

‘Tasting Imagination’: What Role Chemosensory Mental Imagery in Multisensory Flavour Perception?

Charles Spence*

Crossmodal Research Laboratory, Department of Experimental Psychology, University of Oxford, New Radcliffe House, Walton Street, Oxford, OX2 6BW, UK

*E-mail: charles.spence@psy.ox.ac.uk

ORCID iD: Spence: 0000-0003-2111-072X

Received 8 November 2022; accepted 20 December 2022;
published online 30 December 2022; published in print 11 January 2023

Abstract

A number of perplexing phenomena in the area of olfactory/flavour perception may fruitfully be explained by the suggestion that chemosensory mental imagery can be triggered automatically by perceptual inputs. In particular, the disconnect between the seemingly limited ability of participants in chemosensory psychophysics studies to distinguish more than two or three odorants in mixtures and the rich and detailed flavour descriptions that are sometimes reported by wine experts; the absence of awareness of chemosensory loss in many elderly individuals; and the insensitivity of the odour-induced taste enhancement (OITE) effect to the mode of presentation of olfactory stimuli (i.e., orthonasal or retronasal). The suggestion made here is that the theory of predictive coding, developed first in the visual modality, be extended to chemosensation. This may provide a fruitful way of thinking about the interaction between mental imagery and perception in the experience of aromas and flavours. Accepting such a suggestion also raises some important questions concerning the ecological validity/meaning of much of the chemosensory psychophysics literature that has been published to date.

Keywords

olfaction, mental imagery, predictive coding

1. Introduction

This narrative review attempts to provide an explanation for a number of perplexing empirical observations that have emerged from the scientific study of olfaction and flavour perception. One relevant phenomenon here concerns the apparent discrepancy between wine writers who sometimes come out with

1000-word plus descriptions of the taste/flavour profile of a particular quality wine, while the results of carefully-controlled olfactory psychophysics studies suggest that people can discriminate no more than two or three odours from a mixture (see Spence and Wang, 2018a, for a review). How is this discrepancy to be explained? While it might, in part, reflect different tasting protocols (i.e., single sniff *versus* prolonged tasting), or else differences in the complexity/integrity/temporal evolution of whatever is being tasted, it might equally well reflect the little recognized role of mental imagery (Kollndorfer *et al.*, 2015). This review shines a spotlight on the possibly unrecognized role of olfactory/flavour mental imagery (both voluntary and involuntary; see Spence and Deroy, 2013, on this distinction) in multisensory flavour perception.

A second phenomenon that such a consideration of chemosensory mental imagery may help to resolve relates to the perplexing observation that many older people appear to lack subjective awareness of the functional decline of their own chemosensory abilities (e.g., Nordin *et al.*, 1995). It has been suggested that this may relate to the role played by memory and mental imagery for familiar flavours in helping to make up for the loss of chemosensory acuity that typically accompanies the natural process of ageing (Spence, *in press*). These may help to fill in the gaps, as it were, in a person's chemosensory perceptual experience (e.g., Cavazzana *et al.*, 2018; Flohr *et al.*, 2014; Kollndorfer *et al.*, 2015).

The third issue to be addressed in this review is whether odour-induced taste enhancement (OITE) can be considered as a kind of involuntary, or stimulus-driven, multisensory mental imagery (see Nanay, 2018). OITE refers to the frequently-documented finding whereby the presence of olfactory stimuli that are commonly paired with a specific taste in food and drink (e.g., vanilla or strawberry odour, which are both considered to smell sweet) leads to the increased perception of the associated taste when combined in food and drink (see Spence, 2022a, b).

Somewhat surprisingly, OITE (as well as, as it happens, a number of other olfactory–gustatory interactions) appear to be unaffected by whether a given odorant happens to be experienced retronasally or orthonasally (Lawrence *et al.*, 2009; Spence, 2012; though see Amano *et al.*, 2022). This is surprising inasmuch as only retronasal olfaction is constitutively involved in multisensory flavour perception (see Spence *et al.*, 2015). Orthonasal olfaction (e.g., when sniffing), by contrast, tells us about distal objects instead, and so should presumably not be integrated with taste (gustatory) stimuli.

1.1. Olfactory and Crossmodal Mental Imagery: Does It Exist?

At the outset, it is worth noting that not all researchers have necessarily been convinced that olfactory mental imagery even exists (e.g., see Engen, 1987; Herz, 2000; Schab, 1990). Certainly, although similar, there are also important

differences between olfactory mental imagery and that seen in the other senses (e.g., Arshamian and Larsson, 2014; Gilbert *et al.*, 1998; Olivetti Belardinelli *et al.*, 2009). Indeed, just as for other modalities of sensory imagery, individual differences in the vividness of olfactory imagery are marked and widespread (Bensafi and Rouby, 2007). According to Nanay (2018, p. 127): “Olfactory mental imagery is *olfactory* perceptual processing that is not triggered by corresponding *olfactory* sensory stimulation.” He continues: “Olfactory mental imagery can be (and is often) triggered by *non-olfactory* (for example, auditory) sensory stimulation. And this is exactly what I mean by multimodal mental imagery.” (italics in original). Nowadays, the weight of scientific opinion would appear to support the existence of olfactory mental imagery (e.g., Bensafi *et al.*, 2007; Levy *et al.*, 1999; cf. Stevenson and Case, 2005).

Neuroimaging research in normal participants from Levy and colleagues (1999) reveals that participants are able to imagine odours and similar brain regions are activated by both imagining and actually smelling the corresponding odours. That being said, mentally imagining odours gave rise to significantly less brain activation than actually smelling of corresponding odours. Neural activity in piriform cortex has been documented both when people smell something and when they try to mentally imagine an odour, though some functional reorganization has been documented in odour experts (perfumers) in the network of brain regions involved in mentally imagining odours (Plailly *et al.*, 2012). Researchers have demonstrated that olfactory similarity judgements are very similar when the relevant olfactory stimuli are sniffed orthonasally, as compared to when they are merely imagined (Carrasco and Ridout, 1993). Meanwhile, Algom and Cain (1991a, b) have documented how the perceived intensity of odour mixtures was very similar when participants mixed them in memory. The latter researchers go so far as to talk of a memory-perception isomorphism in mixture processing.

2. On the Interaction Between Perception and Imagery in Multisensory Flavour Perception

In a book chapter, Spence and Deroy (2013) drew attention to the notion of crossmodal mental imagery. In particular, they suggested that this might be induced either voluntarily or automatically (see also Proverbio *et al.*, 2011).

2.1. Voluntary Mental Imagery

In an intriguing early study designed to investigate the nature of any cross-modal interactions between olfactory imagery and gustatory perception, Djordjevic *et al.* (2004a) had a group of 20 participants detect sucrose in solution using a two-alternative forced choice (2AFC) procedure. The participants had to try and discriminate which of two solutions, one containing water,

the other containing an individually-titrated threshold level of sucrose, tasted stronger. Sometimes, the participants performed the task the after orthonasally sniffing strawberry or ham odour using a sniff–sip–spit protocol (though note that the participants all smelled the two olfactory stimuli first to familiarize themselves with the odorants being used). Thereafter, 30 strawberry and 30 ham (order counterbalanced) and finally 30 no-smell trials were presented. Sniffing the ham odour significantly lowered participants' accuracy in detecting the sweeter of the two solutions, while performance in the other two conditions (no odour and strawberry odour) turned out to be indistinguishable. Crucially, the same pattern of results was obtained in another group of 20 participants who merely imagined the presence of the odours (after having sniffed them both at the start of the study).

A second within-participants study revealed exactly the same pattern of results, now contrasting sniffing *versus* imagining the smell of ham or strawberry (i.e., there was no longer a baseline no-odour condition). Taken together, therefore, these results provide evidence for the crossmodal interaction of voluntary olfactory mental imagery and taste (gustatory) perception. Intriguingly, other research suggests that similar psychophysical constraints affect the mental mixing of imagined pairs of chemosensory stimuli (described by the researchers concerned as 'memories'), either retronasal odour–taste, taste–taste, or retronasal odour–retronasal odour (see Algom and Cain, 1991a, b; Algom, Marks and Cain, 1993). Algom and Cain studied intensity ratings when physical stimuli were mixed with remembered (or imagined) odours, using various combinations of leaf alcohol and amyl acetate as olfactory stimuli. Their results once again highlighted a similarity in the interaction between voluntary olfactory mental imagery and the olfactory perception of physically presented stimuli.

There is, in fact, a much older literature on the Perky effect (Perky, 1910), demonstrating the interaction of voluntary vivid visual mental imagery and faintly-presented visual stimuli. While Cheves West Perky's research illustrated how a very faint visual perceptual stimulus could be 'incorporated' into a participant's visual mental imagery, Segal and colleagues subsequently switched the focus to demonstrate that voluntary mental imagery (close, in fact, to the notion of voluntary attention) could also enhance a participant's perception within the same sensory modality (Segal, 1971, 1972; Segal and Fusella, 1970, 1971; Segal and Nathan, 1964). Recently, it has been reported that voluntary visual mental imagery can add stimulus-specific sensory evidence to perceptual detection (Dijkstra *et al.*, 2022). And, shifting from a unisensory to a multisensory context, Berger and Ehrsson (2013) controversially demonstrated that voluntarily-imagined visual stimuli could interact with physically presented sounds in the ventriloquism and McGurk effects. So, for example, imagining a visual stimulus at a position different from the one

where a sound was presented was shown to lead to a subjective mislocalization of the sound in the direction of the imagined stimulus. Interestingly, however, the double-flash illusion (Shams *et al.*, 2000), where a peripherally-presented visual stimulus can be made to appear like two flashes simply by presenting two sounds at the same time, would appear to be one of the few crossmodal illusions that cannot be induced through mental imagining the sounds at the relevant moment, perhaps due to the precise timing that is required (see Berger, 2020).

2.2. Automatic Crossmodal Mental Imagery

Over the years, there have been a number of intriguing examples of perception in one modality being triggered automatically by the stimulation of another modality. One of the classic examples here concerns the way in which we hear the voice of those whose silent lip-movements we see. Such observations have been backed up by neuroimaging research documenting the reliable activation of the primary auditory cortex by those viewing visual speech stimuli (Calvert *et al.*, 1997; Hertrich *et al.*, 2011; Pekkola *et al.*, 2005). Researchers have also shown how watching a video in which a large electricity pylon is shown bouncing on the ground leads some people to ‘hear’ a sound as the moment of collision (Fassnidge and Freeman, 2018; MacDonald, 2017). Meanwhile, Fassnidge *et al.* (2017) reported that 22% of a neurotypically-normal sample of participants reported hearing a faint sound when presented with a flash of light. Elsewhere, researchers have reported that a proportion of the population feel as though they can see their arm when they move their limb in front of their face in a completely dark room (Dieter *et al.*, 2014; see also Roberts and Shenker, 2016). Once again, it is worth considering whether this constitutes another example of automatically induced crossmodal mental imagery.

Writing at the end of the 19th-century, MacDougal (1898) also provides a number of enlightening descriptions of individuals who reported experiencing automatically induced crossmodal mental imagery, what Ophelia Deroy has described as ‘sensory evocation’ (Deroy, 2020). So, for example, at one point MacDougal (1898, p. 467) notes how: “One lover of music has told me that frequently, as she listens to the music of an orchestra, an opening rose appears before her against a dark background. The phenomenon is apparently barren of association: there is the music, an auditory experience, and the rose, a visual experience; they appear together — but why, she cannot tell. The phenomenon is analogous to that of coloured hearing and probably to a multitude of other experiences which occur unremarked to every individual”. Indeed, in recent years, a growing number of commentators have raised the possibility that there may be at least some superficial links between the phenomenon of synaesthesia and automatically induced crossmodal mental imagery (e.g., Craver-Lemley and Reeves, 2013; O’Dowd *et al.*, 2019).

3. Predictive Coding and Mental Imagery

According to the predictive coding account (Friston, 2005), perception should not be considered as a process of bottom-up feed-forward feature detection (as was often traditionally thought) but rather as predictive feedback connections being much more important in terms of driving the sensory signals that provide corrective feedback. In fact, according to currently-popular cognitive neuroscience models of sensory perception, the brain uses predictive codes in advance of encountering a sensory stimulus in order to better infer forthcoming sensory events. According to Hohwy (2013, p. 48), perception and mental imagery are thus both indirect in the “sense that what we experience now is given in your top-down predictions of sensory input, rather than the bottom-up signal from the states of [worldly] affairs themselves.” (italics in original). Meanwhile, Clark (2015, pp. 34–35) writes that: “If the so-called visual, tactile, or auditory sensory cortex is actually operating using a cascade of feedback from higher levels to actively predict the unfolding sensory signals (the ones originally transduced using the various dedicated receptor banks of vision, sound, touch, etc.) then we should not be in the least surprised to find extensive multimodal and crossmodal effects (including these kinds of ‘filling-in’; Pessoa and De Weerd, 2003; Pessoa, Thompson and Noë, 1998) even on ‘early’ sensory response.”

Relevant to the present review, by combining high-resolution functional magnetic resonance imaging with multivariate (pattern-based) analyses, Zelano *et al.* (2011) successfully extended the predictive coding account to encompass olfaction. These cognitive neuroscientists examined the spatiotemporal evolution of odour information processing in the human brain during a modified olfactory search task. Crucially, ensemble activity patterns in orbitofrontal cortex (OFC) and anterior piriform cortex (APC) were shown to reflect the attended odour target both prior to and following the onset of the stimulus. In contrast, pre-stimulus ensemble representations of the odour target in posterior piriform cortex (PPC) gave way to post-stimulus representations of the actual odour. Crucially, the robustness of target-related patterns in PPC predicted subsequent behavioural performance. Zelano and colleagues took their results to show that we generate predictive templates or “search images” in PPC, with physical correspondence to odour-specific pattern representations, in order to enhance olfactory perception. In passing, it is here perhaps worth considering the importance of multisensory predictive coding for chemosensory perception given the fact we humans are insensitive (or blind) to the major sources of the macronutrients we need for survival (namely starch, protein, and triacylglycerol; Di Lorenzo, 2021; Mattes, 2021).

Recently, however, Cavedon-Taylor (2022) has stressed the importance of resisting the temptation to equate predictive processing with mental imagery,

as some have wanted to do. Importantly, there are profound individual differences in people's mental imagery abilities. These include the existence of aphantasic individuals who claim to have no conscious visual mental imagery whatsoever (Costandi, 2016; Low, 2019), and yet who are presumably just as capable of predictive coding as those individuals with vivid visual mental imagery (Nanay, 2018).

Given that we have drawn a distinction between voluntary and automatic crossmodal (or multisensory) mental imagery (Nanay, 2018; Spence and Deroy, 2013), it might be fruitful to consider whether the aphantasic's deficit is restricted to the voluntary elicitation of metal imagery, while leaving such automatically induced imagery intact? What is also somewhat unclear from the literature that has emerged recently is the extent to which aphantasia is restricted to the visual modality. Ultimately, it is important to remember that our memories of meals are not simply weaker versions of the original experience, “devoid of the pungency and tang” as William James (1890) once so memorably put it. According to predictive coding accounts, the brain varies the balance between sensory inputs and the brain's expectation with weight given to the driving sensory signal. According to Symons (1993), writing before the advent of the theory of predictive coding, the subjective weakness (or lack of vividness) of mental imagery may simply help to avoid any confusion between mental imagery and perception (at least under normal conditions).

4. Explaining Various Chemosensory Phenomena *via* Predictive Coding

4.1. *Directly Perceived versus Inferred/Imagined Complexity in Fine Wine*

Over recent decades, the results of a number of chemosensory psychophysics studies have revealed that people are unable to identify anything more than two to three individual components in multi-odour mixtures (Frank *et al.*, 2017; Jinks and Laing, 1999, 2001; Laing *et al.*, 2002). Importantly, these robust limits in the number of distinct elements that can be individuated have been documented even when a person can identify each element when presented in isolation (e.g., Marshall *et al.*, 2006; see also Ferreira, 2012a, b). Given the limited bandwidth of the chemical senses, how should the legendary tasting notes of certain wine experts, sometimes extending to as many as one thousand words for a single wine, be explained? Now, while not every word relates to a tasting note, nevertheless, there would often appear to be more chemosensory stimuli/qualities identified than the relevant laboratory-based psychophysics would lead one to expect.

Let's pursue the notion that not everything that the experienced wine taster perceives necessarily has to be perceived in the wine itself. There is, after all, plenty of evidence to suggest that people fill in missing elements in their perceptual experience on the basis of what they expect to see, hear, feel, smell,

or taste. As an example of such olfactory ‘filling-in’, just take Laska and Hudson’s (1992) demonstration that, in a task in which their participants had to discriminate odour mixtures with one component missing, 20–40% of the participants thought that the two samples were identical. That is, they completely missed the fact that one of the odours was absent from the mixture. This example might thus be taken as an olfactory example of filling-in.

Could one, for example, perhaps think of the wine expert’s rich taste experience as an example of amodal completion (i.e., perceptually filling-in some of the aroma/flavour notes that they expect to be there)? One can perhaps think of it as ‘infusing perception with imagination’ (see Brown, 2018). The philosopher Bence Nanay (2010) considers perceptual completion (and amodal perception) to be a form of mental imagery. Modal (and amodal) completion is the name originally given to the way in which visual shapes are completed in the absence of any sensory input (Michotte *et al.*, 1964/1991). Visual objects that are hidden behind an occluder are said to be represented amodally whereas the Kanizsa triangle is considered to represent an example of modal completion (e.g., Gerbino, 2020; Kanizsa and Gerbino, 1982). It is, though, worth noting that not all philosophers necessarily support the distinction between modal and amodal completion. Crucially, however, while the concept of (a)modal completion was first discussed in the context of visual perception, it has subsequently been examined in the auditory and tactile modalities as well. For example, in the tactile/haptic modality, one might think only of the way in which our mind fills in, or represents, the rest of the object we are holding in our hands despite having no direct sensory information from those parts of the object that are not directly in contact with the fingers (Gallace and Spence, 2014). This, according to Nanay (2010, p. 241) is an example of amodal completion. It would seem reasonable to ask whether wine tasting, at least for the more expert (or experienced) taster, might involve some form of chemosensory filling-in, or completion.

According to Brochet and Dubourdieu’s (2001) prototype theory, experienced wine tasters form an impression of what a wine ought to smell and taste like based on whatever prior information they might have had available to them (such as from visually inspecting the liquid in the glass or the information on the label), before tasting the wine itself. Brochet and Dubourdieu’s suggestion was that this prototype might then interfere with the actual perceptual experience when subsequently tasting the wine (see also Spence, 2010a). Relevant here, multiple studies have demonstrated that wine tasters, especially experts, tend to fall victim to colour-induced olfactory biases in wine perception (e.g., Morrot *et al.*, 2001; Parr *et al.*, 2003; Spence, 2010b). Of course, expertise may help with the generation of the relevant mental imagery (Croijmans *et al.*, 2020). A relatively large study of 168 tasters by Wang and Spence (2019) revealed that experienced wine tasters clearly identified fruit aromas

and flavours in a white wine that had artificially been coloured pink to look just like a rosé wine that they did not predict/experience in the unadulterated white wine. Such results make sense from a predictive coding account. While such prototypes might indeed interfere with tasting under those conditions where a wine has been artificially miscoloured to distract a taster, it is worth remembering that normally such visual cues are likely to provide useful information about the sensory qualities of the wine being tasted.

Given the role played by chemosensory mental imagery in wine tasting, especially amongst wine experts who likely have a much richer range of flavour expectations associated with a given wine, one might wonder who actually makes for the more veridical wine taster. Here, it is interesting to note that an extensive body of research has essentially demonstrated very little change in sensory thresholds as a result of training in wine tasting (see Spence, 2019, for a review; though see also Tempere *et al.*, 2012, 2019). Instead, the most obvious change is in the ability to put a name to the olfactory notes (Tempere *et al.*, 2016). It is, though, intriguing to note that visual and olfactory mental imagery training has been shown to exert a significant impact on olfactory perception (Tempere *et al.*, 2014; see also Djordjevic *et al.*, 2004b). Taken together, therefore, one would presumably still have to side with those who argue for expert wine tasters making for better (or more veridical) tasters, at least when not fooled by (e.g.,) miscoloured wine.

Taken together, therefore, when an experienced wine taster says that they can ‘perceive’ a far greater number of components to a quality wine than the olfactory psychophysics research might suggest is possible, it would seem likely, at least according to the account proposed here, that some of what may be contributing to their judgement might, in fact, actually be partly (chemosensory) mental imagery, as a function of what they infer, expect, or have read ought to be in the wine. Such a suggestion would certainly seem to represent a natural extension of the predictive coding ideas to the world of fine wine. It is, in fact, perhaps only by combining the rich time-evolving multisensory perceptual inputs that reveal themselves sequentially to the taster’s palate, together with the expected, imagined, and possibly also filled-in aromas/flavours, that one can perhaps really start to get a handle on how it is that wine writers such as, famously, David Schildknecht, are able to write one thousand words tasting notes or more about the flavour of a wine (Smith, 2008).

At the same time, however, it is important to note the importance of chemosensory mental imagery may also help to explain why it is that people typically perform so poorly in blind taste tests (see Spence, 2010c) while, at the same time, savouring the distinctive multisensory flavour experience when they know what it is they are eating or drinking. One might think of this in terms of philosopher Robert Briscoe’s (2018) phrase “make-perceive” (see Note 1).

4.2. *Olfactory Mental Imagery and the Lack of Subjective Awareness of Chemosensory Loss*

The automatic elicitation of olfactory, gustatory and/or flavour (or chemosensory) mental imagery may also help to explain why it is that many older individuals with documented chemosensory loss, particularly evident in the olfactory (and to a lesser extent gustatory) modality, remain subjectively unaware of their loss. Relevant here, Kollndorfer *et al.* (2015) demonstrated that those suffering from hyposmia (i.e., reduced olfactory function) and normal controls' (if not anosmic patients') self-evaluation of their olfactory performance could be predicted by the individuals score on the Vividness of Olfactory Imagery Questionnaire (VOIQ).

4.3. *Chemosensory Interactions Involving Orthonasal versus Retronasal Olfaction*

The surprising fact that many olfactory–gustatory interactions (Spence, 2012), such as the OITE effect (Spence, 2022b), appear relatively insensitive to the route of olfactory presentation (i.e., orthonasal or retronasal; though see Amano *et al.*, 2022, for an isolated exception) may also fit in here. That said, one important difference from the example of voluntary mental imagery that was studied by Djordjevic and colleagues (2004a), and which can be elicited in the absence of any stimuli in the 'target' modality is that the OITE would appear to require a taste stimulus (Spence, 2022a). In other words, the sensation of a sweet taste from the addition of a sweet-smelling aroma such as vanilla is only experienced on tasting something. While an odorant might be described as smelling sweet, and is consciously associated by a taster with the concept of sweetness, it doesn't give rise to a sweet taste sensation in-and-of-itself (Spence, 2022b). As such, perhaps a better way to think about OITE is as a form of automatic crossmodal mental imagery.

5. Conclusions

In this review, the explanatory benefits of extending the predictive coding framework beyond the visual modality, where it has been most extensively developed (e.g., Clark, 2013, 2015; Friston, 2005; Kirchhoff, 2018), have been highlighted. The suggestion is that such a move potentially helps to provide an explanation for several puzzling phenomena that have been reported in the chemosensory literature on odour and multisensory flavour perception. In particular, (1) the discrepancy between the limited ability of people to identify the components of odour mixtures and the detailed descriptions of wines that have sometimes been provided by wine experts (Smith, 2008; Spence and Wang, 2018b); (2) the failure of many older individuals suffering from a documented decline in their olfactory (and gustatory) perceptual abilities to appreciate their

loss (Kollndorfer *et al.*, 2015; Nordin *et al.*, 1995); and (3) the surprising fact that many olfactory–gustatory interactions, such as the OITE effect (see Spence, 2022b, for a review) appear relatively insensitive to the route of olfactory presentation (i.e., orthonasal or retronasal; see also Spence, 2012). At the same time, however, such an explanation may also help to explain the marked disconnect between the results of blind taste tests, and the highly-differentiated taste experience many people report when they are aware of what they have been made aware of what they are tasting (see Spence, 2010c).

One of the major implications of the suggestion that chemosensory mental imagery may play a much more important role in the multisensory perception of flavour than is typically realized is that one starts to question the ecological relevance of those psychophysical studies conducted in the chemical senses where the participants are presented with unfamiliar combinations of odorants under conditions where they are given minimal information about what it is that they are smelling/tasting. Such perceptual experiences are likely to be especially ‘thin’ given that crossmodally induced chemosensory mental imagery is unlikely to provide much input to the perceptual experience. Ultimately, therefore, if one accepts the key role played by imagination in multisensory taste perception then many traditional psychophysical techniques appear less ecologically valid. Rarely, after all, are we in a position where we have no information to help predict what the chemosensory stimulus might be. If we really do ‘taste imagination’ then perhaps it really is time to reconsider how we choose to conduct our research in the world of food science.

Note

1. “The matter is reduced to its simplest terms in the joke about the man who claims that he can, without fail, identify any wine in the world. Blindfolded, he is put to the test by his friends. Offered a glass, he takes a sip and proudly proclaims: “Red!” (Weiss, 2002, p. 94).

References

- Algom, D. and Cain, W. S. (1991a). Chemosensory representation in perception and memory, in: *Ratio Scaling of Psychological Magnitude*, S. J. Bolanowski and G. A. Gescheider (Eds), pp. 183–198. Erlbaum, Hillsdale, NJ, USA.
- Algom, D. and Cain, W. S. (1991b). Remembered odors and mental mixtures: tapping reservoirs of olfactory knowledge, *J. Exp. Psychol. Hum. Percept. Perform.* **17**, 1104–1119. DOI:10.1037/0096-1523.17.4.1104.
- Algom, D., Marks, L. E. and Cain, W. S. (1993). Memory psychophysics for chemosensation: perceptual and mental mixtures of odor and taste, *Chem. Senses* **18**, 151–160. DOI:10.1093/chemse/18.2.151.

- Amano, S., Narumi, T., Kobayakawa, T., Kobayashi, M., Tamura, M., Kusakabe, Y. and Wada, Y. (2022). Odor-induced taste enhancement is specific to naturally occurring temporal order and the respiration phase, *Multisens. Res.* **35**, 537–554. DOI:10.1163/22134808-bja10080.
- Arshamian, A. and Larsson, M. (2014). Same same but different: the case of olfactory imagery, *Front. Psychol.* **5**, 34. DOI:10.3389/fpsyg.2014.00034.
- Bensafi, M. and Rouby, C. (2007). Individual differences in odor imaging ability reflect differences in olfactory and emotional perception, *Chem. Senses* **32**, 237–244. DOI:10.1093/chemse/bjl051.
- Bensafi, M., Sobel, N. and Khan, R. M. (2007). Hedonic-specific activity in piriform cortex during odor imagery mimics that during odor perception, *J. Neurophysiol.* **98**, 3254–3262. DOI:10.1152/jn.00349.2007.
- Berger, C. C. (2020). Multisensory perception and mental imagery, in: *The Cambridge Handbook of Imagination*, A. Abraham (Ed.), pp. 258–275. Cambridge University Press, Cambridge, UK.
- Berger, C. C. and Ehrsson, H. H. (2013). Mental imagery changes multisensory perception, *Curr. Biol.* **23**, 1367–1372. DOI:10.1016/j.cub.2013.06.012.
- Briscoe, R. (2018). Superimposed mental imagery: on the uses of make-perceive, in: *Perceptual Imagination and Perceptual Memory*, F. Macpherson and F. Dorsch (Eds), pp. 161–185. Oxford University Press, Oxford, UK.
- Brochet, F. and Dubourdieu, D. (2001). Wine descriptive language supports cognitive specificity of chemical senses, *Brain Lang.* **77**, 187–196. DOI:10.1006/brln.2000.2428.
- Brown, D. H. (2018). Infusing perception with imagination, in: *Perceptual Imagination and Perceptual Memory*, F. Macpherson and F. Dorsch (Eds), pp. 133–160. Oxford University Press, Oxford, UK.
- Calvert, G. A., Bullmore, E. T., Brammer, M. J., Campbell, R., Williams, S. C., McGuire, P. K., Woodruff, P. W., Iversen, S. D. and David, A. S. (1997). Activation of auditory cortex during silent lipreading, *Science* **276**, 593–596. DOI:10.1126/science.276.5312.593.
- Carrasco, M. and Ridout, J. B. (1993). Olfactory perception and olfactory imagery: a multidimensional analysis, *J. Exp. Psychol. Hum. Percept. Perform.* **19**, 287–301. DOI:10.1037/0096-1523.19.2.287.
- Cavazzana, A., Röhrborn, A., Garthus-Niegel, S., Larsson, M., Hummel, T. and Croy, I. (2018). Sensory-specific impairment among older people. An investigation using both sensory thresholds and subjective measures across the five senses, *PLoS ONE* **13**, e0202969. DOI:10.1371/journal.pone.0202969.
- Cavedon-Taylor, D. (2022). Predictive processing and perception: what does imagining have to do with it?, *Consc. Cogn.* **106**, 103419. DOI:10.1016/j.concog.2022.103419.
- Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science, *Behav. Brain Sci.* **36**, 181–204. DOI:10.1017/S0140525X12000477.
- Clark, A. (2015). Perceiving as predicting, in: *Perception and Its Modalities*, D. Stokes, M. Matthen and S. Biggs (Eds), pp. 23–43. Oxford University Press, Oxford, UK.
- Costandi, M. (2016). If you can't imagine things, how can you learn? *Guardian*, 4 June 2016. <https://www.theguardian.com/education/2016/jun/04/aphantasia-no-visual-imagination-impact-learning#img-1>.

- Craver-Lemley, C. and Reeves, A. (2013). Is synesthesia a form of mental imagery?, in: *Multisensory Imagery*, S. Lacey and R. Lawson (Eds), pp. 185–206. Springer, New York, NY, USA.
- Croijmans, I., Speed, L. J., Arshamian, A. and Majid, A. (2020). Expertise shapes multimodal imagery for wine, *Cogn. Sci.* **44**, e12842. DOI:10.1111/cogs.12842.
- Deroy, O. (2020). Evocation: how mental imagery spans across the senses, in: *The Cambridge Handbook of the Imagination*, A. Abraham (Ed.), pp. 276–289. Cambridge University Press, Cambridge, UK.
- Di Lorenzo, P. M. (2021). Taste in the brain is encoded by sensorimotor state changes, *Curr. Opin. Physiol.* **20**, 39–45. DOI:10.1016/j.cophys.2020.12.003.
- Dieter, K. C., Hu, B., Knill, D. C., Blake, R. and Tadin, D. (2014). Kinesthesia can make an invisible hand visible, *Psychol. Sci.* **25**, 66–75. DOI:10.1177/0956797613497968.
- Dijkstra, N., Kok, P. and Fleming, S. M. (2022). Imagery adds stimulus-specific sensory evidence to perceptual detection, *J. Vis.* **22**, 11. DOI:10.1167/jov.22.2.11.
- Djordjevic, J., Zatorre, R. J. and Jones-Gotman, M. (2004a). Effects of perceived and imagined odors on taste detection, *Chem. Senses* **29**, 199–208. DOI:10.1093/chemse/bjh022.
- Djordjevic, J., Zatorre, R. J., Petrides, M. and Jones-Gotman, M. (2004b). The mind's nose: effects of odor and visual imagery on odor detection, *Psychol. Sci.* **15**, 143–148. DOI:10.1111/j.0956-7976.2004.01503001.x.
- Engen, T. (1987). Remembering odors and their names, *Am. Sci.* **75**, 497–503.
- Fassnidge, C., Marcotti, C. C. and Freeman, E. (2017). A deafening flash! Visual interference of auditory signal detection, *Conscious Cogn.* **49**, 15–24. DOI:10.1016/j.concog.2016.12.009.
- Fassnidge, C. J. and Freeman, E. D. (2018). Sounds from seeing silent motion: who hears them, and what looks loudest?, *Cortex* **103**, 130–141. DOI:10.1016/j.cortex.2018.02.019.
- Ferreira, V. (2012a). Revisiting psychophysical work on the quantitative and qualitative odour properties of simple odour mixtures: a flavour chemistry view. Part 1: intensity and detectability. A review, *Flavour Fragr. J.* **27**, 124–140. DOI:10.1002/ffj.2090.
- Ferreira, V. (2012b). Revisiting psychophysical work on the quantitative and qualitative odour properties of simple odour mixtures: a flavour chemistry view. Part 2: qualitative aspects. A review, *Flavour Fragr. J.* **27**, 201–215. DOI:10.1002/ffj.2091.
- Flohr, E. L. R., Arshamian, A., Wieser, M. J., Hummel, C., Larsson, M., Mühlberger, A. and Hummel, T. (2014). The fate of the inner nose: odor imagery in patients with olfactory loss, *Neuroscience* **268**, 118–127. DOI:10.1016/j.neuroscience.2014.03.018.
- Frank, M. E., Fletcher, D. B. and Hettinger, T. P. (2017). Recognition of the component odors in mixtures, *Chem. Senses* **42**, 537–546. DOI:10.1093/chemse/bjx031.
- Friston, K. (2005). A theory of cortical responses, *Philos. Trans. R. Soc. B Biol. Sci.* **360**, 815–836. DOI:10.1098/rstb.2005.1622.
- Gallace, A. and Spence, C. (2014). *In Touch With the Future: the Sense of Touch From Cognitive Neuroscience to Virtual Reality*. Oxford University Press, Oxford, UK.
- Gerbino, W. (2020). Amodal completion revisited, *i-Perception* **11**, 2041669520937323. DOI:10.1177/2041669520937323.
- Gilbert, A. N., Crouch, M. and Kemp, S. E. (1998). Olfactory and visual mental imagery, *J. Ment. Imag.* **22**, 137–146.
- Hertrich, I., Dietrich, S. and Ackermann, H. (2011). Cross-modal interactions during perception of audiovisual speech and nonspeech signals: an fMRI study, *J. Cogn. Neurosci.* **23**(1), 221–237. DOI:10.1162/jocn.2010.21421.

- Herz, R. S. (2000). Verbal coding in olfactory versus nonolfactory cognition, *Mem. Cogn.* **28**, 957–964. DOI:10.3758/BF03209343.
- Hohwy, J. (2013). *The Predictive Mind*. Oxford University Press, Oxford, UK.
- James, W. (1890). *The Principles of Psychology* (2 Vols). Henry Holt, New York, NY, USA.
- Jinks, A. and Laing, D. G. (1999). Temporal processing reveals a mechanism for limiting the capacity of humans to analyze mixtures, *Cogn. Brain Res.* **8**, 311–325. DOI:10.1016/S0926-6410(99)00034-8.
- Jinks, A. and Laing, D. G. (2001). The analysis of odor mixtures by humans: evidence for a configurational process, *Physiol. Behav.* **72**, 51–63. DOI:10.1016/s0031-9384(00)00407-8.
- Kanizsa, G. and Gerbino, W. (1982). Amodal completion: seeing or thinking?, in: *Organization and Representation in Perception*, J. Beck (Ed.), pp. 167–190. Erlbaum, Hillsdale, NJ, USA.
- Kirchhoff, M. D. (2018). Predictive processing, perceiving and imagining: is to perceive to imagine, or something close to it?, *Philos. Stud.* **175**(3), 751–767. DOI:10.1007/s11098-017-0891-8.
- Kollndorfer, K., Kowalczyk, K., Nell, S., Krajnik, J., Mueller, C. A. and Schöpf, V. (2015). The inability to self-evaluate smell performance. How the vividness of mental images outweighs awareness of olfactory performance, *Front. Psychol.* **6**, 627. DOI:10.3389/fpsyg.2015.00627.
- Laing, D. G., Link, C., Jinks, A. L. and Hutchinson, I. (2002). The limited capacity of humans to identify the components of taste mixtures and taste–odour mixtures, *Perception* **31**, 617–635. DOI:10.1068/p3205.
- Laska, M. and Hudson, R. (1992). Ability to discriminate between related odor mixtures, *Chem. Senses* **17**, 403–415. DOI:10.1093/chemse/17.4.403.
- Lawrence, G., Salles, C., Septier, C., Busch, J. and Thomas-Danguin, T. (2009). Odour–taste interactions: a way to enhance saltiness in low-salt content solutions, *Food Qual. Pref.* **20**, 241–248. DOI:10.1016/j.foodqual.2008.10.004.
- Levy, L. M., Henkin, R. I., Lin, C. S., Hutter, A. and Schelling, D. (1999). Odor memory induces brain activation as measured by functional MRI, *J. Comput. Assist. Tomogr.* **23**, 487–498. DOI:10.1097/00004728-199907000-00001.
- Low, V. (2019). Picture this: the top animators who can't draw mental images, *Times* 10 April 2019.
- MacDonald, C. (2017). Can you HEAR flashes of light? Take the synaesthesia test that researchers say affects one in five of us. *Daily Mail Online*, 17 January 2017. <http://www.dailymail.co.uk/sciencetech/article-4129468/Take-test-reveals-HEAR-flashes-light.html>.
- MacDougall, R. (1898). Music imagery; a confession of experience, *Psychol. Rev.* **5**, 463–476. DOI:10.1037/h0075017.
- Marshall, K., Laing, D. G., Jinks, A. L. and Hutchinson, I. (2006). The capacity of humans to identify components in complex odor–taste mixtures, *Chem. Senses* **31**, 539–545. DOI:10.1093/chemse/bjj058.
- Mattes, R. D. (2021). Taste, teleology and macronutrient intake, *Curr. Opin. Physiol.* **19**, 162–167. DOI:10.1016/j.cophys.2020.11.003.
- Michotte, A., Thinés, G. and Crabbé, G. (1964/1991). Les compléments amodaux des structures perceptives, in: *Michotte's Experimental Phenomenology of Perception*, G. Thinés, A. Costall and G. Butterworth (Eds), pp. 140–167. Erlbaum, Hillsdale, NJ, USA.
- Morrot, G., Brochet, F. and Dubourdieu, D. (2001). The color of odors, *Brain Lang.* **79**, 309–320. DOI:10.1006/brln.2001.2493.

- Nanay, B. (2010). Perception and imagination: amodal perception as mental imagery, *Philos. Stud.* **150**, 239–254. DOI:10.1007/s11098-009-9407-5.
- Nanay, B. (2018). Multimodal mental imagery, *Cortex* **105**, 125–134. DOI:10.1016/j.cortex.2017.07.006.
- Nordin, S., Monsch, A. U. and Murphy, C. (1995). Unawareness of smell loss in normal aging and Alzheimer's disease: discrepancy between self-reported and diagnosed smell sensitivity, *J. Gerontol. B Psychol. Sci. Soc. Sci.* **50**, 187–192. DOI:10.1093/geronb/50B.4.P187.
- O'Dowd, A., Cooney, S. M., McGovern, D. P. and Newell, F. N. (2019). Do synaesthesia and mental imagery tap into similar cross-modal processes?, *Philos. Trans. R. Soc. B Biol. Sci.* **374**, 20180359. DOI:10.1098/rstb.2018.0359.
- Olivetti Belardinelli, M., Palmiero, M., Sestieri, C., Nardo, D., Di Matteo, R., Londei, A., D'Ausilio, A., Ferretti, A., Del Gratta, C. and Romani, G. L. (2009). An fMRI investigation on image generation in different sensory modalities: the influence of vividness, *Acta Psychol.* **132**, 190–200. DOI:10.1016/j.actpsy.2009.06.009.
- Parr, W. V., White, K. G. and Heatherbell, D. (2003). The nose knows: influence of colour on perception of wine aroma, *J. Wine Res.* **14**, 79–101. DOI:10.1080/09571260410001677969.
- Pekkola, J., Ojanen, V., Autti, T., Jääskeläinen, I. P., Möttönen, R., Tarkiainen, A. and Sams, M. (2005). Primary auditory cortex activation by visual speech: an fMRI study at 3 T, *Neuroreport* **16**, 125–128. DOI:10.1097/00001756-200502080-00010.
- Perky, C. W. (1910). An experimental study of imagination, *Am. J. Psychol.* **21**, 422–452. DOI:10.2307/1413350.
- Pessoa, L. and De Weerd, P. (2003). *Filling-in: from Perceptual Completion to Cortical Reorganization*. Oxford University Press, Oxford, UK.
- Pessoa, L., Thompson, E. and Noë, A. (1998). Finding out about filling-in: a guide to perceptual completion for visual science and the philosophy of perception, *Behav. Brain Sci.* **21**, 723–802. DOI:10.1017/s0140525x98001757.
- Plailly, J., Delon-Martin, C. and Royet, J.-P. (2012). Experience induces functional reorganization in brain regions involved in odor imagery in perfumers, *Hum. Brain Mapp.* **33**, 224–234. DOI:10.1002/hbm.21207.
- Proverbio, A. M., D'Aniello, G. E., Adorni, R. and Zani, A. (2011). When a photograph can be heard: vision activates the auditory cortex within 110 ms, *Sci. Rep.* **1**, 54. DOI:10.1038/srep00054.
- Roberts, M. H. and Shenker, J. I. (2016). Non-optic vision: beyond synesthesia?, *Brain Cogn.* **107**, 24–29. DOI:10.1016/j.bandc.2016.05.007.
- Schab, F. R. (1990). Odors and the remembrance of things past, *J. Exp. Psychol. Learn. Mem. Cogn.* **16**, 648–655. DOI:10.1037/0278-7393.16.4.648.
- Segal, S. J. (1971). Processing of the stimulus in imagery and perception, in: *Imagery: Current Cognitive Approaches*, S. J. Segal (Ed.), pp. 69–100. Academic Press, New York, NY, USA. DOI:10.1016/B978-0-12-635450-8.50011-X.
- Segal, S. J. (1972). Assimilation of a stimulus in the construction of an image: the Perky effect revisited, in: *The Function and Nature of Imagery*, P. W. Sheehan (Ed.), pp. 203–230. Academic Press, New York, NY, USA.
- Segal, S. J. and Fusella, V. (1970). Influence of imaged pictures and sounds on detection of visual and auditory signals, *J. Exp. Psychol.* **83**, 458–464. DOI:10.1037/h0028840.

- Segal, S. J. and Fusella, V. (1971). Effect of images in six sense modalities on detection of visual signal from noise, *Psychon. Sci.* **24**, 55–56. DOI:10.3758/BF03337889.
- Segal, S. J. and Nathan, S. (1964). The Perky effect: incorporation of an external stimulus into an imagery experience under placebo and control conditions, *Percept. Mot. Skills* **18**, 385–395. DOI:10.2466/pms.1964.18.2.385.
- Shams, L., Kamitani, Y. and Shimojo, S. (2000). Illusions. What you see is what you hear, *Nature* **408**, 788. DOI:10.1038/35048669.
- Smith, B. C. (2008). Is a sip worth a thousand words?, *World Fine Wine* **21**, 114–119.
- Spence, C. (2010a). The color of wine — part 2, *World Fine Wine* **29**, 112–119.
- Spence, C. (2010b). The color of wine — part 1, *World Fine Wine* **28**, 122–129.
- Spence, C. (2010c). The price of everything — the value of nothing?, *World Fine Wine* **30**, 114–120.
- Spence, C. (2012). Multi-sensory integration and the psychophysics of flavour perception, in: *Food Oral Processing — Fundamentals of Eating and Sensory Perception*, J. Chen and L. Engelen (Eds), pp. 203–223. Wiley-Blackwell, Oxford, UK.
- Spence, C. (2019). Perceptual learning in the chemical senses: a review, *Food Res. Int.* **123**, 746–761. DOI:10.1016/j.foodres.2019.06.005.
- Spence, C. (2022a). Factors affecting odour-induced taste enhancement, *Food Qual. Pref.* **96**, 104393. DOI:10.1016/j.foodqual.2021.104393.
- Spence, C. (2022b). Odour hedonics and the ubiquitous appeal of vanilla, *Nat. Food* **3**, 837–846. DOI:10.1038/s43016-022-00611-x.
- Spence, C. (in press). Sensory acuity: impact of aging and chronic disease, in: *Functional Foods and Chronic Diseases: Role of Sensory, Chemical and Nutritional Effects*, M. Aliani and M. Eskine (Eds). Academic Press, New York, NY, USA.
- Spence, C. and Deroy, O. (2013). Crossmodal mental imagery, in: *Multisensory Imagery*, S. Lacey and R. Lawson (Eds), pp. 157–183. Springer, New York, NY, USA. DOI:10.1007/978-1-4614-5879-1_9.
- Spence, C. and Wang, Q. J. (2018a). On the meaning(s) of complexity in the chemical senses, *Chem. Senses* **43**, 451–461. DOI:10.1093/chemse/bjy047.
- Spence, C. and Wang, Q. J. (2018b). Searching for the complexity in fine wine, *World Fine Wine* **61**, 140–146.
- Spence, C., Smith, B. and Auvray, M. (2015). Confusing tastes with flavours, in: *Perception and Its Modalities*, D. Stokes, M. Matthen and S. Biggs (Eds), pp. 247–274. Oxford University Press, Oxford, UK. DOI:10.1093/acprof:oso/9780199832798.003.0011.
- Stevenson, R. J. and Case, T. I. (2005). Olfactory imagery: a review, *Psychon. Bull. Rev.* **12**, 244–264. DOI:10.3758/BF03196369.
- Symons, D. (1993). The stuff that dreams aren't made of: why wake-state and dream-state sensory experiences differ, *Cognition* **47**, 181–217. DOI:10.1016/0010-0277(93)90049-2.
- Tempere, S., Cuzange, E., Bougeant, J. C., de Revel, G. and Sicard, G. (2012). Explicit sensory training improves the olfactory sensitivity of wine experts, *Chemosens. Percept.* **5**, 205–213. DOI:10.1007/s12078-012-9120-1.
- Tempere, S., Hamtat, M. L., Bougeant, J. C., de Revel, G. and Sicard, G. (2014). Learning odors: the impact of visual and olfactory mental imagery training on odor perception, *J. Sens. Stud.* **29**, 435–449. DOI:10.1111/joss.12124.

- Tempere, S., Hamtat, M.-L., de Revel, G. and Sicard, G. (2016). Comparison of the ability of wine experts and novices to identify odorant signals: a new insight in wine expertise, *Aust. J. Grape Wine Res.* **22**, 190–196. DOI:10.1111/ajgw.12192.
- Tempere, S., de Revel, G. and Sicard, G. (2019). Impact of learning and training on wine expertise: a review, *Curr. Opin. Food Sci.* **27**, 98–103. DOI:10.1016/j.cofs.2019.07.001.
- Wang, Q. J. and Spence, C. (2019). Drinking through rosé-coloured glasses: influence of wine colour on the perception of aroma and flavour in wine experts and novices, *Food Res. Int.* **126**, 108678. DOI:10.1016/j.foodres.2019.108678.
- Weiss, A. S. (2002). *Feast and Folly: Cuisine, Intoxication and the Poetics of the Sublime*. State University of New York Press, Albany, NY.
- Zelano, C., Mohanty, A. and Gottfried, J. A. (2011). Olfactory predictive codes and stimulus templates in piriform cortex, *Neuron* **72**, 178–187. DOI:10.1016/j.neuron.2011.08.010.