121) = 226.06, $p < .001$, Cramér's $V = .15$) and 3D ($\chi 2$ (121) = 949.01, $p < .001$, Cramér's $V = .11$).

A residual analysis was conducted in order to determine whether the count in each cell was significantly higher or lower than expected. The results can be seen in Table 6.6 for geometric shapes, in Table 6.7 for mandala shapes, and in Table 6.8 for RF shapes, for both experiments that used these stimuli. Each cell in these tables indicates the percentage of individuals choosing the corresponding column's colour for each row's shape. When the adjusted standardized residual for each cell was above 2, indicating this colour was chosen more frequently than expected, this is indicated by bold type. If the adjusted standardized residual for each cell was below 2, indicating this colour was chosen less frequently than expected, this is indicated by underlined type. For each shape these results are presented both for the initial experiment (3A, 3B, or 3C) in the first row next to each shape, and for Experiment 3D in the second row.

But, as noted, others may be interested in what colours deviate from chance-level when an equal distribution is expected across the colour hues for each shapes. The same tables can be used to examine this in two ways. First, the most chosen shapes in each experiment (by percentage) are highlighted in dark blue. Second, the most chosen shapes are highlighted in light blue. Additionally, the following guidelines are presented, which can be interpreted as described above for residual analysis:

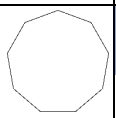
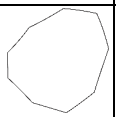
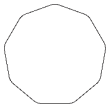
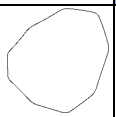
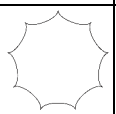
- For Experiment 3A's geometric shapes, any percentage of 0% would equate to a standardised residual below the -2 mark, and any percentage of 15.6% or above would equate to a standardised residual of 2 or above.

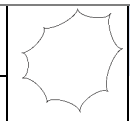
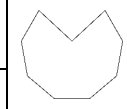
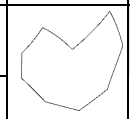
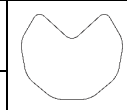
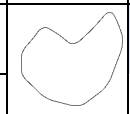
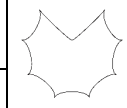
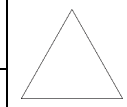
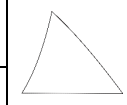
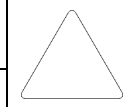
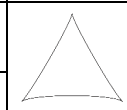
- For Experiment 3B's mandala shapes, any percentage of 0% would equate to a standardised residual below the -2 mark, and any percentage of 16.2% or above would equate to a standardised residual of 2 or above.
- For Experiment 3C's RF shapes, any percentage of 1.3% or below would equate to a standardised residual below the -2 mark, and any percentage of 16% or above would equate to a standardised residual of 2 or above.
- For all stimuli sets of Experiment 3D, any percentage of 5.8% or below would equate to a standardised residual below the -2 mark, and any percentage of 10.8% or above would equate to a standardised residual of 2 or above.

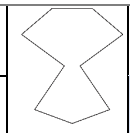
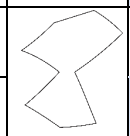
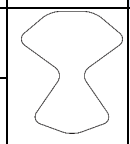
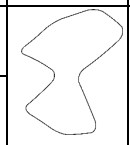
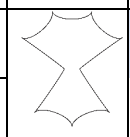
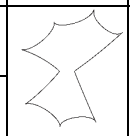
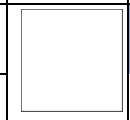
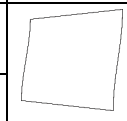
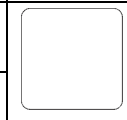
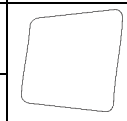
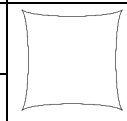
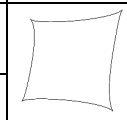
The focus in Chapter 3 is on determining whether there are shape characteristics that can predict chosen colour properties, the analysis of these Chi-square tables since will be brief since this type of data strongly restricts the type of analysis that can be conducted and should be taken with a grain of salt for the violations of the statistical assumption of independence. The fact that the Chi-square tests are statistically significant for all but one of the six tests certainly points to the fact that there is a deviation from the type of distribution would be expected from chance. Additionally, for some shapes, in some stimuli sets, the most common, or second most common colour choices do align between the two experiments, but this is by no means always the case, or even most commonly the case. This would be quite surprising since even with three shapes and three colours, as seen in Chapter 2, there is still notable variation in individual's colour-shape correspondences. Moreover, sometimes two experiments

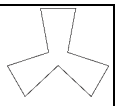
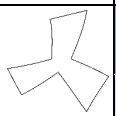
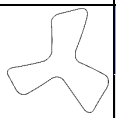
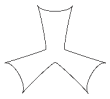
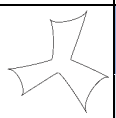
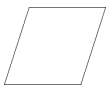
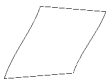
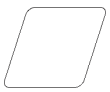
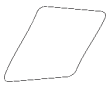
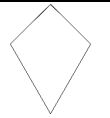
strongly disagree: For example, for mandala shapes in Experiment 3B yellow was chosen 5.9% of the time for shape 5, whilst yellow was chosen 41.3% of the time in Experiment 3D for the same shape. Additionally, sometimes shapes may show strong agreement on one colour hue and yet show varying trends in terms of what other colour hues are often chosen for that shape.

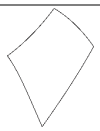
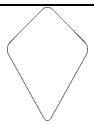
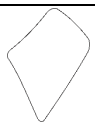
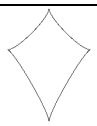
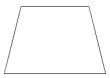
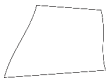
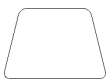
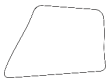
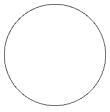
*Table 6.6 A contingency table showing the percentage of individuals choosing each colour triplet for each geometric shape in Experiment 3A and 3D (first and second row, respectively, for each shape) and the positive (**bold**) and negative (underlined) adjusted standardized residuals of those cells above 2 and below -2, respectively. The 'average' row represents the average percentage of individuals choosing each colour category across all shapes. Colour hue triplets chosen the most for each shape separately (by percentage) are highlighted in dark blue, whilst the second most commonly chosen colour hue triplets are highlighted in light blue.*

	Shape	Red	Orange	Yellow	Green	Aquamarine	Sky	Blue	Purple	Pink	Brown	White-Grey	Grey-Black
1		17.2	3.1	7.8	6.3	6.3	9.4	**15.6**	4.7	6.3	9.4	6.3	7.8
		12.0	3.9	7.1	6.2	7.9	5.8	14.8	8.3	7.2	3.4	**17.3**	6.2
2		3.1	4.7	12.5	6.3	3.1	7.8	7.8	9.4	6.3	6.3	20.3	12.5
		8.1	4.1	9.3	7.6	8.8	6.2	**13.4**	6.9	9.9	4.2	**17.1**	4.4
3		**23.4**	1.6	4.7	6.3	6.3	7.8	6.3	7.8	**15.6**	6.3	9.4	4.7
		14.1	**8.3**	**15.0**	10.9	6.3	4.1	7.6	5.1	5.3	4.1	8.5	**10.8**
4		3.1	9.4	7.8	9.4	0	3.1	9.4	10.9	3.1	**14.1**	**25.0**	4.7
		12.0	6.3	**15.5**	**13.4**	6.2	4.6	6.2	4.8	5.8	4.4	9.2	**11.6**
5		7.8	1.6	**34.4**	7.8	6.3	9.4	4.7	3.1	6.3	1.6	9.4	7.8
		9.7	7.6	**15.0**	**15.5**	6.0	4.8	9.9	5.1	5.3	3.4	9.7	**8.1**

6		15.6	3.1	**23.4**	9.4	4.7	3.1	3.1	4.7	7.8	1.6	10.9	12.5
		8.3	6.9	13.8	**16.0**	8.1	4.6	7.2	5.3	8.1	4.9	7.6	**9.2**
7		4.7	6.3	**35.9**	3.1	3.1	6.3	7.8	0	3.1	6.3	9.4	14.1
		16.0	7.1	**16.9**	12.3	5.8	3.4	5.6	4.9	6.2	3.2	7.1	**11.5**
8		10.9	9.4	**25.0**	9.4	4.7	7.8	4.7	6.3	4.7	6.3	6.3	4.7
		12.3	**9.2**	12.9	**14.1**	4.9	4.6	7.1	5.6	7.1	4.4	8.1	**9.7**
9		7.8	3.1	**34.4**	7.8	0	6.3	6.3	6.3	9.4	6.3	6.3	6.3
		10.2	5.8	7.2	5.5	9.9	6.7	**17.6**	6.3	7.1	3.9	**13.4**	6.3
10		14.1	4.7	18.8	6.3	7.8	9.4	4.7	3.1	9.4	**14.1**	4.7	3.1
		6.9	3.9	7.9	6.3	9.7	7.9	12.7	7.4	10.1	5.3	**17.5**	4.4
11		3.1	1.6	10.9	4.7	3.1	0	10.9	10.9	7.8	3.1	4.7	**39.1**
		8.8	6.0	6.5	5.3	**11.6**	**8.5**	**17.3**	7.6	6.7	4.4	12.2	5.1
12		7.8	6.3	**25.0**	6.3	1.6	1.6	9.4	4.7	9.4	6.3	7.8	14.1
		6.7	6.7	8.5	7.1	9.0	**8.6**	**15.5**	7.6	6.9	4.6	12.2	6.7
13		**28.1**	6.3	**20.3**	7.8	1.6	0	6.3	12.5	3.1	3.1	7.8	3.1
		9.3	6.3	12.0	6.2	8.5	8.1	11.3	7.6	8.5	3.9	**13.2**	5.1
14		14.1	6.3	9.4	9.4	**12.5**	4.7	12.5	3.1	0	3.1	17.2	7.8
		9.7	6.2	11.3	7.2	7.9	7.1	12.0	6.2	8.8	4.4	**15.0**	4.2
15		**32.8**	6.3	**21.9**	7.8	0	4.7	12.5	3.1	1.6	3.1	3.1	3.1
		15.0	5.1	**15.3**	7.9	7.9	7.4	12.7	5.5	10.1	2.1	7.4	3.5
16		12.5	6.3	12.5	7.8	3.1	9.4	14.1	1.6	4.7	3.1	17.2	7.8
		9.3	7.4	11.1	7.8	9.7	**8.5**	9.7	6.9	10.1	3.4	11.5	4.8
17		17.2	3.1	15.6	10.9	4.7	6.3	4.7	10.9	9.4	9.4	4.7	3.1
		13.4	7.9	12.0	8.8	8.1	**9.2**	9.9	7.1	9.2	4.2	6.2	4.1
18		7.8	9.4	14.1	12.5	6.3	6.3	**17.2**	4.7	3.1	3.1	14.1	1.6
		7.8	7.9	9.0	6.3	8.5	**9.2**	10.4	7.9	**13.1**	4.2	11.1	4.6

19		7.8	9.4	14.1	10.9	3.1	6.3	6.3	3.1	**15.6**	7.8	7.8	7.8
		13.6	5.1	**17.3**	6.5	9.7	7.2	11.6	5.6	9.9	2.1	6.7	4.6
20		7.8	6.3	9.4	7.8	4.7	10.9	6.3	7.8	10.9	10.9	6.3	10.9
		12.9	6.0	13.9	7.9	7.6	8.1	10.2	7.1	12.2	3.9	6.5	3.7
21		6.3	7.8	10.9	7.8	**12.5**	10.9	3.1	7.8	10.9	6.3	9.4	6.3
		8.5	4.9	6.7	8.5	7.4	5.3	**13.9**	5.1	7.2	**7.1**	**16.2**	**9.2**
22		4.7	6.3	12.5	12.5	6.3	7.8	6.3	9.4	9.4	7.8	10.9	6.3
		5.6	4.6	8.3	7.8	7.8	7.6	10.6	8.3	10.2	**5.8**	**16.6**	6.9
23		10.9	12.5	14.1	9.4	3.1	0	7.8	3.1	10.9	6.3	7.8	14.1
		7.8	5.3	6.9	9.0	7.6	6.7	**15.5**	5.3	5.8	**7.1**	**13.6**	**9.5**
24		10.9	9.4	12.5	**15.6**	9.4	9.4	6.3	3.1	4.7	3.1	7.8	7.8
		5.6	6.2	6.3	9.9	9.9	8.1	12.5	7.4	8.8	**6.5**	**12.7**	6.0
25		17.2	7.8	9.4	9.4	1.6	3.1	12.5	4.7	6.3	3.1	12.5	12.5
		10.2	4.4	8.6	6.7	**10.1**	7.1	**13.8**	5.8	6.9	**5.8**	**15.7**	4.9
26		7.8	7.8	3.1	7.8	3.1	9.4	6.3	9.4	9.4	6.3	**21.9**	7.8
		9.3	5.6	8.3	10.6	7.4	6.2	10.2	5.3	11.6	5.1	**14.8**	5.5
27		15.6	6.3	3.1	7.8	4.7	4.7	**17.2**	6.3	6.3	1.6	12.5	14.1
		16.9	4.6	**15.0**	5.6	2.8	4.9	12.0	4.1	5.6	1.6	**19.9**	6.9
28		4.7	7.8	4.7	7.8	9.4	12.5	**17.2**	6.3	4.7	4.7	10.9	9.4
		7.8	**12.7**	14.1	4.4	5.3	4.8	8.5	2.6	5.8	4.9	23.5	5.6
29		14.1	6.3	10.9	9.4	1.6	4.7	4.7	10.9	4.7	7.8	18.8	6.3
		8.1	**11.1**	9.2	2.5	5.3	5.3	7.9	5.5	6.3	**5.6**	**29.5**	3.7
30		17.2	4.7	3.1	7.8	7.8	7.8	9.4	6.3	4.7	6.3	18.8	6.3
		6.5	**10.8**	11.8	6.3	6.0	4.9	7.9	3.5	4.9	5.1	**25.4**	6.7
31		14.1	6.3	6.3	10.9	6.3	1.6	7.8	3.1	3.1	3.1	14.1	**23.4**

		8.5	6.3	12.5	**6.3**	10.4	6.9	11.8	5.1	**14.6**	3.0	11.6	2.8
32		17.2	9.4	4.7	9.4	6.3	3.1	7.8	7.8	7.8	3.1	9.4	14.1
		11.5	7.8	9.9	7.1	8.1	6.9	10.1	7.9	**18.2**	3.0	4.1	5.6
33		14.1	6.3	6.3	12.5	7.8	6.3	9.4	9.4	4.7	1.6	10.9	10.9
		9.0	4.6	9.7	8.1	7.8	5.5	**15.2**	**10.8**	**16.8**	3.2	5.1	4.4
34		10.9	3.1	7.8	9.4	9.4	7.8	7.8	10.9	9.4	4.7	9.4	9.4
		13.2	5.5	10.9	7.4	6.5	7.8	12.5	8.3	**13.9**	1.9	5.1	6.9
35		17.2	6.3	6.3	7.8	9.4	4.7	3.1	6.3	6.3	6.3	12.5	14.1
		8.6	5.6	13.4	8.3	9.3	6.7	10.2	6.0	11.1	3.4	**12.5**	4.8
36		15.6	3.1	9.4	7.8	9.4	6.3	7.8	3.1	6.3	6.3	12.5	12.5
		12.0	7.2	12.0	6.0	8.6	7.4	11.6	8.1	**13.2**	2.5	5.3	6.0
37		7.8	4.7	4.7	9.4	6.3	6.3	**18.8**	3.1	4.7	7.8	14.1	12.5
		10.8	5.3	10.6	7.9	8.3	8.3	**15.5**	7.1	10.4	3.0	7.4	5.5
38		6.3	9.4	7.8	7.8	1.6	7.8	9.4	10.9	6.3	7.8	**23.4**	1.6
		10.6	3.5	7.4	7.1	7.4	7.9	11.8	**11.6**	**13.1**	3.9	6.0	**9.7**
39		15.6	6.3	3.1	7.8	10.9	9.4	6.3	4.7	7.8	4.7	14.1	9.4
		10.2	7.8	10.9	6.7	**11.1**	6.3	10.1	7.1	**13.6**	2.1	10.8	3.4
40		7.8	7.8	9.4	7.8	4.7	12.5	6.3	7.8	3.1	1.6	20.3	10.9
		12.2	5.3	11.8	7.9	8.6	6.2	9.7	**9.7**	**16.8**	3.4	4.1	4.4
41		10.9	6.3	6.3	7.8	7.8	12.5	10.9	4.7	9.4	7.8	12.5	3.1
		11.8	7.1	9.5	8.1	6.0	6.9	**13.8**	**10.2**	**15.5**	3.0	4.1	4.1
42		14.1	6.3	6.3	6.3	3.1	7.8	9.4	4.7	10.9	6.3	17.2	7.8
		11.8	5.5	11.1	5.6	6.5	5.1	**13.6**	**10.4**	**14.5**	2.5	5.8	**7.6**
43		**20.3**	3.1	10.9	6.3	7.8	7.8	4.7	4.7	**15.6**	4.7	9.4	4.7
		9.7	5.1	14.8	8.3	9.0	7.6	10.9	5.6	11.5	2.1	10.8	4.6

44		18.8	7.8	9.4	10.9	7.8	4.7	6.3	3.1	9.4	4.7	15.6	1.6
		12.3	5.3	12.9	6.7	7.9	7.2	**14.1**	7.8	**14.5**	2.6	4.8	3.9
45		12.5	4.7	9.4	4.7	7.8	10.9	7.8	3.1	**15.6**	6.3	14.1	3.1
		12.3	4.6	13.8	6.7	8.3	6.2	**13.4**	6.3	**12.7**	3.0	7.8	4.9
46		14.1	9.4	9.4	9.4	9.4	7.8	9.4	3.1	9.4	9.4	7.8	1.6
		13.9	3.9	9.5	6.7	7.8	**9.2**	9.9	**10.8**	9.9	2.6	7.6	**8.3**
47		**20.3**	6.3	12.5	6.3	3.1	12.5	4.7	7.8	10.9	1.6	7.8	6.3
		5.6	2.5	8.5	**47.6**	7.2	2.6	4.1	3.4	11.8	2.1	2.6	1.9
48		14.1	4.7	14.1	1.6	6.3	7.8	9.4	9.4	**14.1**	0	15.6	3.1
		10.8	6.2	14.3	**14.5**	8.5	3.2	7.9	6.3	9.7	4.4	6.0	**8.3**
49		**20.3**	6.3	6.3	12.5	0	4.7	10.9	9.4	4.7	6.3	12.5	6.3
		6.9	3.9	10.8	**40.0**	7.6	4.8	5.6	4.2	9.9	1.2	3.9	1.2
50		4.7	7.8	10.9	6.3	9.4	9.4	12.5	7.8	4.7	3.1	15.6	7.8
		9.5	5.6	**15.5**	**13.2**	9.9	4.6	11.1	3.9	9.0	**6.3**	6.5	4.8
51		10.9	4.7	1.6	9.4	6.3	10.9	10.9	**12.5**	0	10.9	9.4	12.5
		9.0	6.5	14.1	**21.7**	7.1	6.3	8.6	6.3	10.8	3.2	4.1	2.3
52		10.9	10.9	7.8	4.7	9.4	9.4	12.5	9.4	9.4	4.7	9.4	1.6
		11.1	**8.8**	**18.9**	**13.2**	5.5	6.9	7.8	5.6	10.1	3.9	3.9	4.4
53		4.7	3.1	9.4	6.3	10.9	**15.6**	9.4	4.7	4.7	4.7	17.2	9.4
		9.5	6.0	14.5	**19.2**	8.3	8.1	9.0	5.6	9.9	3.9	3.9	2.1
54		14.1	10.9	10.9	7.8	0	9.4	7.8	**15.6**	6.3	4.7	10.9	1.6
		11.6	**8.8**	**21.7**	10.9	6.3	6.2	7.6	4.1	10.1	4.9	4.2	3.5
55		**20.3**	3.1	**23.4**	0	0	3.1	12.5	0	6.3	4.7	18.8	7.8
		9.2	6.7	**15.7**	**18.9**	5.5	5.8	10.1	6.5	12.0	2.8	3.9	3.0
56		7.8	10.9	4.7	9.4	6.3	9.4	4.7	3.1	6.3	10.9	**23.4**	3.1

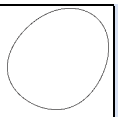
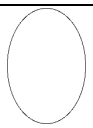
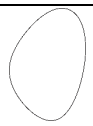
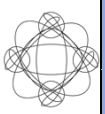
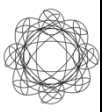
		**14.3**	5.5	**23.5**	11.8	5.5	4.2	10.2	3.5	10.6	2.8	3.7	4.4
57		3.1	**17.2**	17.2	6.3	4.7	1.6	3.1	7.8	6.3	6.3	**25.0**	1.6
		12.2	5.6	**17.5**	12.5	7.1	5.8	10.9	4.8	**14.1**	3.5	3.4	2.6
58		3.1	12.5	15.6	6.3	9.4	6.3	4.7	1.6	1.6	**12.5**	**23.4**	3.1
		15.9	7.1	**24.7**	8.5	6.7	3.5	7.2	5.6	8.8	3.5	3.2	5.3
Average 3A		12.2	6.6	12.0	8.0	5.6	7.0	8.6	6.3	7.1	5.8	12.7	8.1
Average 3D		10.5	6.2	12.3	10.3	7.7	6.4	10.9	6.5	10.1	3.8	9.8	5.6

*Table 6.7 A contingency table showing the percentage of individuals choosing each colour triplet for each mandala shape in Experiment 3B and 3D and the positive (**bold**) and negative (underlined) adjusted standardized residuals of those cells above 2 and below -2, respectively. The 'average' row represents the average percentage of individuals choosing each colour category across all shapes. Colour hue triplets chosen the most for each shape separately (by percentage) are highlighted in dark blue, whilst the second most commonly chosen colour hue triplets are highlighted in light blue.*

	Shape	Red	Orange	Yellow	Green	Aquamarine	Sky	Blue	Purple	Pink	Brown	White-Grey	Grey-Black
1		5.9	7.4	8.80	13.20	5.90	7.40	**20.60**	5.90	10.30	7.40	2.90	4.40
		26.1	7.8	10.40	7.20	6.90	4.10	7.10	6.50	8.30	3.20	7.20	5.30
2		14.7	**17.60**	7.40	4.40	2.90	4.40	7.40	8.80	11.80	7.40	5.90	7.40
		9.90	4.80	12.30	6.20	5.60	4.60	7.10	**7.80**	8.80	**12.70**	**10.90**	**9.30**
3		16.20	5.90	5.90	5.90	10.30	1.50	14.70	8.80	16.20	5.90	5.90	2.90
		21.70	**9.00**	11.50	7.80	7.80	4.40	**9.70**	5.60	8.50	4.10	5.80	4.20
4		8.80	10.30	8.80	1.50	7.40	7.40	8.80	14.70	8.80	2.90	7.40	13.20
		7.20	7.10	8.80	5.80	6.70	**6.20**	8.50	5.60	7.10	**12.30**	**15.90**	8.80

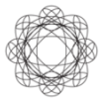
5		13.20	4.40	5.90	13.20	11.80	8.80	7.40	4.40	8.80	5.90	7.40	8.80
		10.80	7.60	**41.30**	5.80	3.70	3.20	4.60	5.10	6.70	1.90	5.30	4.10
6		7.40	11.80	11.80	2.90	4.40	2.90	8.80	14.70	13.20	.00	7.40	**14.70**
		12.00	5.80	**31.60**	9.50	4.60	4.20	4.10	5.30	8.60	2.10	7.60	4.60
7		11.80	1.50	11.80	8.80	10.30	4.40	10.30	11.80	11.80	2.90	10.30	4.40
		8.60	7.20	**34.20**	7.10	4.60	3.70	7.20	2.50	8.50	5.30	3.70	7.40
8		11.80	4.40	11.80	8.80	11.80	.00	11.80	8.80	10.30	2.90	2.90	**14.70**
		7.40	7.80	**16.90**	8.60	7.40	3.90	7.80	5.60	9.90	**10.40**	8.50	5.80
9		8.80	8.80	8.80	7.40	13.20	5.90	10.30	5.90	11.80	4.40	8.80	5.90
		7.60	7.90	**30.70**	8.80	5.10	4.60	4.80	4.80	7.40	7.60	5.60	5.10
10		10.30	8.80	7.40	4.40	.00	5.90	19.10	8.80	23.50	.00	8.80	2.90
		6.00	7.20	17.60	8.60	5.50	**6.50**	8.30	6.20	9.50	**12.70**	7.60	4.20
11		10.30	13.20	8.80	5.90	4.40	7.40	13.20	10.30	8.80	4.40	8.80	4.40
		9.20	6.50	18.50	9.70	3.70	3.50	6.00	4.80	7.90	4.20	3.20	**22.80**
12		**19.10**	8.80	8.80	5.90	7.40	8.80	14.70	7.40	10.30	1.50	2.90	4.40
		9.50	6.90	17.50	9.70	6.20	4.10	5.10	4.60	9.70	5.30	4.80	**16.80**
13		7.40	10.30	11.80	8.80	13.20	2.90	10.30	10.30	8.80	2.90	4.40	8.80
		27.70	5.50	21.20	**11.10**	4.10	3.70	6.20	4.10	5.80	2.30	5.80	2.60
14		5.90	10.30	13.20	4.40	11.80	2.90	7.40	14.70	10.30	5.90	2.90	10.30
		12.00	6.30	16.80	11.80	**8.10**	4.40	**10.60**	4.10	5.30	3.00	**12.50**	5.10
15		14.70	10.30	8.80	8.80	5.90	5.90	16.20	4.40	10.30	2.90	4.40	7.40
		27.20	6.70	**24.90**	6.90	6.50	3.90	6.00	1.90	5.50	1.60	5.80	3.20
16		7.40	5.90	4.40	8.80	2.90	8.80	11.80	5.90	17.60	4.40	5.90	**16.20**
		10.80	6.70	15.50	10.60	**7.90**	6.00	**10.80**	5.10	7.90	4.10	**11.80**	2.80
Average 3B		10.80	8.70	9.00	7.10	7.70	5.30	12.00	9.10	12.00	3.90	6.10	8.20
Average 3D		13.30	6.90	20.60	8.50	5.90	4.40	7.10	5.00	7.80	5.80	7.60	7.00

*Table 6.8 A contingency table showing the percentage of individuals choosing each colour triplet for each RF shape in Experiment 3C and 3D and the positive (**bold**) and negative (underlined) adjusted standardized residuals of those cells above 2 and below -2, respectively. The 'average' row represents the average percentage of individuals choosing each colour category across all shapes. Colour hue triplets chosen the most for each shape separately (by percentage) are highlighted in dark blue, whilst the second most commonly chosen colour hue triplets are highlighted in light blue.*

		Red	Orange	Yellow	Green	Aquamarine	Sky	Blue	Purple	Pink	Brown	White-Grey	Grey-Black
	Shape												
1		9.3	1.3	5.3	**37.3**	6.7	6.7	5.3	4.0	**20.0**	1.3	.0	2.7
		17.1	**8.3**	**22.2**	**12.0**	5.3	6.3	6.0	4.2	7.2	1.9	6.9	2.5
2		10.7	4.0	14.7	10.7	6.7	4.0	**16.0**	6.7	5.3	2.7	8.0	**10.7**
		11.5	6.3	**17.1**	8.5	8.5	7.6	11.3	3.2	6.2	4.4	11.3	4.2
3		9.3	4.0	10.7	**24.0**	9.3	4.0	9.3	5.3	21.3	1.3	.0	1.3
		8.8	7.4	10.4	5.5	9.0	5.1	7.1	**9.2**	**11.6**	**9.7**	6.0	**10.2**
4		12.0	4.0	14.7	14.7	6.7	4.0	8.0	1.3	2.7	2.7	**20.0**	**9.3**
		7.8	6.2	11.6	6.2	6.3	5.8	8.1	7.4	**13.2**	**11.8**	7.4	8.1
5		6.7	1.3	18.7	13.3	10.7	8.0	8.0	**14.7**	9.3	4.0	4.0	1.3
		7.8	**9.0**	8.1	7.8	8.6	7.9	9.2	6.2	11.1	**11.1**	8.5	4.8
6		16.0	9.3	17.3	12.0	5.3	9.3	12.0	2.7	6.7	2.7	2.7	4.0
		7.1	6.0	9.7	9.2	7.4	7.2	8.3	7.4	**11.6**	**11.5**	8.3	6.3
7		9.3	6.7	20.0	9.3	8.0	4.0	14.7	9.3	13.3	1.3	2.7	1.3
		12.3	5.1	13.2	9.2	8.3	3.2	8.6	7.4	12.0	5.3	3.7	**11.6**
8		**21.3**	9.3	13.3	12.0	6.7	6.7	5.3	6.7	5.3	5.3	4.0	4.0

		9.3	6.9	**13.9**	**10.9**	5.5	6.7	7.2	4.4	**12.3**	6.0	5.6	**11.1**
9		8.0	**12.0**	22.7	12.0	4.0	2.7	8.0	8.0	12.0	1.3	2.7	6.7
		17.1	3.2	6.2	4.6	4.9	4.6	**17.8**	4.4	3.7	2.6	**17.3**	**13.6**
10		13.3	10.7	21.3	9.3	2.7	6.7	6.7	10.7	6.7	2.7	8.0	1.3
		9.0	3.9	6.9	4.2	8.3	6.9	**14.8**	6.5	8.5	5.1	**19.9**	6.0
11		10.7	6.7	6.7	8.0	5.3	8.0	8.0	10.7	21.3	4.0	5.3	5.3
		13.9	5.1	6.3	5.1	6.3	5.3	**16.8**	4.6	5.5	3.2	**18.5**	9.3
12		13.3	8.0	17.3	13.3	9.3	1.3	10.7	8.0	8.0	2.7	5.3	2.7
		8.3	4.4	5.6	5.8	**10.8**	**10.1**	**13.2**	7.2	7.6	5.1	**14.6**	7.2
Average 3C		11.7	6.4	15.2	14.7	6.8	5.4	9.3	7.3	11.0	2.7	5.2	4.2
Average 3D		10.8	6.0	10.9	7.4	7.4	6.4	10.7	6.0	9.2	6.5	10.7	7.9

6.10 Comparing Categorical and Continuous Results for Experiments 3A, 3B, and 3C

The below tables compare categorical and continuous models for Experiments 3A, 3B, and 3C for each colour outcome dimension. It demonstrates, as with other comparisons you can find below in the Appendices (6.12 and 6.14), that the parameterisation can have an effect on the results one gets for colour-shape associations, although commonalities are also found. Moreover, it is not the simplification of shapes into binary parameters that causes the inconsistent results between stimuli sets as inconsistencies also abound when comparing the continuous models.

6.10.1 Red/Green.

*Table 6.9 Table showing the results for categorical and continuous shape predictor LMM models for Experiments 3A, 3B, and 3C for the outcome colour dimension of red/green. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

Parameters		Experiment 2A		Experiment 2B		Experiment 2C	
		Categorical model	Continuous model	Categorical model	Continuous model	Categorical model	Continuous model
Regression coefficients (fixed effects)							
Intercept		62.38 (1.76)***	61.50 (1.61)**	46.64 (1.76)***	47.77 (.84)***	47.28 (1.61)***	44.17 (.85)***
Angularity	=0/R	-1.96 (.90)*	.92 (.43)*	-.20 (1.39)	.22 (.70)	-4.38 (1.36)**	2.37 (.80)**
Symmetry	=0/R	-2.09 (.82)*	.94 (.45)*	.58 (1.39)	-.44 (.70)	-.24 (1.36)	.03 (.69)

Complexity	=1/R	3.55 (1.80)*	-.70 (.47)	1.76 (1.97)	-.59 (.71)	-.13 (1.67)	-.89 (.80)
	=2	.64(1.43)		2.20 (1.97)		-2.29 (1.67)	
	=3	1.67(.90)		-.19 (1.97)			
Variance components (random effects)							
Residual		628.18 (14.71)***	628.43 (14.71)***	525.16 (23.25)***	525.78 (23.28)***	417.98 (20.58)***	419.80 (20.67)***
Participants		155.20 (29.35)***	155.20 (29.35)***	14.65 (8.27)	14.61 (8.27)	19.14 (8.98)*	18.99 (8.98)*

6.10.2 Yellow/Blue.

*Table 6.10 Table showing the results for categorical and continuous shape predictor LMM models for Experiments 3A, 3B, and 3C for the outcome colour dimension of yellow/blue. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

		Experiment 2A		Experiment 2B		Experiment 2C	
Parameters		**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**
Regression coefficients (fixed effects)							
Intercept		57.21 (1.81)***	57.86 (1.65)***	51.02 (2.96)***	50.54 (1.06)***	46.22 (2.15)***	48.65 (1.23)***
Angularity	=0/R	-.08 (.96)	.69 (.46)	.69 (1.58)	-.34 (.80)	-1.34 (1.76)	1.06 (1.03)
Symmetry	=0/R	-1.16 (.88)	.29 (.48)	-.57 (1.58)	.56 (.80)	-.81 (1.76)	.19 (.89)

Complexity	=1/R	.07 (1.91)	-1.12 (.50)*	.60 (2.23)	-.30 (.81)	5.34 (2.16)*	-2.62 (1.04)*
	=2	4.73 (1.52)**		-5.39 (2.23)*		5.17 (2.16)*	
	=3	1.86 (.96)		2.61 (2.23)			
Variance components (random effects)							
Residual		710.10(16.65)***	711.90(16.67)***	677.44 (30.00)***	686.48 (30.40)***	700.12 (34.47)***	701.77 (34.55)***
Participants		162.26(30.85)***	162.24(30.85)***	34.01 (13.23)*	33.45 (13.23)*	54.82 (18.70)**	54.68 (18.70)**

6.10.3 Lightness.

*Table 6.11 Table showing the results for categorical and continuous shape predictor LMM models for Experiments 3A, 3B, and 3C for the outcome colour dimension of lightness (measured from light to dark). Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

		Experiment 2A		Experiment 2B		Experiment 2C	
Parameters		**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**
Regression coefficients (fixed effects)							
Intercept		48.73(1.25)***	44.57 (.99)***	50.96 (2.14)***	44.21 (1.21)***	43.98 (2.28)***	45.57 (1.37)***
Angularity	=0/R	-.07(.99)	.82 (.48)	-4.59 (1.58)**	1.95 (.81)*	1.26 (1.83)	-.28 (1.07)
Symmetry	=0/R	-2.64(.90)**	2.02 (.49)***	-.26 (1.58)	.40 (.81)	-4.17 (1.83)*	2.03 (.92)*

Complexity	=1/R	-13.23 (1.96)***	2.18 (.51)***	-4.03 (2.24)	.69 (.82)	6.18 (2.24)**	-2.31 (1.07)*
	=2	-3.85 (1.56)*		-8.38 (2.24)***		2.93 (2.24)	
	=3	-3.63 (.99)***		-4.86 (2.24)*			
Variance components (random effects)							
Residual		749.83 (17.56)***	755.64 (17.69)***	682.15 (30.31)***	691.96 (30.64)***	751.06 (36.98)***	750.81 (36.97)***
Participants		49.22 (10.99)***	49.12 (10.99)***	56.70 (17.14)**	56.09 (17.14)**	77.42 (23.07)**	77.45 (23.07)**

6.10.4 Saturation.

*Table 6.12 Table showing the results for categorical and continuous shape predictor LMM models for Experiments 3A, 3B, and 3C for the outcome colour dimension of saturation. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

		Experiment 2A		Experiment 2B		Experiment 2C	
Parameters		**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**
Regression coefficients (fixed effects)							
Intercept		60.79 (.55)***	59.51 (.43)***	60.32 (.99)***	59.12 (.51)***	61.35 (.98)***	60.02 (.48)***
Angularity	=0/R	-.38 (.45)	.33 (.22)	-1.28 (.76)	.58 (.39)	-2.69 (.85)**	1.59 (.50)**
Symmetry	=0/R	-.94 (.41)*	.68 (.22)**	.31 (.76)	.01 (.39)	.39 (1.05)	.52 (.43)

Complexity	=1/R	-2.58 (.41)*	.44 (.23)	-.60 (1.08)	.07 (.39)	1.65 (1.05)	-.70 (.50)
	=2	.90 (.89)**		-1.13 (1.08)			
	=3	-1.40 (.45)**		-1.11 (1.08)			
Variance components (random effects)							
Residual		155.36 (3.64)***	155.98 (3.65)***	157.30 (6.97)***	157.62 (6.98)***	164.29 (8.09)***	165.02 (8.13)***
Participants		9.09 (2.08)***	9.08 (2.08)***	7.71 (3.04)*	7.69 (3.04)*	3.32 (2.86)	3.26 (2.86)

6.10.5 Warmth.

*Table 6.13 Table showing the results for categorical and continuous shape predictor LMM models for Experiments 3A, 3B, and 3C for the outcome colour dimension of warmth. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

		Experiment 2A		Experiment 2B		Experiment 2C	
Parameters		**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**	**Categorical model**	**Continuous model**
Regression coefficients (fixed effects)							
Intercept		45.94 (.91)***	44.75 (.70)***	46.61 (1.56)***	45.85 (.69)***	47.94 (1.66)***	48.12 (.89)***
Angularity	=0/R	-.44 (.75)	.23 (.36)	-7.31 (1.25)	.25 (.63)	2.38 (1.41)	-1.43 (.82)
Symmetry	=0/R	-.12 (.68)	.19 (.37)	.41 (1.25)	-.22 (.63)	-.31 (1.41)	.24 (.71)

Complexity	=1/R	-3.02 (1.48)*	1.09 (.38)**	-1.44 (1.77)	.44 (.64)	-2.58 (1.72)	1.69 (.83)*
	=2	-.76 (1.18)		1.31 (1.77)		.01 (1.72)	
	=3	-1.64 (.75)*		-2.29 (1.77)			
Variance components (random effects)							
Residual		426.53 (9.99)***	426.26 (9.98)***	425.01 (18.82)***	426.90 (18.90)***	444.91 (21.91)***	445.49 (21.93)***
Participants		23.68 (5.49)***	23.68 (5.49)***	6.27 (5.75)	6.15 (5.75)	21.68 (9.77)*	21.63 (9.78)*

6.11 Effect of Experiment Within Each Stimuli Set

Table 6.14, Table 6.15, and Table 6.16 below show the effect of experiment and shape predictors on colour characteristics and the interaction effects between the two for each stimuli set separately. The results highlight that sometimes experiment did make a difference and had interaction effects but did not do so consistently or very often. As such, variation in responses did not simply derive from differences in experimental set-ups, demands, and analysis, but rather point to a general large amount of variance that the factor of experiment cannot account for.

6.11.1 Effect of experiment: Geometric shapes.

*Table 6.14 Table showing the results for LMMs predicting colour dimensions from shape predictors, experiment (0= Experiment 3A, 1= Experiment 3D), and their interactions. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable.*

Parameters		Red/Green	Yellow/blue	Lightness	Saturation	Warmth
Regression coefficients (fixed effects)						
Intercept		47.26 (.41)***	53.90 (.42)***	43.95 (.48)***	57.83 (.61)***	45.49 (.47)***
Angularity	=0	.94 (.32)**	-.12 (.35)	-.47 (.37)	.25 (.31)	.29 (.34)
Symmetry	=0	.98 (.29)**	-.01 (.32)	.99 (.34)**	.50 (.28)	-.28 (.31)
Complexity	=1	-.38 (.63)	-1.28 (.69)	-.78 (.74)	1.10 (.62)	1.03 (.68)

	=2	-1.07 (.50)*	.36 (.55)	.14 (.59)	.34 (.49)	-.09 (.54)
	=3	-1.33 (.32)***	-.83 (.35)*	-1.59 (.37)***	-.51 (.31)	1.34 (.34)***
Experiment	=0	15.02 (1.28)***	3.31 (1.31)*	4.78 (1.52)**	2.96 (1.91)	.45 (1.47)
Angularity * Experiment	0*1	-2.90 (1.00)**	.03 (1.10)	.40 (1.17)	-.63 (.98)	-.74 (1.07)
Symmetry * Experiment	0*1	-3.07 (.91)**	-1.15 (1.00)	-3.62 (1.06)**	-1.45 (.89)	.16 (.98)
Complexity * Experiment	1*0	3.93 (1.98)*	1.35 (2.18)	-12.46 (2.32)***	-3.67 (1.94)	-4.05 (2.13)
	2*0	1.71 (1.57)	4.37 (1.73)*	-3.99 (1.84)*	.55 (1.55)	-.67 (1.70)
	3*0	2.99 (1.00)**	2.69 (1.10)*	-2.04 (1.17)	-.90 (.98)	-2.98 (1.07)**
Variance components (random effects)						
Residual		683.94 (5.10)***	830.67 (6.19)***	938.61 (7.00)***	661.17 (4.93)***	795.24 (5.93)***
Participants		47.40 (3.33)***	41.39 (3.14)***	68.08 (4.75)***	164.17 (9.88)***	69.40 (4.68)***

6.11.2 Effect of experiment: Mandala shapes.

*Table 6.15 Table showing the results for LMMs predicting colour dimensions from shape predictors, experiment (0= Experiment 3B, 1= Experiment 3D), and their interactions. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable.*

Parameters		Red/Green	Yellow/blue	Lightness	Saturation	Warmth
Regression coefficients (fixed effects)						
Intercept		46.53 (.70)***	54.00 (.92)***	47.73 (.88)***	60.80 (.86)***	46.04 (.82)***
Angularity	=0	2.74 (.53)***	-1.92 (.63)**	-.92 (.65)	-1.82 (.53)**	-.18 (.59)
Symmetry	=0	.40 (.53)	2.18 (.63)**	1.97 (.65)**	.17 (.53)	-1.35 (.59)*
Complexity	=1	-1.41 (.74)	-2.84 (.90)**	-1.41 (.92)	1.07 (.75)	2.69 (.84)**
	=2	-1.78 (.74)*	.04 (.90)	-.13 (.92)	.13 (.75)	.64 (.84)
	=3	1.29 (.74)	-3.10 (.90)**	-1.74 (.92)	1.34 (.75)	2.03 (.84)*
Experiment	=0	.11 (2.15)	-2.99 (2.50)	3.23 (2.70)	-48 (2.63)	.57 (2.49)
Angularity * Experiment	0*1	-2.94 (1.61)	2.61 (1.94)	-3.67 (1.98)	.54 (1.61)	-.55 (1.81)
Symmetry * Experiment	0*1	.17 (1.61)	-2.75 (1.94)	-2.24 (1.98)	.14 (1.61)	1.75 (1.81)
Complexity * Experiment	1*0	3.18 (2.27)	3.44 (2.74)	-2.62 (2.81)	-1.68 (2.28)	-4.13 (2.56)
	2*0	3.98 (2.27)	-5.43 (2.74)*	-8.25 (2.81)**	-1.26 (2.28)	.68)2.56)
	3*0	-1.48 (2.27)	5.71 (2.74)*	-3.13 (2.81)	-2.45 (2.28)	-4.32 (2.56)
Variance components (random effects)						
Residual		626.88 (9.08)***	914.44 (13.25)***	955.53 (13.85)***	629.78 (9.13)***	797.50 (11.56)***

Participants		45.19 (4.77)***	35.49 (5.26)***	83.03 (8.06)***	182.59 (12.47)***	77.67 (7.19)***

6.11.3 Effect of experiment: RF shapes.

*Table 6.16 Table showing the results for LMMs predicting colour dimensions from shape predictors, experiment (0= Experiment 3C, 1= Experiment 3D), and their interactions. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable.*

Parameters		Red/Green	Yellow/blue	Lightness	Saturation	Warmth
Regression coefficients (fixed effects)						
Intercept		48.54 (.74)***	54.92 (.81)***	42.55 (.92)***	56.37 (.90)***	43.39 (.85)***
Angularity	=0	1.21 (.62)	-1.46 (.68)*	-1.78 (.74)*	.44 (.63)	1.05 (.68)
Symmetry	=0	2.30 (.62)***	-.47 (.68)	-.01 (.74)	-.03 (.63)	.19 (.68)
Complexity	=1	-1.54 (.76)*	-.81 (.83)	4.33 (.91)***	1.49 (.77)	.66 (.83)
	=2	-1.00 (.76)	-1.40 (.83)	3.73 (.91)***	1.47 (.77)	.71 (.83)
Experiment	=0	-1.25 (2.16)	-8.70 (2.36)***	1.44 (2.70)	4.98 (2.62)	4.55 (2.48)
Angularity * Experiment	0*1	-5.59 (1.82)**	.13 (1.98)	3.05 (2.17)	-3.13 (1.83)	1.33 (1.99)
Symmetry * Experiment	0*1	-2.54 (1.82)	-.34 (1.98)	-4.16 (2.17)	-1.31 (1.83)	-.50 (1.99)

Complexity * Experiment	1*0	1.40 (2.22)	6.16 (2.42)*	1.85 (2.66)	-1.11 (2.24)	-3.25 (2.44)
	2*0	-1.28 (2.22)	6.57 (2.42)**	-.80 (2.66)	.18 (2.24)	-.69 (2.44)
Variance components (random effects)						
Residual		655.35 (11.03)***	776.55 (13.07)***	937.85 (15.78)***	667.14 (11.23)***	787.81 (13.26)***
Participants		36.80 (5.18)***	44.99 (6.22)***	91.90 (9.58)***	177.96 (13.07)***	77.99 (8.09)***

6.12 Interaction Effects with only Continuous Predictors for Experiment 3D

If you compare the results in Table 6.17 below, to Table 3.7 and Table 3.8 that contain the results for models run with angularity and symmetry as categorical variables and only complexity as rated continuous variable, there are both similarities and differences found in interaction effects between the two kinds of models. Both models find no significant interaction effects for saturation and warmth, and an interaction between angularity and symmetry for lightness. The mixed categorical/continuous model finds a significant interaction effect between symmetry and angularity, whilst the continuous model only, finds an interaction effect between symmetry and complexity instead. Finally, for red/green commonalities (angularity X symmetry and angularity X symmetry X complexity) but also differences are found: the angularity complexity effect is only significant for the mixed model, whilst the symmetry X complexity interaction is only significant for continuous model.

These subtle differences highlight the immense complexity of determining what colour-shape correspondences exist, since determining whether conceiving of shapes as continuously measured phenomenological experiences, or polar dimensions, can significantly affect outcomes, even if there are, arguably, more similarities than differences in this particular case. However, this has both practical and theoretical implications as discussed in Chapter 5, Section 5.2.2.1 and 5.2.2.3.

*Table 6.17 Table showing the results for the LMMs of perceptual shape characteristics predicting the five colour dimensions for interaction models with only continuous shape predictors for Experiment 3D. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

Parameters		Red/Green	Yellow/blue	Lightness	Saturation	Warmth
Regression coefficients (fixed effects)						
Intercept		47.77 (.27)***	53.25 (.26)***	44.42 (.37)***	58.48 (.58)***	45.96 (.39)***
Angularity	R	-.73 (.12)***	.41 (.14)**	-.17 (.15)	-.23 (.13)	-.11 (.14)
Symmetry	R	-.36 (.12)**	-.14 (.14)	.10 (.15)	.15 (.13)	.15 (.14)
Complexity	R	.17 (.13)	.34 (.15)*	.87 (.16)***	.37 (.13)**	-.26 (.14)
Angularity *Symmetry	R	-.36 (.13)**	.11 (.14)	-.40 (.15)**	-.18 (.13)	.02 (.14)
Angularity *Complexity	R	.04 (.12)	-.14 (.14)	-.11 (.15)	.12 (.13)	.06 (.14)
Symmetry *Complexity	R	.44 (.13)**	-.38 (.15)*	.19 (.16)	.20 (.13)	.09 (.14)
Angularity *Symmetry *Complexity	R	-.32 (.12)**	.21 (.14)	-.19 (.14)	-.06 (.12)	.05 (.13)
Variance components (random effects)						
Residual		685.50 (4.42)***	858.82 (5.53)***	979.74 (6.31)***	722.10 (4.65)***	842.59 (5.43)***

Participants	33.96 (2.49)***	27.94 (2.25)***	64.96 (4.54)***	182.12 (11.32)***	73.94 (4.97)***

6.13 Pairwise Comparisons for the Significant Interaction Effects of Stimuli Set in Experiment 3D

*Table 6.18 Table showing the pairwise comparisons (LSD method of comparison, in other words, significance levels are not adjusted for multiple comparison) for the significant interaction effects between stimuli set and colour dimensions found in Table 3.9, Table 3.9, and Figure 3.7 for Experiment 3D. P-values below .05 are indicated with a * in the mean difference column. Complexity categories were creating by binning the rated complexity variable into three equal levels. Since, as noted above, this does not split each stimuli set in an even manner, pairwise comparisons for complexity interactions can only be shown between certain stimuli sets.*

	Stimulus (I)	Stimulus (J)	Mean difference (I-J)	SE	*P*-value (3 d.p.)
			RED/GREEN		
			Angularity*Stimuli set		
Mandala	Round	Angular	2.89*	.55	.000
	Angular	Round	-2.89*	.55	.000
RF	Round	Angular	1.37*	.64	.032
	Angular	Round	-1.37*	.64	.032
Geometric	Round	Angular	1.30*	.31	.000
	Angular	Round	-1.30*	.31	.000
Round	Mandala	RF	-2.14*	.69	.002
		Geometric	.32	.50	.524
	RF	Mandala	2.14*	.69	.002
		Geometric	2.45*	.59	.000
	Geometric	Mandala	-.32	.50	.524
		RF	-2.45*	.59	.000
Angular	Mandala	RF	-3.66*	.68	.000

		Geometric	-1.28*	.50	.010
	RF	Mandala	3.66*	.68	.000
		Geometric	2.38*	.54	.000
	Geometric	Mandala	1.28*	.50	.010
		RF	-2.38*	.54	.000
Symmetry*Stimuli set					
Mandala	Asymmetrical	Symmetrical	.38	.55	.486
	Symmetrical	Asymmetrical	-.38	.55	.486
RF	Asymmetrical	Symmetrical	2.21*	.64	.000
	Symmetrical	Asymmetrical	-2.21*	.64	.000
Geometric	Asymmetrical	Symmetrical	.70*	.30	.021
	Symmetrical	Asymmetrical	-.70*	.30	.021
Asymmetrical	Mandala	RF	-3.82*	.68	.000
		Geometric	-.64	.49	.194
	RF	Mandala	3.82*	.68	.000
		Geometric	3.18*	.55	.000
	Geometric	Mandala	.64	.49	.194
		RF	-3.18*	.55	.000
Symmetrical	Mandala	RF	-1.98*	.69	.004
		Geometric	-.32	.50	.516
	RF	Mandala	1.98*	.69	.004
		Geometric	1.66*	.57	.004
	Geometric	Mandala	.32	.50	.516
		RF	-1.66*	.57	.004
Yellow/Blue					
Angularity*Stimuli set					

Mandala	Round	Angular	-1.70*	.62	.006
	Angular	Round	1.70*	.62	.006
RF	Round	Angular	-1.41*	.71	.048
	Angular	Round	1.41*	.71	.048
Geometric	Round	Angular	-.11	.35	.751
	Angular	Round	.11	.35	.751
Round	Mandala	RF	-1.59*	.77	.039
		Geometric	-2.29*	.56	.000
	RF	Mandala	1.59*	.77	.039
		Geometric	-.70	.66	.289
	Geometric	Mandala	2.29*	.56	.000
		RF	.70	.66	.289
Angular	Mandala	RF	-1.30	.77	.089
		Geometric	-.71	.56	.206
	RF	Mandala	1.30	.77	.089
		Geometric	.60	.60	.319
	Geometric	Mandala	.71	.56	.206
		RF	-.60	.60	.319
Symmetry*Stimuli set					
Mandala	Asymmetrical	Symmetrical	2.15*	.62	.000
	Symmetrical	Asymmetrical	-2.15*	.62	.000
RF	Asymmetrical	Symmetrical	-.50	.71	.481
	Symmetrical	Asymmetrical	.50	.71	.481
Geometric	Asymmetrical	Symmetrical	-.18	.34	.600
	Symmetrical	Asymmetrical	.18	.34	.600
Asymmetrical	Mandala	RF	-.12	.76	.875

		Geometric	-.33	.55	.546
	RF	Mandala	.12	.76	.875
		Geometric	-.21	.62	.729
	Geometric	Mandala	.33	.55	.546
		RF	.21	.62	.729
Symmetrical	Mandala	RF	-2.77*	.77	.000
		Geometric	-2.66*	.55	.000
	RF	Mandala	2.77*	.77	.000
		Geometric	.11	.64	.864
	Geometric	Mandala	2.66*	.55	.000
		RF	-.11	.64	.864
Saturation					
Angularity*Stimuli set					
Mandala	Round	Angular	-1.89*	.57	.001
	Angular	Round	1.89*	.57	.001
RF	Round	Angular	.32	.66	.627
	Angular	Round	-.32	.66	.627
Geometric	Round	Angular	.53	.32	.099
	Angular	Round	-.53	.32	.099
Round	Mandala	RF	2.63*	.70	.000
		Geometric	1.46*	.51	.004
	RF	Mandala	-2.63*	.70	.000
		Geometric	-1.17	.61	.054
	Geometric	Mandala	-1.46*	.51	.004
		RF	1.17	.61	.054
Angular	Mandala	RF	4.89*	.70	.000

		Geometric	3.88*	.51	.000
	RF	Mandala	-4.84*	.70	.000
		Geometric	-.95	.55	.082
	Geometric	Mandala	-3.88*	.51	.000
		RF	.95	.55	.082
Lightness					
Angularity*Stimuli set					
Mandala	Round	Angular	-.82	.66	.216
	Angular	Round	.82	.66	.216
RF	Round	Angular	-2.14*	.76	.005
	Angular	Round	2.14*	.76	.005
Geometric	Round	Angular	-.12	.38	.753
	Angular	Round	.12	.38	.753
Round	Mandala	RF	4.89*	.82	.000
		Geometric	3.15*	.59	.000
	RF	Mandala	-4.89*	.82	.000
		Geometric	-1.74*	.71	.014
	Geometric	Mandala	-3.15*	.59	.000
		RF	1.74*	.71	.014
Angular	Mandala	RF	3.56*	.82	.000
		Geometric	3.85*	.60	.000
	RF	Mandala	-3.56*	.82	.000
		Geometric	.29	.64	.651
	Geometric	Mandala	-3.85*	.60	.000
		RF	-.29	.64	.651
Complexity*Stimuli set					

Mandala	Low	High	-.79	.76	.297
RF	Low	Medium	3.56*	.79	.000
Geometric	Low	Medium	-.48	.44	.273
		High	-1.35*	.48	.005
	Medium	Low	.48	.44	.273
		High	-.87*	.44	.047
	High	Low	1.35*	.48	.005
		Medium	.87*	.44	.047
Low	Mandala	RF	.43	.89	.625
		Geometric	3.85*	.72	.000
	RF	Mandala	-.43	.89	.625
		Geometric	3.42*	.67	.000
	Geometric	Mandala	-3.85*	.72	.000
		RF	-3.42*	.67	.000
Medium	RF	Geometric	-.625	.58	.283
High	Mandala	Geometric	3.294*	.52	.000

6.14 Effect of Stimuli with Continuous Shape Predictors in Experiment 3D

As the models found in Table 3.9 and Table 3.10, where angularity and symmetry are categorical variables and complexity is the only continuously rated predictor, both angularity and symmetry interact with symmetry for red/green and yellow/blue. In addition, saturation interacts with angularity as in the previously tested model. No significant interaction effects are found for warmth in either model, however, the full continuous predictor model shown in Table 6.19 below, does uncover some significant interactions between lightness and stimuli set for symmetry unlike the models containing a mix of categorical and continuous variables. As such, interaction effects do not appear to be driven only by fundamental differences in the stimuli sets that are obscured by the binary variables. However, it is possible that certain effects do depend on more subtle explications of shape along a continuum, rather than as polar dimensions if their exact interplays are more complex than a simple interaction effect where high and low ends of a variable have opposite effects.

*Table 6.19 Table showing the results for the LMMs of continuously rated perceptual shape characteristics predicting the five colour dimensions for Experiment 3D. Each cell can be read as coefficient (standard error)$^{significance\ level}$. * indicates an effect that is significant at the .05 level, ** at the .01 level, and *** at the .001 level. Reference categories are indicated beside each variable, where an R indicates a continuously rated variable.*

Parameters	Red/Green	Yellow/blue	Lightness	Saturation	Warmth

Regression coefficients (fixed effects)						
Intercept		47.55 (.29)***	53.48 (.28)***	43.60 (.38)***	58.10 (.59)***	46.02 (.40)***
Angularity	R	-.63 (.15)***	.13 (.17)	.11 (.18)	-.23 (.15)	-.07 (.16)
Symmetry	R	-.18 (.15)	.10 (.17)	-.25 (.18)	-.20 (.15)	-.06 (.16)
Complexity	R	.53 (.17)**	.29 (.19)	.60 (.21)**	.06 (.18)	-.47 (.19)*
Stimuli set	1	-.99 (.46)*	-.24 (.52)	4.41 (.55)***	3.23 (.47)***	.93 (.51)
	2	2.43 (.46)***	-.19 (.51)	-.97 (.54)	-.95 (.47)*	-1.61 (.50)**
Angularity *Stimuli set	R*1	-.84 (.32)**	.72 (.35)*	.34 (.38)	1.24 (.32)***	.31 (.35)
	R*2	-.60 (.54)	1.13 (.61)	1.58 (.65)*	-.09 (.56)	-.85 (.60)
Symmetry *Stimuli set	R*1	.17 (.54)**	-2.29 (.61)***	-1.40 (.65)*	.00 (.56)	1.14 (.60)
	R*2	-.94 (.35)**	.12 (.40)	.05 (.42)	.21 (.36)	-.00 (.39)
Complexity *Stimuli set	R*1	.10 (.32)	.74 (.36)*	-.08 (.39)	-.34 (.33)	-.49 (.36)
	R*2	1.37 (.69)*	-.49 (.77)	-4.68 (.82)***	-.92 (.71)	.49 (.76)
Variance components (random effects)						
Residual		684.95 (4.41)***	858.39 (5.53)***	977.50 (6.30)***	729.99 (4.64)***	841.93 (5.42)***

Participants	33.96 (2.49)***	27.95 (2.25)***	64.99 (4.54)***	182.13 (11.32)***	73.94 (4.97)***

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