Modulation of visual-motor responses by the perception of object affordance, automatic imitation and action agency



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Thesis presented for the degree of Doctor of Philosophy
in Experimental Psychology

Trinity Term 2018

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Submitted Trinity 2018

Abstract

When we interact with the environment in our everyday life the relationship between what we see and what we do is under continuous coupling, i.e., our perceptions and actions are built through a continuous reciprocal flow of information between sensory and motor processes. This thesis reports a series of experiments investigating perception-action coupling in terms of modulation of response selection and execution processes by the perception of object affordances, automatic imitation and action agency.

In Chapter 2, I focused on demonstrating the automaticity of the action priming effect directing attention and its relationship with awareness of object affordances. Different from the classical studies on object affordances, I addressed this relationship through attentional effects to avoid SRC effects as a confound. The result suggested that, at least for error rates, when the relationship between an object and its action-related stimulus is explicit, affordances can elicit an attentional bias towards a representation of the action that a recently seen object affords.

In Chapter 3, I investigated the temporal aspects of automatic imitation focusing on the discussion regarding the stage of information processing where the interfering effects of observing an incongruent action takes place. The results demonstrated that the automatic imitation effect interferes not only with response selection but also with response execution, therefore providing new evidence of the reach of perception-action coupling effects.

In Chapter 4, I investigated the role of a prominent self-stimulus and the sense of agency in the automatic imitation effect. The results clearly demonstrated that automatic imitation effects can be modulated as a function of self-related information, reducing sensitivity to observed movements as a consequence of self-focus.

Overall, this thesis demonstrated a strong relationship between perception and action affecting the response process. Actions can be primed by the perception of either object affordance properties or by the perception of actions performed by others.

This thesis is dedicated to Glyn W. Humphreys,
who did not get a chance to see its completion
and to Nicholas Yeung, since this thesis
would not be completed without his help.

Acknowledgments

First, I would like to thank my supervisor Prof. Glyn Humphreys, for his kindness, support and, above all, for trusting me. He taught me there is always something good to extract from every person (and every data).

I am also immensely grateful to Prof. Nick Yeung, for stepping in as my supervisor and helping me at the moment I needed the most. This thesis would not have been completed without his understanding and the crucial, kind and careful support he offered me.

I am grateful to Prof. Cecilia Heyes for teaching me to question and critique, for her constructive feedback and for inspiring me in the field of social cognition.

I would also like to thank Matthew Apps for his kind support at the later stage of my writing. I also appreciate the support and help provided by Prof Jane Riddoch and Dr. Nele Demeyere whenever I have needed them.

A special thank you to Rachel King and Charu Raghavan for always being there, for the enthusiastic support. Both of them helped me redefine friendship.

I am grateful for having the opportunity to know and share my time with wonderful people from my lab: Zargol, Maggie, Laura, Juan, Ayla.

I am grateful to all participants who took part in my experiments. Also, I am grateful to Rebecca Cardus, Claire Gregory and Charlotte Thompson for making my life at the Department of Experimental Psychology much easier.

Last but definitely not least, I would like to thank my husband and dear friend Marcus, for his support, understanding and having my back at all times. A special thank you to my daughter Beatriz, for always remind me of what is really important in life.

The research reported was supported by a studentship from the National Council for Scientific and Technological Development (CNPq) - Brazil.

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Chapter 1

Thesis Introduction

1.1 Modulation of visual-motor responses by the perception of object affordance, automatic imitation and action agency

When we interact with the environment in our everyday life the relationship between what we see and what we do is under continuous coupling, i.e., our perceptions and actions are built through a continuous reciprocal flow of information between sensory and motor processes. A good way to demonstrate this is, for instance, through the obvious failure of a skilled baseball player to hit an approaching ball if his eyes are closed or, the inability to perceive a texture of a surface if we cannot actively explore it by moving our fingers over it. Furthermore, in a conversation between two people, the understanding can be completely different if one cannot see the facial expressions, the gestures and the body of the other. However, this fundamental coupling between perception and action has not always been recognized that way. In the 20th century, the dominant perspective was that the brain extracted knowledge from sensations (Friston, 2018). Some models have assumed that outputs of perception are used to drive a subsequent, terminal stage of response execution, where perceptual analysis only guides action, with no reciprocal effects on perception (Cutsuridis, Hussain, & Taylor, 2011). More recently, there has been substantial behavioural and neurophysiological evidence showing that visual stimuli can cause activation of motor structures in a highly automatic manner (McBride, Boy, Husain, & Sumner, 2012), and also action representations can facilitate some instances of visual perception processing, e.g., object recognition (Helbig, Steinwender, Graf, & Kiefer, 2010; Makris, Hadar, & Yarrow, 2013; Tucker & Ellis, 2001). Within the speech domain, studies have demonstrated that disruption in somatotopic mapping of speech sounds in

motor cortex can modulate their perception, giving further support for the view that motor representations play a role in perception (Möttönen & Watkins, 2009).

Studies of how we interact with the environment and other people has shown the fundamental importance of understanding the perception-action coupling. The way we manipulate an object can influence how we perceive it. When interacting with other people, their actions can influence your own actions, even without awareness of it. Moreover, this influence can be different if the interaction involves a friend or an unfamiliar person.

In this thesis, I focus on the modulation of action response processing by different modulators: 1) object affordances (i.e., visual properties linked to specific actions); 2) similar movements with social meaning (automatic imitation); and 3) action agency. In this introductory chapter I first give a summary of current views on perception-action coupling. I then introduce key findings in the two domains where my empirical questions lie: domain specificities in the context of interactions with the environment (i.e., objects) and other people's actions. I then derive my research questions from these findings.

1.1 THE COUPLING OF PERCEPTION – ACTION

When James Gibson (1979) proposed "We must perceive in order to move, but we must also move in order to perceive," (p. 223) he illustrated the principle using the visual information generated when an observer moves relative to the environment. He argued that when moving, a global pattern of optical flow is generated at the moving point of observation. At the same time, this information can be used to regulate the forces applied by the observer in controlling subsequent movements, which in turn generate a new flow

field, and so on in a circularly causal coupling (Warren, 1990). Below I review further perspectives concerning the coupling of perception and action.

1.1.1 The sensorimotor theory

The sensorimotor theory of action claims that the presentation of a stimulus is both a necessary and sufficient condition for triggering its appropriate response. Accordingly, any action is a re-action: it is regarded as a causal consequence of stimulation (Hommel, Müsseler, Aschersleben, & Prinz, 2001). This idea can be traced back to Descartes's analysis of the relationship between perception and action, where activity on the motor side must be understood as response to activity on the sensory side of the brain (Descartes, 1664).

In sensorimotor theory, perception and action are coded separately. Stimuli and response are, by definition, distinct and incommensurate. The internal representation of stimulus codes relates to patterns of stimulation arising in receptor systems, whereas movement codes relate to patterns of excitation travelling to effector systems and, consequently, there is no possibility that these codes be compared with each other (Prinz, 2018). Therefore, sensorimotor theory implies a translation stage that bridges stimulus codes and movement code.

1.1.2 The ideomotor theory

Ideomotor theory was brought about by the question of how the idea of an action produces its intended action. According to William James (1890), our voluntary action, which is strongly connected with an intention to do something, occurs when the we know the sensorimotor effects of that action. A major assumption of the ideomotor theory states that an action is initiated by the anticipation of its effects. However, before this mechanism

can be applied, there must be a learning phase where the individual is guided about a variety of actions and their specific effects. Greenwald (1970) extended this notion by claiming that these associations can also be used in the reverse order: when individuals perceive events that they have learned may result from certain movements, perception of these events may evoke the movements leading to them. Therefore, the extended ideomotor theory implies that action planning and control are no longer separate from the perceptual representations of environmental events (Prinz, 2005).

In line with the ideomotor notion is the common coding theory of perception and action, which postulates that perception and action rely on common codes (Hommel et al., 2001; Prinz, 1997a). The action code is not a representation of the action per se, it actually reflects the perceptual consequences that the action produces. Since actions are coded in terms of their perceptual effects, perception and action occupy a common representational domain. Thus, this view implies commensurability between perception and action and, as an important consequence, it means they can be more or less understood on the same ground.

1.1.3 The predictive coding theory

Recently, it has been argued that the brain is, essentially, a prediction machine (Clark, 2013), continually attempting to predict the external causes of sensory information. Predictive coding is a computational framework which proposes that incoming sensory inputs are constantly compared with internal expectations or predictions in a hierarchical way. When there is a discrepancy between predictions and the input, this is referred to as a prediction error, which is used to update the internal model about the causes of the sensory event in a Bayesian manner (Clark, 2013; Friston, 2005). According to Friston, (Friston, 2009; Friston, Kilner, & Harrison, 2006) the

thermodynamics concept of free energy principle explains why brain mechanisms will always try to minimize error by either changing the predictions (perception) or by changing the predicted sensory inputs (action). This process is organized hierarchically, e.g., the prediction error arising from a given level serves as the input to the next level in a recursive Bayesian process. Thus, perception can be described as the process of minimizing prediction errors between higher and lower-levels; action is the active process to resample the environment in order to reduce prediction error. The outcome is a dynamic system that constantly updates models of its environment at multiple hierarchically organized levels.

However, predictive coding has not been mapped out physiologically on the neuronal level. Kogo & Trengove (2015) emphasize that the details of the neurophysiological mechanisms, especially how the errors are computed and minimized, need to be articulated in neuronal terms and not only phenomenologically described in a theoretical framework.

Together, sensorimotor and ideomotor theories contrast the role of external (sensory) and internal (volitional) causes of action. This difference reveals a methodological impasse: since stimuli are directly observable entities, it is easy to record and/or manipulate, whereas goal representations are unobservable entities that cannot be recorded and manipulated that way (Hommel et al., 2001). In this sense, the ideomotor theory, as an inverse model, is in accordance to the predictive coding of planned action, and motor commands are used to make adjustments in order to reduce prediction error (Shin, Proctor, & Capaldi, 2010). However, possibly due to the powerful explanation in physical terms, the sensorimotor theories of action have been more widely used than ideomotor theories (Prinz, 2018).

Thus, in the next session I present two approaches regarding the coupling between perception and action: the interactions in relation to the environment in which we are immersed, and in relation to the others surrounding us. The former consists of interactions between an individual and an object, its space and time. The latter consists of interactions among individuals, e.g., during imitation or a simple conversation. Usually, these interactions are studied using the relationship between stimuli and response to infer its effect on performance.

1.2 INTERACTIONS BETWEEN THE INDIVIDUAL AND THE ENVIRONMENT

All forms of adaptive behaviour require the processing of sensory information (regulated by environmental feedback) and their transduction into a series of goal-directed actions (regulated by internal feedback) (Fuster, 2004). Sensory information comes from the space we are in, the objects we interact with, and the temporal dimension of our lives. It can be seen in the simple act of driving along a road and stopping at traffic lights: Actions must be made when processing information from the space (where is the relative position of the car), from objects (the traffic lights colours) and from the temporal dimension (when the colour will change).

1.2.1 Affordances

"*The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment*". (Gibson, 1979, p. 127).

Affordance theory states that the world is perceived not only in terms of object shapes and spatial relationships but also in terms of object possibilities for action. To elucidate this idea, Gibson gives the example of a horizontal, flat, extended, and rigid surface that affords support. A given surface that provides support for one actor, may not provide support for another actor (perhaps because of a differential in weight or size). Although there is only one surface in question here, the affordance of support exists for one actor whereas it does not exist for another. It is important to note that the affordance is not a property of the experience of the actor but rather of the action capabilities of the actor. Interestingly, even if the surface is not intended to provide support, if it does in fact support a given actor, then the affordance of support exists.

Warren (1984) investigated affordances in visual guidance of stair climbing. They defined the stair affordance as "climbable" and "unclimbable". Participants were divided into a short group (mean height 5 ft. 4.4 in) and a tall group (mean height 6 ft. 2.7 in). The results demonstrate that both groups judged stairways as unclimbable at a riser height in proportion to their leg lengths and could be expressed as a constant proportion of each actor's leg length, 0.88. In this experiment, the underlying dynamics of the individual–environment system clearly determined the judgement for the control of the climbing action. In support of this proposal, Mark and Vogele (1987) also found perceived maximum seat height to be a constant proportion of each person's leg length; curiously, it was the same intrinsic ratio of surface height to leg length reported in Warren's study of climbing.

Studies involving graspable objects have demonstrated that the simple viewing of an object can automatically elicit motor system activity supporting possible actions toward that object, which can be either directly recorded, or inferred from behaviour (Craighero,

Fadiga, Umilta, & Rizzolatti, 1996; Tucker & Ellis, 2001). Ellis and Tucker (2000) asked subjects to make a wrist rotation of a given direction whilst viewing objects which would require wrist rotations if they were to be grasped. Responses executed in the presence of objects compatible with a clockwise wrist rotation produced faster reaction times than those compatible with an anti-clockwise rotation. The results showed that action-relevant stimuli primed associated components of the afforded action such as grasp or wrist rotation, showing automatic extraction of action-relevant information from perceived objects.

Nonetheless, Proctor and Miles (2014) debate that there is little evidence to justify application of the ecological concept of affordance to laboratory studies. They discuss that differences in performance as a function of pairing of different stimulus and response sets or mappings of individual stimuli within a set to specific responses can be better explained as Stimulus-Response Compatibility effects (see below). They argue that in the domain of compatibility effects in choice-reaction tasks, researchers have more to gain from attending to insights derived from operating controls in design environments than to those derived from dynamic interactions with natural environments.

1.2.2 Stimulus-Response Compatibility

When we are driving a car and want to make a left or right turn, we must to signal to which side we are going to turn. After practice, it becomes automatic to process information from the mirrors, the car position and its speed. It is also in an automatic manner that we move the turn signal switch up or down to signal right or left. Although it is a convention learned, there are reasons why the convention is "right – up" and "left - down". Several studies in ergonomics (Chan & Chan, 2011; Hoffmann & Chan, 2011; Iani, Milanese, & Rubichi, 2014; Sen & Das, 2000; Swei-Pi, 1997) have demonstrated

that even though there is not an evident spatial correspondence between stimuli and responses, for instance, the position of the turn sign switch and the light flashing, performance is better when "up" stimuli are mapped to right responses and "down" stimuli are mapped to left responses (up-right/down-left mapping) than otherwise (up-left/down-right mapping) (Iani et al., 2014). In cognitive psychology, this phenomenon is known as Stimulus-Response Compatibility (SRC) (Fitts & Seeger, 1953) and it can be defined as the degree of association between a given stimulus and a required response, i.e., when a stimulus and its correspondent response share a given feature (e.g., a spatial position) has greater compatibility than when no feature is shared. A high level of SRC is typically associated with a shorter reaction time, whereas a low level of SRC tends to result in a longer reaction time. One of the most accepted accounts to explain the up-right/down-left advantage, an orthogonal SRC, is the salient-features-coding (Weeks & Proctor, 1990) which attributes the advantage to asymmetric coding of the stimulus and response alternatives. They argue that "up" and "right" are the salient polar referents for their respective vertical and horizontal dimensions. Hence, the stimulus-response translation is faster because the salience relations in the stimulus set are maintained in the mapping to the response set and a simple rule, based on correspondence of salient features, can be applied. Our lives are full of many other examples, from the relative knobs position in our stoves (Hoffmann & Chan, 2011) to the configuration of the number in the telephone keypad we use every day (Lutz & Chapanis, 1955).

In experimental psychology, classical effects like the Stroop (Stroop, 1935) and the Simon (Simon, 1969) effects are also cases of SRC. Both are demonstrated using specific tasks to measure the interference of irrelevant stimuli on response selection and execution (although there are some differences regarding the processes that might be responsible for these effects (Li, Nan, Wang, & Liu, 2014)). Typically, an imperative stimulus is presented

together with a task-irrelevant stimulus (or stimulus attribute) that shares some feature with the required response. In the case of the original Simon task, a case of left-right SRC, the imperative stimuli were a high-pitched tone (1000 Hz) and a low-pitched tone (400 Hz), each presented to one ear at a time and requiring a correspondent response (say, a key press on the right or left side, respectively). The spatial feature of the imperative stimulus is task-irrelevant. Consequently, it is possible to have two different situations in the Simon task: i) the tone that requires the press of the right key is presented to the right ear and ii) the tone that requires the press of the right key is presented to the left ear (and, conversely, for the other imperative tone). When pressing the key, participants appear to be unable to ignore the irrelevant spatial information provided by the stimulus position. Therefore, RT is shorter when there is spatial compatibility between the stimulus' irrelevant location and the response than when they are incompatible.

A close examination of the Stroop and Simon effects shows that irrelevant inanimate stimuli can delay responding by interfering during the process of response selection and execution (Eimer, Hommel, & Prinz, 1995; Hommel, 1995, 1996; Proctor & Vu, 2006; Proctor, Van Zandt, Lu, & Weeks, 1993). Currently, the most accepted models of SRC effects are dual-process models that differentiate the process of selecting the response in two routes. An intentionally-guided or indirect route, which relies on short-term associations and is defined by task instructions, mediates the activation of the motor response after a perceptual analysis of the imperative stimulus. In parallel, an automatic or direct route relies on the activation produced by long-term stimulus-response (S-R) associations that are innate or overlearned, and mediates the activation of the motor response correspondent to the stimulus which is task-irrelevant (Proctor & Vu, 2006). Kornblum et al. (1990) add a basic framework for compatibility effects based on the idea of "dimensional overlap" between stimulus and response dimensions. By

outlining different ways in which stimulus and response dimensions may overlap, their model is able to define a taxonomy of different types of compatibility tasks. Therefore, when the intentionally-guided and the automatic route activate the same motor programs, e.g., in compatible trials where there is an overlap between dimensions, the response will be executed faster and performance will accurate. On the other hand, if the two routes activate different motor programs as in incompatible trials, with no overlap between dimensions, the automatic route leading to a misleading response must be suppressed and consequently the response will be slower and performance will be more prone to mistakes (Kornblum, Hasbroucq, & Osman, 1990).

Taken together, affordances and SRC effects are often used to address the perception-action coupling that occurs when we interact with the environment. However, it is important to distinguish both effects in the experimental design rationale. Tucker & Ellis (1998), for example, asked subjects to view objects that afford either a right- or left-hand response and to make either a right- or left-hand key press to report whether each object was upright or inverted. Crucially, response times (RTs) were shorter when the responses were made by the afforded hand (compatible trials) than the non-afforded hand (incompatible trials). This effect has been attributed to the affordance of the object's handle, but it could be equally regarded as resulting from spatial compatibility effects, due to the visual asymmetry created by the graspable feature, irrespective of any affordances. Indeed, Cho & Proctor (2010) presented evidence that Tucker and Ellis' (1998) findings are not due to an affordance, but rather due to the spatial compatibility of the handle's relative location, essentially a Simon effect. In their study, the authors presented a frying pan with its handle oriented to the left or right sides. When participants responded to the object's vertical orientation, compatibility effects were obtained when responses were

given using left and right-hand responses and also when the judgements were indicated with different fingers of the same hand. They argue that, because a grasping affordance should differentially affect keypress responses only when they are made with different hands (and should not vary according to the spatial relationship of fingers within a hand), their experiments clearly provide strong evidence for the Simon effect. Thus, although affordances and SRC effects similarly suggest the importance of perception-action coupling, in specific cases they can provided competing accounts of observed experimental effects. In particular, previous demonstrations of the influence of object affordances may actually reflect SRC effects.

Therefore, in my first empirical chapter, I address actions primed by object affordances using an attentional task. Considering evidence that action relations between a hand depicted in interaction with an object can direct visual attention (Humphreys et al., 2013), I ask whether and how automatic object affordances would bias attention towards an action-related stimulus. In this manipulation, there is no direct relation between the imperative stimulus and its correspondent response, which avoids any possible SRC effect.

1.3 INTERACTIONS BETWEEN THE INDIVIDUAL AND THE OTHERS

In my second line of experiments in this thesis, I focus on perception and action coupling within a social setting. Humans naturally engage in a wide range of social interactions. Previous research has focused on the role of higher cognitive functions, such as theory of mind and language processing, in social exchange. However, recent studies on the neurophysiology of action perception suggest that basic perception–action links are also crucial for many social behaviours.

1.3.1 Neurophysiological evidence of perception-action coupling

The recognition of an action was initially conceived as based only on the visual system; that is, an analysis of the visual components of the specific action, the agent involved, the object to which the action is directed and the context in which it is inserted (Buccino, Binkofski, & Riggio, 2004). Thus, the interaction of all these elements, once visually identified, would allow the observer to recognize and understand an action made by another person. An alternative account admits that the observation of an action would stimulate an "internal motor representation" that would involve the same neural structures involved in the execution of the observed action. According to this account, although no movement is executed, the motor representation evoked by observation would be sufficient for action recognition and understanding. With the discovery that there is activation of neurons in the parietal and pre-motor cortex during the observation of actions, so-called "mirror neurons" (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996), there is a possible neurophysiological substrate which explains the coupling between perception and action in social contexts. This account, however, does not exclude the possibility that other cognitive processes, based on object description and movement might be involved.

The discovery of mirror neurons had a great impact on the study of human behaviour. As they seem to integrate observation and action, they have been the focus of studies on how a human being understands actions of others and to what extent he or she is able to share experiences. However, the extent of which the mirror neurons can explain action understanding has receive significant criticism. There is evidence that the mirror neuron activity is more related to action selection than action understanding (Hickok, 2009, 2013; Hickok & Hauser, 2010).

1.3.2 Automatic Imitation

In Brazil, there is game called "dead or alive" that is very popular among children. The basic idea is to concentrate on the voice commands given by an instructor instead of his/her body movements (Fig. 1.1). The instructor will say either "dead" or "alive", which means squat or stand, respectively. However, at the same time as the command is uttered, the instructor will adopt one of the two positions. Players should adopt only the position said by the instructor, and the challenge is not to be affected by the instructor's movements. Anyone who adopts a position contrary to what was commanded is taken out of the game. This game, often played at schools, is used to teach children to focus and concentrate, as well as to control their movements. In psychology, researchers have already addressed this kind of interaction. They argue that, instead of being just a lack of focus and self-control, it occurs due to a natural tendency to copy observed actions even when they are not relevant to the task but have the power to interfere with performance (Heyes, 2011). Neurophysiologists had also demonstrated that when we observe a movement, not only our visual system but also the motor system is activated (di Pellegrino et al., 1992; Gallese et al., 1996). Hence, when observing an action, we automatically map it into our motor repertoire (Jeannerod, 2001; Wolfgang Prinz, 1997b; Rizzolatti, Fogassi, & Gallese, 2001) and, if an action execution is required, the motor output can express some interference from the action mapped. This interference, measured in terms of RT and accuracy, is larger when the properties of the stimulus presented and the response required share similarities. In this sense, the game presented above could be explained on the basis of the similarities between what children need to do (squat/dead or stand/alive) and what they see (the instructor's movements of squatting or standing). When the instructor stands and children need to be "alive", there is a high compatibility and the two routes activate the same motor response, so children are faster to respond and do it

accurately. On the other hand, when the instructor squats and children need to stand, the compatibility is very low and the two routes activate different motor responses, so they tend to be slower to respond and more prone to make a mistake. This rationale is the same used to address automatic imitation using an SRC task.

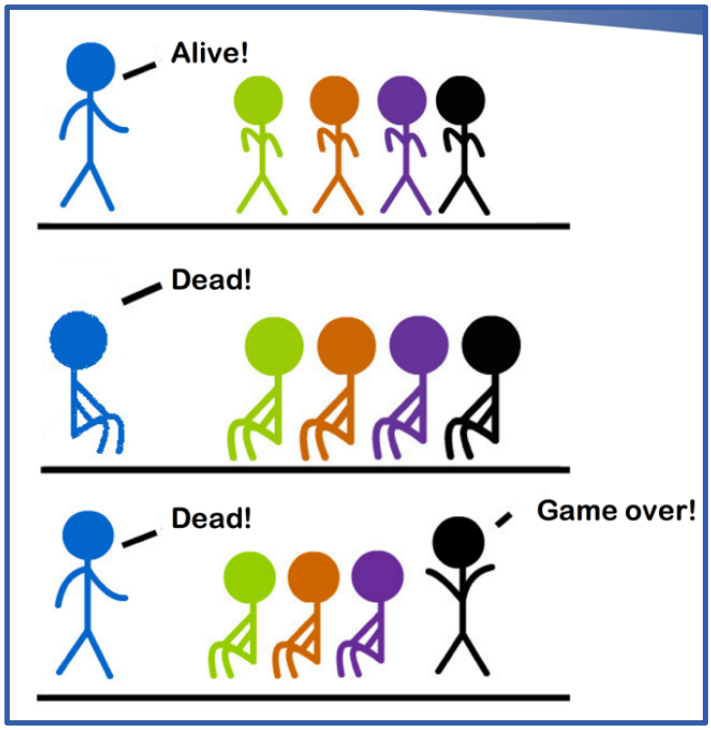


Figure 1.1. Dead or alive game where players should obey the commands said by the instructor instead of his/her body movements. In the first two rows participants are correct according to the commands. Coincidentally but not mandatory, the commands match the instructor's body movement. In the third row, one of the participants copied the instructor's body movement instead of the commands and, according to the rules, the game is over for him/her.

Like the game mentioned above, automatic imitation is a type of SRC effect in which the topographical features of task-irrelevant action stimuli facilitate similar responses and hamper dissimilar ones (Heyes, 2011). The SRC effect has been used to explain several studies demonstrating the automatic imitation effect (Brass, Bekkering,

Wohlschläger, & Prinz, 2000; Catmur & Heyes, 2011; Leighton & Heyes, 2010; Stürmer, Aschersleben, & Prinz, 2000).

Stürmer et al. (2000) were the first ones to use methods and theories from SRC research to explore the mechanisms underlying the imitation of body gestures. In their interference paradigm, participants were asked to perform a hand movement (counterbalanced opening/closing) while viewing a compatible or an incompatible (hand opening/closing) action. Participants were faster to perform a hand opening action while viewing a compatible action (hand opening) than when viewing an incompatible one (hand closing), with this effect being reversed for the performance of hand closing actions. Similar effects on response times have been shown by Brass et al. (Brass et al., 2000; Brass, Bekkering, & Prinz, 2001b), Vogt, Taylor, & Hopkins (2003), Heyes et al. (2005), Press and colleagues (Press, Bird, Flach, & Heyes, 2005; Press, Bird, Walsh, & Heyes, 2008; Press, Gillmeister, & Heyes, 2006), Bertenthal, Longo, & Kosobud, (2006b), and Liepelt, Cramon, & Brass (2008). These effects are considered evidence of automatic imitation primarily because the identity of the compatible or incompatible observed movement is always task-irrelevant.

Further experiments have shown that observing another's actions interferes not only with response times but also with performance accuracy. For example, Kilner, Paulignan, & Blakemore (2003) and Kilner, Hamilton, & Blakemore (2007) asked participants to move their arm in time with the observed movements of a human or robot arm. The stimulus arm moved compatibly (in the same plane) or incompatibly (at 90º) with the participants' movements. Variance in arm movement was used as an index of interference to the executed arm movement. Compared with the baseline condition in which participants made arm movements without watching anything, there was significantly increased variance in their arm movements when they observed another

human making arm movements that were incongruent with their own. In contrast, variance did not increase when the observed incongruent movement was made by a robotic arm. Thus, the interference effect was not simply due to increased attentional demands or task complexity or any other artefactual effect of observing an incongruent movement. These results suggest that observed movements are processed differently according to whether they are made by a human or a robot.

Correspondingly, there is evidence that people show systematic biases in perception, memory, and attention to favour information related to themselves over information related to other people (Sui & Humphreys, 2016). A series of studies indicate a role of self-related information in reinforcing individual's own intentions in automatic imitation tasks through heightened self-focus (Spengler et al., 2010), narcissism tendencies (Obhi, Hogeveen, Giacomin, & Jordan, 2014), pro/antisocial primes (Wang & Hamilton, 2013) and self-relevant words (van Baaren, Maddux, Chartrand, de Bouter, & van Knippenberg, 2003).

Taken together, the studies reviewed above demonstrate that automatic imitation can be addressed using SRC tasks. Usually, the task-irrelevant stimulus is said to interfere with stimulus-response processing during the response selection stage (Bird, Osman, Saggerson, & Heyes, 2005; Cooper, Catmur, & Heyes, 2013; Heyes, 2011) and it follows the same rationale of non-social SRC studies (Eimer et al., 1995; R. Proctor & Vu, 2006). However, the results of simple reaction time (SRT) tasks, in which there is only a single, predetermined response, challenge the view that SRC effects are only related to the response selection stage, since in this type of task response selection requirements are minimal (Brass et al., 2001; Press et al., 2008, 2006; Stürmer et al., 2000). Therefore, in my second empirical chapter I investigated the temporal aspects of automatic imitation

to evaluate whether not only response selection but also response execution could be affected by input modulation in an automatic imitation task. Further, in the last empirical chapter I use the same automatic imitation experimental design combined with self-related stimuli as an index of the sensitivity of automatic imitation effects to factors like self-focus and agency.

1.4 THESIS OUTLINE

The aim of the present research is to study the relationship between perception and action. As detailed above, the extent and mechanisms of perception and action coupling are not entirely understood. Hermann Lotze (1817–1881) and Hermann von Helmholtz (1821-1894) considered that active movement and touch play a role in the genesis of three-dimensional visuospatial awareness (Briscoe & Grush, 2015). Conversely, Pylyshyn (1999) claims that vision is "cognitively impenetrable." According to his view, perception is unitary and distinct, and its outputs are unaffected by the processes receiving them (such as action or cognition). Where higher-order cognitive effects are found, he argues that they have a locus outside early vision. In recent decades, however, this debate has had a tendency towards an agreement about the interdependency between perception and action. A substantial amount of work has been done regarding the coupling between perception and action at the individual level (the individual interacting with its surroundings). More recently, the interest at the social level (the individual interacting with others) has grown over the years.

The research presented in this thesis aimed to explore and discuss the interaction between perception and action at the individual and social level. Particularly, I investigated the domain specificities underlying the effects of actions primed by object affordances and the SRC effects in an automatic imitation task.

In Chapter 2, I sought to demonstrate the automaticity of the action priming effect directing attention and its relationship with the awareness of object affordances. In Experiment 2.1, I tested whether implicit and explicit object-affordance relationships could be sufficient to direct visual attention towards an action-related stimulus in a pure perceptual discriminative task. Considering that previous studies have shown that objects prime their associated actions, here I am looking at whether this priming further leads to attention being directed towards visual stimuli consistent with those actions (i.e., hand grips). An important point of this investigation is that, here, no similar action or spatial compatibility is required. Instead, I am measuring object priming via attentional modulation towards a task-irrelevant stimulus. Importantly, the imperative stimulus and its correspondent response is not related to any kind of action representation the object could prime, which rules out any possible SRC effect. Experiment 2.2 then tested whether modulation of attentional mechanisms towards an action-related stimulus would be brought about by the predictability of the relevant stimuli, acquired by associative learning, regardless of any affordance association. In this experiment I address the proposal of contextual cueing from Chun & Jiang (1998), where visual context may guide spatial attention towards the location of targets embedded among an array of distractors by incidentally learned associations.

In Chapter 3, I investigated the temporal aspects of automatic imitation focusing on the discussion regarding the stage of information processing where the interfering effects of observing an incongruent action takes place. Experiment 3.1 is a validation of our experimental setup according to Brass et al. (2000). Experiment 3.2 was designed to assess the time window during which the task-irrelevant stimulus can interfere with response. This was done by adding different intervals between the imperative and task-irrelevant stimuli in order to explore the time-course of the congruency effect. Catmur

(2008), demonstrated that the congruency effect is not significant until the simultaneous presentation of the imperative and task-irrelevant stimulus. However, by analysing congruent, incongruent and baseline trials separately from the congruency effect, I can better explore the role of the contingency between imperative and task-irrelevant stimuli on the process of selecting the response. Finally, in Experiment 3.3, I asked whether the task-irrelevant stimulus could act on response execution. I tested it by giving participants previous information about the response to be selected including a cue before the imperative stimulus, giving participants sufficient time to fully complete the response selection stage before presenting the task-irrelevant stimulus.

In Chapter 4, I investigated the role of a prominent self stimulus and the sense of agency as an input modulator of the automatic imitation effect. Experiment 4.1 tested whether the automatic imitation effect could be affected by a prominent stimulus-induced self-bias. Experiment 4.2 tested whether an explicit relationship between the labelled background and the agent of the task-irrelevant movement would enhance the congruency effect on trials where the task-irrelevant movement agent is the "self" compared to trials with a "stranger" agent. Experiment 4.3 then tested whether the interaction of agency and self-bias with the automatic imitation effect would be also present in a task controlled for spatial compatibility.

In Chapter 5, I present a general discussion of the experiments of this thesis. In this chapter, I draw conclusions and implications from the previous empirical chapters, discuss limitations and propose future possibilities to explore in the context of perception-action coupling at the individual and social level.

1.5 OVERVIEW OF STATISTICAL ANALYSES

The data were organised and filtered using Python 3.0 (Python Software Foundation). Statistical tests reported in this thesis were conducted using Statistica software 11.0 (Statsoft). In case of violations of sphericity according to Mauchly's sphericity test (Mauchly, 1940) for repeated-measures ANOVAs, Greenhouse-Geisser corrected F-values are reported (Greenhouse & Geisser, 1959).

1.5.1 Accuracy

Accuracy measures were calculated using the percentage of correct responses for each participant for all different factors of a given task separately. Then, for each factor, the participants' individual percentages were averaged in order to yield the arithmetic mean of that sample. Accuracy was transformed using an arcsine square root considering its discrete and non-normal distribution in the Experiments of Chapters 3 and 4.

1.5.2 Reaction time

The RTs on trials with incorrect responses were excluded from analyses. RTs smaller than 100 ms were considered anticipations and greater than 1000 ms a slow response in all experiments and were excluded from analyses.

1.5.3 Distribution of reaction times

To perform distribution analyses, the "Vincent averaging" technique was used (Ratcliff, 1979; Vincent, 1912). Basically, the RTs were sorted in ascending order and binned in classes of equal size (same number of trials), and the mean of each bin was computed. This was done for each subject separately.

Chapter 2

Object Affordances and Action Priming

2.1 Introduction

The visual environments we are immersed in our everyday life typically contain multiple objects with which we interact. To succeed in such environments, we need to be able to select the actions and stimuli that are of prime relevance to our behavioural goals. In this sense, it is reasonable to assume that actions are selected based on what an object affords. In the same line, however, can we assume that objects which allow a relevant action to be performed would be prioritized? It is, therefore, critical to explore how the specific constraints of action might modulate visual selection. Is our attention directed to the possible actions an object affords? Does the action we must perform influence which visual information is prioritized? The following literature review and the experiments described in this chapter explore the hypothesis that observing the object's physical properties would be sufficient to direct visual attention towards a compatible action-related stimulus in a purely perceptual discrimination task.

2.1.1 THE COUPLING OF OBJECT AFFORDANCES AND ACTION

Grasping an object from a table is a common action in our everyday lives but it requires very complex motor behaviour. The object's physical features like its size, orientation and shape must be somehow evaluated in order to choose the most appropriate hand configuration to grasp it. Therefore, visual features of an object must be "translated" into a precise hand movement. One could argue that those object's visual properties are automatically linked to a specific hand movement. To test this idea, Craighero et al. (1996) asked whether the presentation of an object's physical features before a grasping movement can interfere with movement execution. They primed normal subjects, while ready to execute a grasping movement, by visually presenting them

with drawings (a bar orientation) irrelevant to the task to be executed. They expected that the observation of the bar orientation would automatically prime the appropriate hand position, interfering with the grasping movement. Participants had to grasp a bar in one of two possible orientations with their right hand. The participants knew in advance the bar orientation and the appropriate motor response. However, the non-predictive prime (a rectangle rotated 45º clockwise or anticlockwise) was presented before the signal. The results showed that, in the compatible condition, where the prime depicted the same orientation of the to-be-grasped bar, reaction time for initiating a grasping movement was reduced in comparison to the incompatible condition (in which the prime was presented in the opposite orientation). The authors argue that motor actions can be primed by visual stimuli. Even when an action is predetermined and ready to be executed, the motor system is still able to process other action information from the environment.

Nevertheless, Tucker and Ellis (1998) criticised the types of stimuli used in this kind of experiment. They argued that most stimuli used in Stimulus Response Compatibility (SRC) research have no natural significance for action, usually varying on a few abstract dimensions such as colour and orientation. They claimed that our everyday actions are governed by non-abstract, meaningful relations between the visual environment and the action systems of the observer. Thus, the compatibility effects on SRC tasks, which are generally assumed to operate on mental codes of the stimulus and response features, should also consider the physical correspondence between the two. Therefore, the authors created a SRC experimental design using pictures of real objects to further explore the hypothesis that the actions an object affords are automatically potentiated by visual objects (Tucker and Ellis, 1998). They presented graspable objects with their handle oriented toward either the right or left side and in an upright or inverted position. However, participants had to decide as fast as possible only whether the

displayed object was upright or inverted. In Experiment 1, participants responded by pressing a left or right button with their correspondent left and right hands. In Experiment 2, participants responded with the index and middle fingers of their right hand. If the representation of a visual object includes action components, such as the preferential activation of the hand most suited to perform a reach-and-grasp movement, then one might expect this activation to facilitate simple keypress responses carried out by the compatible hand and to interfere with those same responses carried out by the incompatible hand. Conversely, if dissociating the left-right response positions from the effectors used to implement the action led to a similar effect, then we can conclude that compatibility effect was due to location-based response codes. Interestingly, the results showed that the irrelevant left-right orientation of the centrally placed target produced a compatibility effect on responses executed by the left and right hands, but not on left-right responses executed by adjacent fingers of the same hand. Only when there was a spatial relation between the different responses and the different affordances produced by varying the objects' left-right orientations did a compatibility effect emerge. Left-right orientation was not even relevant to the task and it was extracted across the stimulus set. The authors conclude that the actions afforded by a visual object are intrinsic to its representation. Therefore, the studies from Craighero et al (1996) and Tucker and Ellis (1998) suggested that representing object visual information involves, inevitably, representing information about possible actions and thereby automatically potentiating them.

Considering the proposition of Tucker and Ellis (1998) that the mental representation of a graspable object involves not only a description of its visual properties but also encodes the motor programs to act upon it, Di Pellegrino, Rafal, & Tipper (2005) tested patients with right-parietal injury, who presented with poor orienting of attention

to the side of space contralateral to their lesion. They hypothesized that if the observation of a cup's handle enhances visual selection toward the hand most suited to grasp the handle, then we would expect more awareness on the left side for objects with handles evoking a left-handed grasp as opposed to objects with handles eliciting a right-handed grasp. Indeed, they found that the patients showed better awareness of a cup presented on the contralesional side if its handle was oriented to the left. Replacing the handles with visual cues (oval patches of size and mean luminosity equal to the handles) on the left of the cup did not have the same effect. The authors argued that the handle of the cup evoked a visuo-motor response that enhanced awareness for the stimulus. Symes, Tucker, Ellis, Vainio, & Ottoboni (2008) similarly reported that a prepared grasp could modulate attention to and awareness of an object in normal participants. In this study, participants prepared a defined precision or power grip to respond, with the task being to respond when they detected a change in any object presented in a multi-object display. Changes in the displays were masked by other visual transients making the task difficult. They found that participants were markedly better at detecting a change in an object which would be grasped in a manner matching the prepared grip (e.g., a small object when a precision grip was prepared vs. a large object when a power grip was prepared), compared to when the prepared grip and the object were incompatible. Symes et al. then suggested that motor attention could serve to bias competition of multiple representations of objects in a scene, favouring automatically action-compatible object attributes.

Evidence showing the automaticity of action potentiation by objects also comes from neuroimaging studies. Grèzes, Tucker, Armony, Ellis, & Passingham (2003) investigated the neural correlates of the influence of action-relevant and object-intrinsic (but task-irrelevant) properties on motor responses that were either compatible or

incompatible with the action an object affords. The participants were required to make power or precision grip responses based on the categorization of visually presented objects into natural or man-made items. Within each category, objects were either 'small' (usually grasped with a precision grip) or 'large' (usually grasped with a power grip). Imaging revealed activations in the parietal, premotor and inferior prefrontal cortex which covaried with compatibility between responses (power or precision grip) and the size of the object (small or large), i.e., the greater the size of the compatibility effect across participants, the greater the activation in those areas. The authors interpreted this result as evidence of activity related to object affordance processing. Indeed, the results are in line with Kornblum, Hasbroucq, & Osman (1990) dimensional overlap model, which postulates an automatic response activation and a voluntary stimulus-response (S-R) translation. In the case of incompatible trials, one response is suggested by the category of the object (given by task instructions, the intentional route) and a different one by the object's intrinsic properties (the automatic route).

Taken together, the studies reviewed above provide some evidence of a coupling between object affordances and their most appropriate action. However, these studies always included stimuli and responses with some degree of feature overlap or compatibility. Nevertheless, it is still unclear whether this coupling automaticity depends on similarity between the stimulus and response. This leaves an open question of whether action representations can be automatically primed even if a different type of response action (and consequently motor attention) is required or even in the absence of S-R feature overlapping.

2.1.2 MODULATION OF ACTION PRIMING AUTOMATICITY

Models of attentional control have usually described its modulation in terms of 1) current goals; with attention voluntarily allocated towards items in a goal-driven manner, e.g., when searching for a book in the shelf, 2) physical salience; where attention can be captured involuntarily by physically salient stimuli, e.g., a loud noise or sudden movement, and 3) selection history; where attention is biased towards previously rewarded features, e.g., a particular target colour associated with high and low monetary rewards (Awh, Belopolsky, & Theeuwes, 2012). Nonetheless, some studies revealed a lack of modulation of attention towards the target when the stimulus was merely presented before a search display (Soto, Humphreys, & Heinke, 2006). Specifically, Girardi, Lindemann, & Bekkering (2010) argue that the notion that the processing of visual object information occurs in an automatic fashion does not indicate that simply viewing graspable objects automatically potentiates components of the actions they afford. Thus, Borghi et al. (2005) propose that the presentation of visual primes should be combined with some pre-activation of the motor system in order to evoke motor information of a specific kind.

The extent of the idea that processing of action-related object features obligatorily activates consistent action plans has been recently explored by several studies (Bub & Masson, 2006; Girardi et al., 2010; Tipper, Paul, & Hayes, 2006). In a task where participants were asked to judge object shape or colour, Tipper et al. (2006) found an action priming effect for object shape, a feature involved in coding hand's configuration, but not for object colour. Pellicano, Iani, Borghi, Rubichi, & Nicoletti (2010) demonstrated priming effects with upright-inverted judgments but inverse priming effects with colour judgments. In particular, they found priming effects in upright-inverted

judgments only when the object (a flashlight) was depicted in the switched-on state. Importantly, both studies used key pressing on a computer keyboard to collect responses, i.e., they did not require an action similar to the stimulus as response. Therefore, we can conclude that for some objects it might be necessary that there is some attention paid to its affordance to elicit action priming rather than the object in an inert state.

Indeed, Valyear, Chapman, Gallivan, Mark, & Culham (2011) demonstrated the dependence of action priming on the saliency of affordances to an observer. The authors observed action priming when participants saw real objects and were instructed to use each one, but not when the instructions were merely to move the object. However, when the two types of tasks were presented in the same block of trials, they observed priming for both tasks. Further evidence that action plans can be task-dependent and not just automatically evoked comes from Yu, Abrams, & Zacks (2014). They showed that button pressing responses were primed by objects only when the object orientation-judgment task was paired with a concurrent action-related task (to imagine picking up each object), designed to elicit motor imagery. In this case, the authors suggest that grasp priming *should not* be considered automatic because it depends on task-specific mental sets. These results are particularly interesting because it suggests the possibility of two different ways of interacting with objects, as discussed in Bub, Masson, & Cree (2008): 1) *volumetric gestures* are associated with the overall shape and weight properties of objects and concern the hand posture used to grasp an object to lift or move it, rather than to use it for its defined purpose and 2) *functional gestures*, which involve specific manipulation of objects in accordance with their proper conventional use.

Additionally, evidence from imaging studies has helped us to understand this possible conflict regarding object visual properties. Mecklinger, Gruenewald, Weiskopf, & Doeller (2004), for instance, showed that when participants retain information about

the object affordance to a subsequent movement discrimination task, manipulable objects activated the ventral premotor cortex (PMC) as well as the inferior frontal and posterior parietal areas. When information was retained for a size discrimination task, the same objects activated occipital and posterior parietal brain regions, presumably reflecting the selective processing of sensory object features. Furthermore, Buxbaum & Kalénine (2010) have proposed that two different neural circuits underlying different affordances might be activated, one based on the object structure (dorso-dorsal stream), and another related to object function (dorso-ventral stream).

Taken together, the studies reviewed above indicate that action priming occurs in a way that is sensitive to the experimental task and the circumstances allowing it. However, the studies of object affordance and action priming commonly showed that the tasks that are successful in eliciting action priming are those that emphasize either the action-relevant aspects of an object (Mecklinger et al., 2004; Pellicano et al., 2010; Tipper et al., 2006; Valyear et al., 2011) or a specific motor attention during the response (Grèzes et al., 2003; Symes et al., 2008; Yu et al., 2014). Hence, an important aspect to be investigated of actions primed by object affordance is whether its automaticity depends on attention being directed to relevant object's dimensions or even towards specific ways to interact with it.

It is well known that implicit recognition of object affordances can bias object competition and visual spatial attention toward the locations of graspable objects (Handy, Grafton, Shroff, Ketay, & Gazzaniga, 2003; Vainio, Symes, Ellis, Tucker, & Ottoboni, 2008; Ward, 1999). Hence, considering the coupling between perception and action more broadly, it would be reasonable to expect that when object affordances primes an action, it will also bias attention towards that action.

Therefore, the aim of the experiments reported in this chapter was to investigate whether the object priming effect can automatically direct attention directed towards action related images. I measured the modulation of performance during a perceptual discrimination task that was combined with object affordances and images of action-related representations. In Experiment 2.1, I looked at the sensitivity of object priming using two levels of attention to object affordances to investigate whether implicit/explicit affordances can direct attention to compatible action-related stimuli during a perceptual discrimination task. I also investigated, in Experiment 2.2, whether such effects (if any) of attentional mechanisms modulation could be brought about by an object-affordance and action pre-learnt association or simply induced by the contingency between a stimulus and an action, i.e., by learning to associate across trials one given stimulus (an object) and an action (a grip representation).

2.2 Attention to Object Affordance in Action Priming

Experiment 2.1

Experiment 2.1 investigated the relationship between the automaticity of the object priming effect and the attention directed towards action-related images. I wanted to test whether general identification of an object is sufficient to modulate attention towards a representation of the action it affords, or whether this attentional modulation depends on the encoding of the object's physical properties via working memory (WM) and the attention directed to its affordance.

Working memory is generally conceived as a temporary attentional capacity that stores and manipulates information necessary for such complex cognitive tasks as

language comprehension, learning, and reasoning for a limited amount of time (Baddeley, 1992, 2012). There is evidence that object information held in WM can exert an involuntary influence on visual selection. Soto, Heinke, Humphreys, & Blanco (2005), for instance, showed that features or objects maintained in working memory could guide spatial attention and saccades in an involuntary manner. Olivers, Meijer, & Theeuwes (2006) found that a singleton in the search display that matched the stimulus in working memory induced a larger attentional capture effect. Therefore, considering that previous studies have shown that objects prime their associated actions, here I am looking at whether this priming lead to attention being directed towards visual stimuli consistent with those actions (i.e., hand grips) automatically or, whether it needs further some top-down modulation (e.g., via WM). An important point of this investigation is that no similar action or spatial compatibility is required. Instead, I am measuring object priming via attentional modulation towards a task-irrelevant stimulus. Importantly, the imperative stimulus and its correspondent response is not related to any kind of action representation the object could prime. Thus, I asked participants to either identify the object displayed or to imagine how to grasp it from the top of a table. This was done in order to investigate the effect of these tasks on a subsequent visual search in which the target appeared next to a task-irrelevant action image that could be compatible or incompatible with the affordance of the object.

There were two different groups of participants: in the explicit action priming (EAP) group, participants were asked to identify the most appropriate action to the object appearing at the beginning of the trial (represented by a power or precision grip), and had to hold this action representation in WM as the search task occurred, in order to respond a probe question at the end of the trial. In the implicit action priming (IAP) group, there was no instruction relating an action to the object displayed. Instead, participants were

asked to pay attention to the sequence of two objects displayed and, in case they were the same, to proceed with the task or, to withhold their responses when they were different (catch trials). Therefore, in the IAP group, no further information or action representation had to be held in WM during the subsequent search task. Hence, participants' performance during visual search (measured by RT and accuracy) could inform us whether the mere identification of the initial object (IAP group) was sufficient to direct attention to one of the following task-irrelevant hand grips. In this case, target detection should be more efficient when the target is located close to a grip compatible with the object presented as opposed to an incompatible grip. This might follow if objects automatically evoke a visuo-motor grasp response to the stimulus (e.g., Tucker & Ellis, 1998). On the other hand, if attention could only be modulated when the action afforded by the object was explicit and kept active during the discrimination task, then effects of a match between the action representation and the grip presented in the search display should emerge only in the EAP condition. In the case of the former, the results would be in accordance with the view that object observation is enough to activate its correspondent action representations. Importantly, this would also show that this activation is independent of a further motor attention related to the action that the object could prime.

2.2.1. METHODS

Participants

A total of twenty-eight right-handed participants were tested (fourteen in each group), 16 of whom were female. Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971) with a cut-off of 61. The participants' ages ranged from 18 to 32 years (M = 21.4). All participants had normal or corrected-to-normal-vision. They gave informed consent and received course credit or money (10

pounds/hour) for their time. This study and all the subsequent ones were approved by the Central University Research Ethics Committee of the University of Oxford

Apparatus and Stimuli

The priming stimulus set consisted of 20 colour images of large and small everyday objects (10 of each) previously selected (see Appendix 1). Each object was cropped from its background, scaled to fit within a 440-pixel-diameter circle, and presented in a visual orientation as if it were on a table. The size of the objects was approximately, 5° x 7° of visual angle. The search array consisted of two coloured images of a right hand in either a power or precision grip position (12^o x 8^o) combined with a 0.6^o x 0.12^o vertical line (target) or a 0.6^o x 0.12^o tilted line (distractor) (Fig. 2.1). The tilted line target and the vertical line distractor were displayed approximately 2° from the centre of the grip pictures at the same position in a trial, i.e., either to the left (25% of trials), to the right (25%), above (25%) or below (25%) of the grip pictures. The grip pictures with their respective stimuli (target or distractor) were equidistant (3.5^o) from a central fixation point (0.8^o x 0.8^o). Stimulus presentation and data collection were implemented in E-Prime (Version 2.0 – Psychology Software Tools). Stimuli were presented on a 23" Dell U2312HM LCD colour monitor (Dell Inc.), with resolution of 1920 x 1080 pixels and 60 Hz refresh rate. Responses were collected by using a keyboard. The head distance to the monitor's screen was kept constant with the aid of a chin rest positioned at 50 cm from the monitor.

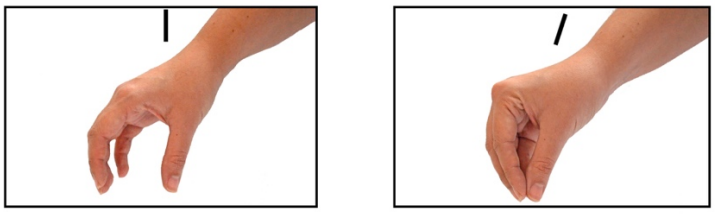


Figure 2.1. Precision (left) and power (right) grip images of Experiment 2.1 The distractor (vertical line) and the target (tilted line) are shown at the top of each grip image.

Design and Procedure

Experiment 2.1 included two groups of participants. One group performed an implicit action priming (IAP) task, and the other performed an explicit action priming (EAP) task (Fig. 2.2). Participants sat in front a computer monitor with their head positioned on the chin rest, their right hand on the keyboard, and their left hand free on their lap. Each trial began with a fixation cross (+) displayed on the centre of the screen for 400 ms. After the fixation cross disappeared, two object pictures were displayed sequentially for 600 ms each with the fixation cross reappearing for 300 ms between them. The sequence of pictures could show either the same object twice or two different objects. When the two pictures displayed the same object, participants were instructed to engage in the subsequent visual search task. However, in 20% of the trials the consecutive pictures displayed different objects (catch trials), for which participants were instructed to withhold any response and wait for the next trial.

Participants in the EAP group were informed they would perform two tasks: 1) object-grip match and 2) search task. Participants were instructed to "pay attention to the objects displayed in order to judge which grip (precision or power) would be the most appropriate to use when grasping that object from a table". For the IAP group

participants were instructed "to observe the objects displayed and wait until the search task". The object display was followed by the visual search task where participants saw a search array containing the target (tilted line) and the distractor (vertical line), each surrounding one of the two coloured images of a right hand in either a power or precision grip position (Fig. 2.1). Participants were instructed to respond as quickly as possible when identifying the target. Participants had to press the key "M" if the target was on the right or "C" if it was on the left side of the screen. The search display stayed on the screen for 1500 ms or until the response. For the EAP group, following the search task, the second task consisted of a probe question "Which grip matches the object seen previously?", presented together with the pictures of two different grips displayed on each side of the screen. Participants were asked to respond to the probe question based on what they judged at the beginning of the trial by pressing "M" if the grip they chose was on the right or "C" if it was on the left. The purpose of the probe was to ensure that participants kept an action related to the object in their WM throughout the trial. For the IAP group no probe question was presented.

There were two conditions randomly presented: (1) on compatible trials (81% of all trials), the line target was next to a picture of a grip compatible with the object presented (power grip for large objects or precision grip for small objects) and the distractor line was next to a picture of a grip incompatible with the object displayed (precision grip for large objects or power grip for small objects), (2) on incompatible trials (19% of trials), the distractor was next to a picture of a grip compatible with the object displayed and the target was next to a picture of a incompatible grip. The experiment consisted of 296 trials in total (60 catch trials and 236 valid trials). From the total of valid trials, 192 were compatible (81%) and 44 were incompatible (19%). The experiment ran in one single block. Trials with incorrect responses to the probe question or catch trials

were removed from accuracy analyses. Also, trials containing incorrect responses to the search task, probe question, or catch trials were removed from RT analyses. Reaction times (RTs) smaller than 100 ms (anticipation) and greater than 1000 ms (slow response) were removed and not further analysed.

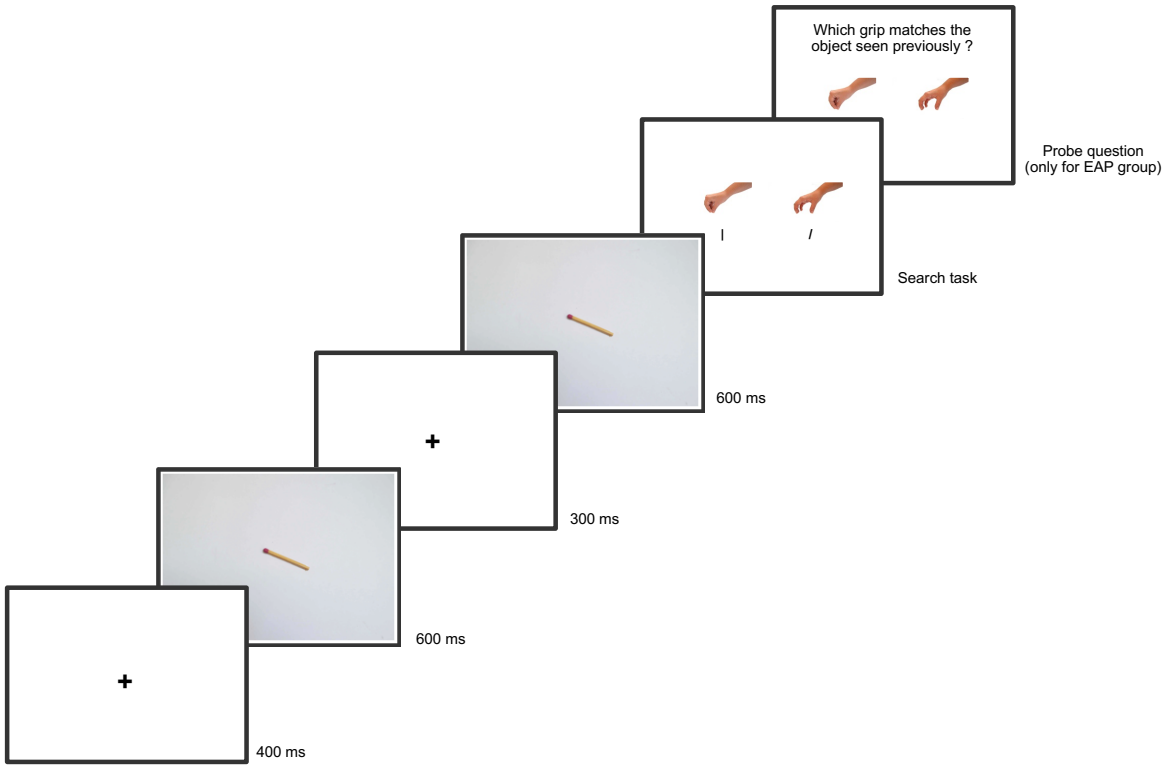


Figure 2.2. Experimental design for IAP and EAP groups for Experiment 2.1. The probe question was displayed only for the EAP group.

2.2.2 RESULTS

Experiment 2.1 investigated whether object priming could direct attention to action-related images. I asked whether the mere identification of an object is sufficient to modulate attention to a representation of the action it affords, or whether it depends on the observation of the object's physical properties and attention to its affordance. The

key hypothesis of this experiment is that object observation would automatically prime the actions it affords and, consequently, attention should be directed towards the actions that are compatible with the objects observed. Therefore, I would expect a compatibility effect on accuracy and RT, i.e., participants' responses would be faster and/or more accurate when the target is near a grip image compatible with the grip that is primed by the preceding object. Moreover, I expect a greater compatibility effect in EAP group than IAP group. To test these predictions, I ran a 2 x 2 x 2 mixed-design ANOVA on accuracy and RT measures with group (IAP vs. EAP) as a between-participants factor and compatibility (compatible and incompatible) and object size (small and large) as within-participant factors. In addition, I ran a paired t-test to compare the accuracy for large and small objects on the probe question presented on EAP group. These analyses are described below.

Accuracy

Our first analysis focused on accuracy of responding to the probe question, as a preliminary check that participants paid attention to the object as intended. I tested the accuracy on the probe question (EAP group) between the large and small objects. A paired t-test revealed no reliable difference between the two object sizes (90% for small objects vs. 87% for large objects, $t(13)=1.41$, $p=.17$). Also, participants correctly withheld the response in 98.5% of catch trials for both groups, indicating that attention was, indeed, directed towards the object at the beginning of each trial.

To test the key prediction that attention would be drawn towards grip images that are compatible with the preceding object, the mean of accuracy for the discrimination task was calculated for each participant, separately, for both groups, compatibilities and

object sizes. A 2 x 2 x 2 mixed-design ANOVA[1] was calculated having object size (small and large) and compatibility (compatible and incompatible) as within-participant factors, together with the between-participant factor of group (EAP and IAP). The analysis revealed a marginal main effect of group ($F_{(1,26)}$ = 3.86; p =.060; η_p^2 =.12), showing that the IAP group was somewhat more accurate (mean=98.5%; SE=1.5) than the EAP group (mean=94.3%; SE=1.5). Surprisingly, although participants tended to be more accurate when the target appeared close to a grip compatible with the object (98%) than close to an incompatible grip image (95%), the main effect of compatibility ($F_{(1,26)}$=2.63; p=.11; η_p^2 =.09) did not reach statistical significance, nor did the main effect of object size (F < 1) (see Table 2.1). It is critical to note, however, that the difference in EAP group between compatible and incompatible stimuli seems strongly driven by some outliers who made a high number of errors on incompatible trials (including two participants responding close to chance) (Fig. 2.3). Nevertheless, consistent with our main prediction, there was a significant two-way interaction between group and compatibility ($F_{(1,26)}$ = 4.55; p =.042; η_p^2 =.15). Post-hoc analyses (Newman-Keuls test) revealed that participants in the EAP group were significantly more accurate in compatible trials (mean=97.2%; SE=.6) compared to incompatible trials (mean=91.4%; SE=2.5; p=.018), whereas no significant compatibility effect was found in the IAP group (mean for compatible trials = 98.1%; SE=.6; mean for incompatible trials = 98.9%; SE=2.5; p=.63). There was an additional two-way interaction between compatibility and object size ($F_{(1,26)}$ = 5.50; p =.027; η_p^2 =.17). Post-hoc analyses indicated that participants were more accurate (p=.022) in compatible trials (mean=98%; SE=.5) compared to incompatible trials (mean=94%; SE=1.7) when the object presented was small, but no difference was found between compatibilities when the object was large (97% vs. 96%, respectively; p=.43). No further

[1] see page 156 for discussion of limitations of ANOVA for non-normal data.

interactions were found. Therefore, the most important result regarding accuracy is the presence of a congruency effect for EAP group but not for IAP group.

Table 2.1. Descriptive statistics of accuracy calculated, separately, for each compatibility and object size for both groups in Experiment 2.1.

	IAP				EAP			
	Compatible		Incompatible		Compatible		Incompatible	
	Small	Large	Small	Large	Small	Large	Small	Large
Lower Limit	97%	96%	94%	93%	96%	94%	84%	87%
Mean	98%	98%	99%	99%	98%	96%	90%	93%
Upper Limit	100%	99%	100%	100%	99%	98%	94%	99%
Std. Error	0.7%	0.8%	1%	1%	0.7%	0.8%	2.5%	3%

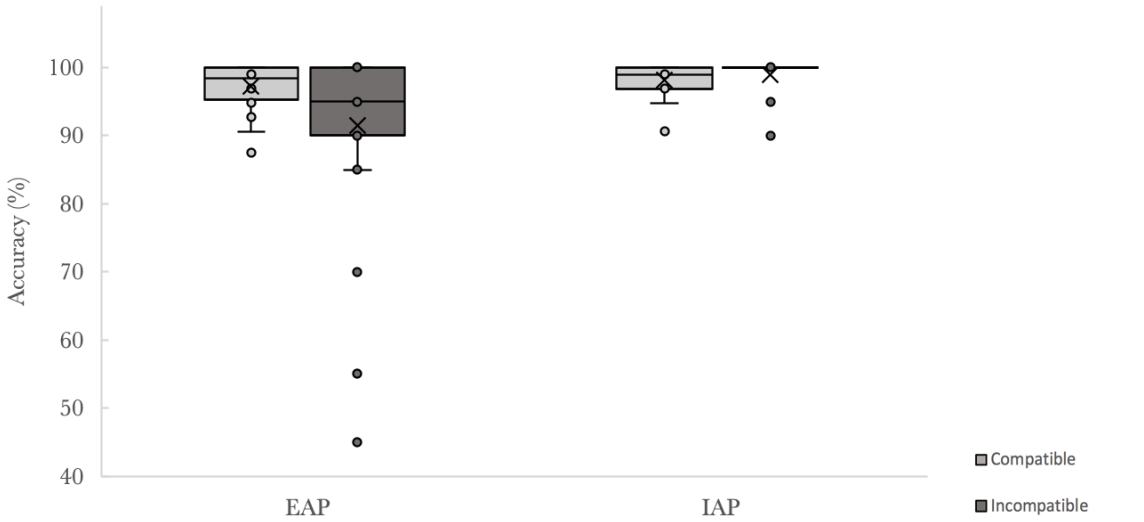


Figure 2.3. Box plots of accuracy for IAP and EAP groups and compatible and incompatible conditions for Experiment 2.1 showing the third quartile and first quartile range of the data and data outliers.

Reaction time

Median RTs were calculated for each participant, separately for each condition in the factorial combination of compatibility and object size. A 2 x 2 x 2 mixed-design ANOVA was calculated having object size (small and large) and compatibility (compatible and incompatible) as within-participant factors, together with the between-participant factor of group (EAP and IAP). The analyses showed no significant RT difference between groups (IAP mean = 600 ms, SE= 27.0; EAP mean = 616 ms, SE= 28.0; $F < 1$). There was no significant main effect of compatibility ($F_{(1,26)} = 1.41$; $p = .24$; $\eta_p^2 = .052$), nor a significant main effect of object size ($F_{(1,26)} = 1.70$; $p = .20$; $\eta_p^2 = .062$) (see Table 2.2). There was a significant two-way interaction between compatibility and object size ($F_{(1,26)} = 14.71$; $p < .001$; $\eta_p^2 = .361$). Following the same pattern seen in the accuracy data, post-hoc analyses (Newman-Keuls test) revealed a significant RT difference as a function of compatibility for small objects ($p = 0.0007$) but not for large objects ($p = 0.17$). Most importantly and, different from accuracy, the RT analysis did not show an interaction between group and compatibility ($F < 1$), which does not allow us to conjecture about the relationship between automaticity of the action priming effect and the awareness of object based on the search RT data.

Table 2.2. Descriptive statistics of RT calculated, separately, for each compatibility and object size for both groups in Experiment 2.1.

	IAP				EAP			
	Compatible		Incompatible		Compatible		Incompatible	
	Small	Large	Small	Large	Small	Large	Small	Large
Lower Limit	525	551	550	535	537	561	573	558
Mean	585	612	607	593	598	622	630	616
Upper Limit	645	673	664	651	658	683	687	675
Std. Error	29	30	28	28	29	30	28	28

2.2.3 DISCUSSION

The aim of Experiment 2.1 was to investigate whether object priming could direct attention to action-related images. I wanted to understand whether the mere observation of an object's physical properties would be sufficient to modulate attention to a representation of the action that the object affords, or whether this attentional priming depends on explicit encoding of the affordance. To investigate this question, I manipulated the explicitness of action priming and, therefore, the information held in WM during the execution of the discrimination task. Participants initially saw an object which they either had to simply identify (IAP group) or, in addition, to judge how to grasp it (EAP group). In the IAP group, with 'mere object identification', I expected that participants would not be conscious of the relationship between the objects displayed at the beginning of the trial and the grips displayed during the search task. In the EAP group, after judging how they would grasp the object from a table, the chosen grip had to be maintained in their WM throughout the search task execution, so it could subsequently

be matched to the correct answer during the probe question. I measured the compatibility effect on accuracy and RT, i.e., participants' responses when the target is near a grip image compatible with the grip that is primed by the preceding object compared to when it is distant. Importantly, I expect a greater compatibility effect (if any) in EAP group than IAP group, considering the relationship between the object and its action afforded are explicit and, therefore, more prominent.

Two important results were observed. First, the significant interaction between the IAP and EAP groups and congruency for accuracy measure showed an object priming effect on EAP group but not for IAP. However, this result suggests that, at least for error rates, explicit relationship between an object and an action-related stimulus is an *important* condition to elicit an attentional bias towards the spatially associated target. Crucially, this is not contradicted by the RT analysis.

Secondly, the significant interaction between compatibility and object size for accuracy and RT measures, showing a compatibility effect for small objects for both groups (for large objects the absence of a significant effect is inconclusive). This result could lend support to the idea that an explicit object-affordance relationship is not *necessary* to guide visual attention towards an action-related stimulus. However, the lack of compatibility effect for large objects requires caution. Another possibility is that the affordance relationship between large objects and power grip in the stimulus set I employed is not as strong as between small objects and precision grip. The procedure to select the objects (see Appendix 1) showed that, although highly associated, power grip was not always unanimous for the large object set. A more trivial explanation is simply that the statistical power was not large enough to reveal a significant effect for large objects, and it is possible that the compatibility effect for the large object-power grip association might benefit from increasing the sample size. Also, I believe that the type of

target and distractor used in this experiment might not be the most appropriate to use with grip pictures. When the target/distractor are below the grip pictures, it can give the impression that the grip is directed towards the target/distractor. This happens specially with the picture of a precision grip, which can be associated with a pointing hand or an arrow, leading to a greater salience comparing to the power grip. This confounding aspect could be solved by changing the type of target/distractor, with no cost to the task.

In addition, another possible confounding factor is the fact that the compatible condition constituted 81% of the trials. Therefore, it is not possible to establish, within this experimental design, if the observed effect for small objects is due to a real object-affordance influence on visual attention or simply due to a predictability effect, where the participants learn the most probable association between small objects and a more salient stimulus (precision grip), regardless of any affordance relationship. This question could be better clarified by using different proportions of compatible and incompatible trials. If the compatibility effect remained in a condition with the same proportion of compatible and incompatible trials or even in an unfavourable condition with only 20% of compatible trials, I could rest assured that the compatibility effect is not merely due to the development of a predictable association between those stimuli. Hence, I sought to address the precision grip/target-distractor and predictability effect limitations in Experiment 2.2.

2.3 Action Priming and Associative Mechanisms

Experiment 2.2

The aim of Experiment 2.2 was to test the hypothesis that, if object affordances do automatically influence attention towards action-related stimuli, the effect should

emerge even when there is no contingency between the object presented and the target position, i.e., when the object is not predictive of the target position. In Experiment 2.1 81% of the trials were compatible, i.e., for the majority of trials, the type of object at the beginning of the trial could help participants to predict where the target would be presented: A small object informed participants that the target would appear close to a precision grip image in 80% of the trials, whereas large objects informed a target location close to a power grip image at the same rate. Therefore, I address here the proposal of contextual cueing from Chun & Jiang (1998), where visual context may guide spatial attention towards the location of targets embedded among an array of distractors by incidentally learned associations. Thus, in Experiment 2.2, I aimed at refining the experimental design used in Experiment 2.1, exploring the sensitivity of object priming to meaningful regularities and covariances between the objects and hand images within the search display scene. To achieve this aim, I controlled the proportions of compatible and incompatible trials to give (or not) participants predictability of the target position based on not only affordances but also contingencies. Across three different groups, I varied the frequency of the trials that had the target presented adjacent to the correct grip image regarding the object presented. i.e., compatible trials (small object – precision grip and large object – power grip). Thus, I had one high frequency group (80:20, similar to EAP group from Experiment 2.1) which I expected to yield the greater compatibility effect, since it combines two consonant effects, one lower frequency (20:80), with a smaller compatibility effect, since it combines conflicting effects, and one with equal frequency (50:50), which should show an intermediate effect.

In addition, to address the differential compatibility effect found for small and large objects, I modified the type of target used in order to avoid differences in saliency (see Apparatus and Stimuli below). Also, I used only the explicit (EAP) experimental

design, since the findings of Experiment 2.1 did not show any compatibility effect in the IAP group either for accuracy or RT measures.

2.3.1 METHODS

Participants

A total of seventy-two right-handed participants were tested. Six participants had to be excluded due to poor accuracy (score lower than 3 standard deviations from the mean) in the probe question (4) and in the search task (2). The final sample consisted of 66 participants, 44 of whom were female. Sample size per group was larger than in Experiment 2.1 in order to increase statistical power for a mixed-design ANOVA. The participants' ages ranged from 18 to 33 (M = 22.4). All participants had normal or corrected-to-normal-vision. They gave informed consent and received course credit or money (10 pounds/hour) for their time.

Apparatus and Stimuli

The object set and the grip pictures chosen for Experiment 2.2 were the same as in Experiment 2.1. In order to avoid the potential confounding between the grip pictures and target/distractor, as discussed before in Experiment 2.1, the vertical and tilted lines were replaced by black border squares surrounding the pictures of the grips. Therefore, the search array consisted of the two coloured images of a right hand in either a power or precision grip position (12^o x 8^o) used in Experiment 2.1. Each image had a surrounding border with a width (thickness) of 0.12^o or 0.20^o: when the square with the thicker border represented the target, the one with thinner border was the distractor (Fig. 2.4). Target and distractor thickness were counterbalanced across participants. A pilot experiment, performed by 10 additional participants, was previously run varying border thicknesses

to ensure that target and distractor could be discriminated with at least 80% accuracy, while also remaining a relatively challenging perceptual discrimination. Target and distractor were equally frequently and randomly displayed on the left and right side of the screen. The apparatus was the same as in Experiment 2.1.

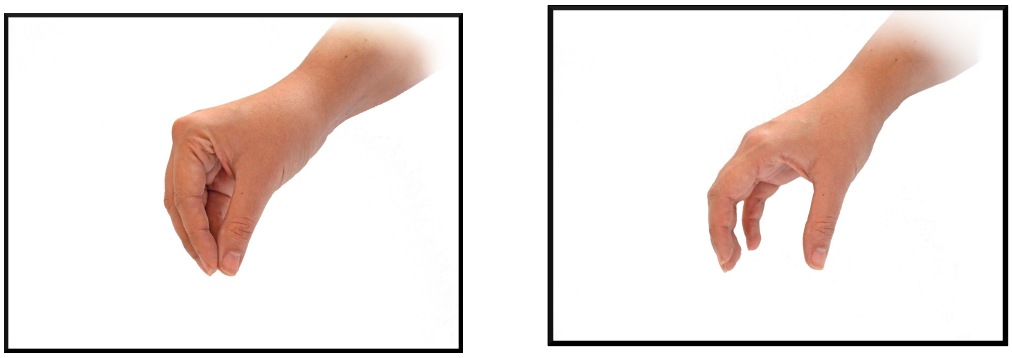


Figure 2.4. Images of a precision grip with an illustration of the thin border (left) and a power grip with a thick border (right) of Experiment 2.2.

Design and Procedure

Experiment 2.2 retained the same rationale and basic features of the EAP condition in Experiment 2.1. Catch trials were removed since participants' accuracy in responding to the probe question in Experiment 2.1 provided an indication that sufficient attention was directed to the object displayed. As consequence, the object was presented just once for 600 ms, after the disappearance of the fixation cross.

The main change in Experiment 2.2 consisted in the allocation of the participants to three groups which differed regarding the proportions of compatible and incompatible trials: the 80:20 group had 80% of compatible trials and 20% of incompatible ones; the 50:50 group had equal proportions of compatible and incompatible trials; finally, the 20:80 group had 20% of compatible trials and 80% of incompatible ones. Also, to boost

the statistical power, I increased the number of trials to 320 in total. In the 80:20 condition, 256 trials (80%) were compatible and 64 (20%) were incompatible; in the 50:50 condition, 160 trials (50%) were compatible and 160 (50%) were incompatible; and in 20:80, 64 trials (20%) were compatible and 256 (80%) were incompatible. The experiment ran in one single block.

2.3.2 RESULTS

Experiment 2.2 investigated the action priming effect controlling for different levels of contingency between the object displayed and the target position. I asked whether the identification of an object and its physical properties would modulate attention towards its most appropriate hand grip regardless of the object's target predictability. Thus, the main hypothesis of this experiment was that the observation of an object's physical properties would automatically prime the actions it affords (indicated through the compatibility effect) and, therefore, this will lead to a modulation of attention towards the images representing that action. I would expect a main effect of compatibility on accuracy and RT for all three groups. Moreover, considering that the three groups have different predictability factors as confound, I also expect a main effect of group and an interaction between group and compatibility. To test these predictions, I ran a 3 x 2 x 2 mixed-design ANOVA on accuracy and RT measures with group (80:20; 50:50 and 20:80) as a between-participants factor and compatibility (compatible and incompatible) and object size (small and large) as within-participant factors. In line with the analysis of EAP group in Experiment 2.1, I checked that participants paid attention to the object as intended by focusing on accuracy of responding to the probe question. This analysis used a 3 x 2 ANOVA with group as a between-subjects factor and object size (small and large)

as within-subject factors to compare the accuracy on the probe question. The results of these analyses are described below.

Accuracy

Overall, probe response accuracy was high (94%). The 3 x 2 ANOVA comparing the accuracy for large and small objects on the probe question for the three groups revealed a main effect of object size ($F_{(1,62)}$ = 18.16; p <.0001; η_p^2 =.24), showing that probes containing small objects had a higher accuracy (mean=90%, SE=1) compared to large objects (mean=87%, SE=1.5). There was no main effect of group nor a significant interaction between group and object size (Fs < 1, p>.15).

Mean accuracy for the discrimination task was calculated for each participant, separately for the three groups, compatibilities and object sizes. A 3 x 2 x 2 mixed-design ANOVA analysis was calculated having group (20:80, 50:50 and 80:20) as between-participant factor and compatibility (compatible and incompatible) and object size (small and large) as within participant factor. The results revealed a main effect of compatibility ($F_{(1,62)}$ = 5.97; p =.018; η_p^2 =.10), showing that participants were more accurate on compatible trials (mean=95.5%; SE=0.7) than on incompatible trials (mean=92%; SE=1.5). Again, similar to experiment 2.1, there were some outliers showing high error rates, but the between-condition differences do not depend on these outliers, being seen for the majority of data points from individual participants (see Fig. 2.5). There were no significant main effects of group or object size (Fs < 1) (Table 2.3). Importantly, there was no significant interaction between group and compatibility ($F_{(1,62)}$ = 1.56; p=.21; η_p^2 =.05), indicating that the compatibility effect did not differ consistently as a function of the object's predictability in relation to the target position. However, there was a highly significant two-way interaction between compatibility and object size ($F_{(1,62)}$ = 27.63;

$p<.0001$; $\eta_p^2 = .33$). Post-hoc analyses (Newman-Keuls test) revealed that participants were significantly more accurate ($p<.0001$) in compatible trials compared to incompatible when the object presented was small. In addition, there was no significant difference between both compatibilities for large objects ($p>.3$). No further interactions were found ($Fs<1.5$; $ps>.30$).

Therefore, the most important result regarding accuracy measure is the overall congruency effect for all the three groups. Participants did perform better on compatible trials when compared to incompatible trials regardless of the levels of contingency between the object displayed and the target position.

Reaction time

Median RTs were calculated for each participant, separately for each condition in the factorial combination of compatibility and object size. A 3 x 2 x 2 mixed-design ANOVA was calculated having group (20:80, 50:50 and 80:20) as a between-participant factor and compatibility (compatible and incompatible) and object size (small and large) as within-participant factors. The results indicated a significant main effect of group ($F_{(2,62)} = 10.96$; $p < .0001$; $\eta_p^2 = .26$). Post-hoc analyses (Newman-Keuls test) showed that participants in group 50:50 responded slower than participants in the 80:20 and 20:80 groups ($ps<.001$), but no significant difference was found between the 80:20 and 20:80 groups ($p=.90$). No significant main effects of compatibility or object size were found ($ps>.30$). However, there was a statistically significant two-way interaction between compatibility and object size ($F_{(1,62)} = 35.78$; $p <.0001$; $\eta_p^2 = .40$). Post-hoc analyses revealed a compatibility effect (34ms) for small objects ($p<.0001$) and an inverse compatibility effect (i.e., incompatible trials faster than compatible trials, -29ms) for large objects ($p=.008$). There was also a reliable three-way interaction (Fig. 2.6) among group,

compatibility and object size ($F_{(2,62)} = 4.46$; $p = 0.015$; $\eta_p^2 = .12$). Post-hoc analyses showed that in the 50:50 group, RTs were shorter in compatible trials when contrasted with incompatible trials only when the object displayed was small ($p < .001$), but no compatibility effect was found for large objects ($p=.64$) (see Table 2.4). In the 20:80 group the post-hoc analyses showed a greater RT for compatible in comparison to incompatible trials (inverse compatibility effect) when the displayed object was large ($p < .01$) but not when it was small. The 80:20 group did not have a significant difference between compatibilities for any object size ($ps>.07$). This is rather surprising because this was the group that I predicted the bigger compatibility effect, especially when compared to the 50:50 group, given that in this condition the probabilities and compatibility effects should work together.

Taken together, the two most important results here are 1) the compatibility effect for small objects in the 50:50 group and the inverse effect for large objects in group 20:80 and 2) the lack of compatibility effect for the group where it was expected to reach the biggest difference, i.e., the 80:20 group.

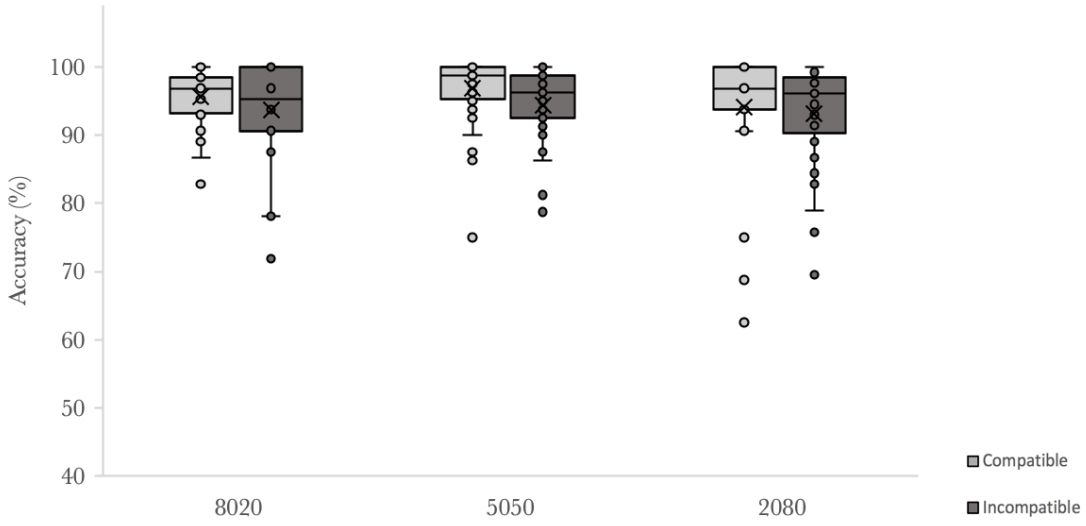


Figure 2.5. Box plots of accuracy for IAP and EAP groups and compatible and incompatible conditions for Experiment 2.2 showing the third quartile and first quartile range of the data and data outliers.

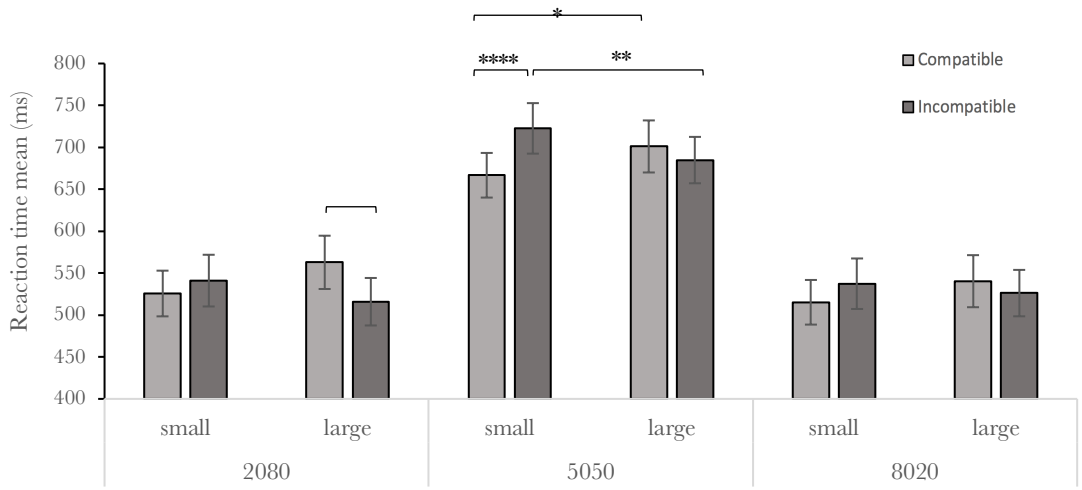


Figure 2.6. Reaction times for each group (2080, 5050, 8020), compatibility (compatible and incompatible) and object size (small, large) in Experiment 2.2. Error bars represent the standard error of the mean. **** $p < .001$; *** $p < .005$; ** $p < .01$; * $p < .05$.

Table 2.3. Descriptive statistics of accuracy calculated, separately, for each compatibility and object size for the three groups in Experiment 2.2.

	20:80				50:50				80:20			
	Compatible		Incompatible		Compatible		Incompatible		Compatible		Incompatible	
	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large
Lower Limit	91	91	86	89	95	93	83	88	94	91	86	90
Mean	94	94	92	95	98	96	89	93	97	94	92	95
Upper Limit	97	97	97	100	100	98	95	98	100	98	98	100
Std. Error	1	1	3	3	1	1	3	3	1	2	3	3

Table 2.4. Descriptive statistics of RT calculated, separately, for each compatibility and object size for the three groups in Experiment 2.2.

	20:80				50:50				80:20			
	Compatible		Incompatible		Compatible		Incompatible		Compatible		Incompatible	
	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large
Lower Limit	471	480	500	460	613	662	639	629	462	477	478	471
Mean	526	563	541	516	667	701	723	685	515	540	537	526
Upper Limit	580	603	626	572	720	783	763	740	568	598	602	581
Std. Error	27	31	32	28	27	30	31	28	27	30	31	28

2.3.3 DISCUSSION

In this experiment, I attempted to improve the design of Experiment 2.1 to better explore the action priming effect hypothesized as inherent to object observation. The rationale was to distinguish a possible compatibility effect, brought about by an affordance relationship, from a predictability effect, where the association between the two visual stimuli is simply based on a highly frequent contingency—two effects that were confounded in Experiment 2.1. Experiment 2.2 added two groups to exclude (50:50 group) or reverse (20:80) the predictability effect by varying the proportions of compatible and incompatible trials. In all three groups, after seeing an object which they had to identify and judge how to grasp it, participants had to maintain the chosen grip in working memory (WM) as the search task was conducted in order to answer the probe question.

Considering our main interest in this experiment, the accuracy measure showed, though a compatibility effect, the object priming effect that biased attention towards a grip related image, independent of predictability and contextual cueing. Crucially, this effect was confirmed though RT analyses in the 50:50 group. This group is of special interest because the contingency learning has virtually no role, since the proportions of compatible and incompatible trials were equal. Thus, the significant difference between compatible and incompatible trials could be explained by an attentional shift towards an action-related stimulus (i.e., precision grip) caused by an action priming when participants observed an object (i.e., a small object). Indeed, this is what the results for RT in small objects showed. However, a significant effect would also be expected regarding compatible pairs composed by large objects and the power grip, which was not observed.

Importantly, although the accuracy measure revealed a main effect of compatibility, it also showed an interaction between compatibility and object size, indicating that it occurs only for small objects. The same result is confirmed by RT

analyses. Also, a common feature present in all conditions in the three groups is a shorter RT when the picture surrounded by the target in the discrimination task is a precision grip, henceforth referred to as the "precision grip stimulus effect". This was the case in compatible trials of small objects for the three groups (although only in the 50:50 group it reached statistical significance). It was also the case in incompatible trials of large object, i.e., when a large object is presented and, then, the target is displayed surrounding a precision grip (again, only the 20:80 group reached statistical significance and the other two a numerical trend). In this same line, the conditions in which the power grip was surrounded by the target, regardless of it being compatible or incompatible and regardless of it being the most frequent or not, always showed a slower RT. Crucially, this precision grip stimulus effect can retrospectively be seen also in Experiment 2.1. However, because of the lack of significance in the difference between precision and power grip for large objects in that experiment, this effect was not clear.

Although there are some data in the literature indicating a difference in RT for precision and power grips, they point towards a faster RT for power rather than precision grip (Borghi et al. 2005). These authors suggest that grasping objects with a precision grip requires more time, as it is typically used for skilled actions and requires finer control. In this sense, I suggest that the precision grip stimulus effect may be due to a possible higher salience of the precision grip configuration or, alternatively, to a suboptimal correspondence between the grip and the object due to the selection of objects. Nonetheless, because the precision grip stimulus effect permeates throughout the experiment, an analysis of compatibility or predictability effects should take into account the possible interaction between these three effects.

Further, there was a surprising lack of compatibility effect in the 80:20 group, which was expected to be enhanced by a contingency learning. A deeper analysis of the

80:20 and also the 20:80 groups can bring some insights about the predictability effect. In those groups, the addition of an extra information, by means of different proportions between the pairs of stimuli (therefore modulating their predictability), can explain their overall shorter RTs in comparison to the 50:50 group. In addition, I suggest that the compatibility effect could be better detected in this group because of the overall RT being slower than in the 80:20 and 20:80 groups. Moreover, although participants were faster in conditions in which the target was surrounded by a precision grip, the shortest RTs are in those conditions with the higher frequency, e.g., the compatible small object–precision grip condition in the 80:20 group and the incompatible large object–precision grip condition in the 20:80 group, pointing to a positive interaction between the two effects. When the conditions with higher frequency were those where the target was associated with a power grip (the compatible large object–power grip condition in the 80:20 group and the incompatible small object–power grip condition in the 20:80 group), RTs were longer because of interference from the precision grip stimulus effect leading to a negative interaction between the two effects. I believe that the predicted superior compatibility effect in the 80:20 and 20:80 groups was weakened or even abolished because of interference from the unexpected precision grip stimulus effect. A deeper scrutiny of the compatibility and predictability effects should be carried out after the exact role of this grip effect being determined and clarified.

2.4 General Discussion

In the present chapter, one of the main interests was to investigate whether object priming effects can automatically direct attention towards action-related images and whether this effect is dependent on an object affordance's explicitness. I also examined whether this attentional modulation could be brought about by a simply induced contingency between a stimulus and an action, i.e., by learning to associate across trials one given stimulus (an object) and an action (a grip representation) or whether it is dependent on an affordance-action pre-learnt association.

The accuracy measure from the perceptual discrimination task in Experiment 2.1 suggests that, indeed, the object priming effect modulates attention towards an action related image only when the object affordance is explicit (EAP group). This was confirmed by Experiment 2.2. Participants were more accurate when discriminating the target when it was surrounded by the image of an action related to the object presented as a prime. Conversely, participants were less accurate when the target was surrounded by the image of an action unrelated to the prime object.

The RT measure did not provide clear evidence of modulation of attention as accuracy, neither in Experiment 2.1 nor in Experiment 2.2. The 20:80 group, where I expected a smaller compatibility effect (if any), showed a significant inverse compatibility effect in trials with large objects. Surprising, the 80:20 group, where the positions of most of the targets could be predicted based on a contingency and object priming effects, did not show a compatibility effect for any of the object's sizes. In fact, the only group that showed the expected compatibility effect was the 50:50, where objects had equal contingency with the target position and, therefore, no predictive information. However, these results highlight an unexpected but strong interaction between compatibility and

object size. It is possible to observe in Figure 2.4 that whenever the compatibility effect occurs (either statistically significant, as in the 50:50 group, or as a numerical trend, as in the 20:80 and 80:20 group), it was due to a faster RT in trials where the target appeared surrounding a precision grip image. On the other hand, whenever an inverse compatibility effect occurs (either statistically significant, as in the 20:80 group, or as a numerical trend, as in the 50:50 and 80:20 group), it was also due to a faster RT in trials where the target appeared surrounding a precision grip image. The aforementioned precision grip stimulus effect, persistent throughout the experiments, might have favoured response when the target was surrounded by a precision grip, regardless of its compatibility or predictability.

Grèzes et al. (2003) report a result similar to the one I obtained with the precision grip stimulus effect, although they reached a different conclusion. In a behavioural experiment, participants performed power or precision grip responses based on the categorization of objects (small and large) into natural or man-made. Despite object size being irrelevant to the task, the grip used to respond could be either compatible or incompatible with the object displayed. The authors interpreted the interaction between object size and type of grip as being masked by the presence of two independent main effects (object size and type of grip). However, considering Grèzes et al. and our results, I suggest that an alternative and more plausible explanation would be the suboptimal correspondence between the large objects selected and the power grip. Therefore, below I propose two possible, not mutually exclusive, elements that could contribute to a greater precision grip salience: a different salience for the precision grip configuration and suboptimal correspondence between the grip and the object due to the selection of objects.

2.4.1 GRIP CONFIGURATION

The specific type of grip an object affords has been used in different ways to explore the coupling between object perception and action representations. Some studies used the actual grip as response (Ellis & Tucker, 2000; Girardi, Lindemann, & Bekkering, 2010), the grip posture (pantomime) (Buxbaum, Sirigu, Schwartz, & Klatzky, 2003), animation of a grasping movement (Vainio, Hammarén, Hausen, Rekolainen, & Riskilä, 2011) or key press in a keyboard as reference to a given grip (Yu et al. , 2014). Typically, the grip configuration is determined arbitrarily by scientists on the basis of logical assumptions (Guérard & Brodeur, 2014) or a limited set of objects is used in association with obvious hand postures (Bub, Masson, & Cree, 2008; Girardi, Lindemann, & Bekkering, 2010). However, a recent study provided norms for the types of grip employed when grasping and using objects, with a set of 296 photographs of objects (Lagacé et al. , 2013). Their aim was to normalize the grips on several dimensions, including familiarity, visual complexity, name agreement, category, object agreement, and manipulability, allowing better control over a number of variables. The types of grip were classified according to the strength (power, intermediate, and precision), as well as the position and number of fingers involved in the grip.

The majority of studies involving grasps classify their grips as power, intermediate or precision. I arbitrarily selected the precision and power grip configuration for grasping the object to pick it up instead the configuration for using the object mainly because it represents the first stage during an interaction with an object. The same stage of interaction was used to make the pictures of the grips; i.e., the observed final position of the participant's fingers while interacting with the different objects. However, the Human Grasping Database (Feix, Romero, Schmiedmayer, Dollar, & Kragic, 2016) classifies at least twelve different types of precision grip and fifteen different types of power grip.

Therefore, it is quite likely that our pictures may not be the best representation of the most appropriate grip for a given object. One possibility is that our grip pictures could be considered different movements of the same grip along the hand trajectory. The power grip can be seen as an open hand that could possibly end in a precision grip, as depicted in the actual precision grip picture. Then, the main difference between the two pictures would be not the type of grip but the initial vs. final state of the underlying movement. In this sense, the precision grip could be favoured in relation to the power grip because the former holds a clearer grip representation. Also, it is possible that the precision grip picture has a higher visual salience in comparison to the power grip. The hand with a precision grip, which is similar to a closed hand, is represented in much less space than the power grip, which has all fingers separated and, consequently, occupies more space. Another reason for a higher visual salience is that the precision grip can be associated with a pointing hand or an arrow, which has been shown to trigger involuntary attentional orientation (Tipples, 2008).

2.4.2 SELECTION OF OBJECTS

An increasing number of researchers opt for pictures of objects, highlighting the need for more ecological stimuli, as pictures offer a more realistic depiction of everyday concepts (Brodeur, Guérard, & Bouras, 2014). Some studies provided norms on a range of important dimensions known to influence cognitive processes. For instance, Salmon et al. (Salmon, McMullen, & Filliter, 2010) normed familiarity and age of acquisition but no other dimensions, such as visual complexity and name agreement. However, there are some studies dedicated to normalizing a range of object's motor dimensions that may influence cognitive processing. These objects have been normed on dimensions such as

their visual complexity, familiarity, symmetry and object agreement (Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010; Brodeur et al. , 2014; Salmon et al. , 2010).

I employed pictures of everyday usage objects, previously tested in relation to the grip it affords. However, this set of object pictures was not normalized and some uncontrolled dimensions, in the small or large object sets, may have affected the affordance perception. Specifically, it is possible that some large objects are dubious regarding to which grip it affords better. Some large objects have parts that can be grasped with a precision grip, although the most common grip for it would be a power grip. For instance, a pair of sunglasses can be grasped either with a power grip or with a precision grip in order to avoid the contact of the fingers with the lenses. Another case is a flask that can be grasped from the side with a power grip or from the top with a precision grip on the lid. The hair brush and the salad tong have both a handle which, although affords a power grip, it is a more cylindrical grip than the power grip used to grasp the other objects. Although the probe question at the end of the trial, requiring the participants to match the object seen previously with one of the two types of grip, was answered correctly in the great majority of the trials, it is possible that some object features that might cause doubt to the participant were processed implicitly. This could have led some large objects to be recognized as affording a precision grip, increasing the RT when trials contained the pair large object – power grip. Additionally, in order to control for the size of the stimuli being displayed I had to minimize some large objects (remote control, corkscrew) and maximize some small objects (nut, pill, button) to make them visible enough. It is possible that the size scaling affected the object perception and its identity in different ways, contributing to make it ambiguous about which grip it affords.

Future investigations could use the same power grip pictures with a different and normalized set of pictures for the precision grip, for instance, using the bank of grip

pictures from Lagacé et al. (2013). If the effect towards the precision grip remains it can be an indicative of an actual difference between the two types of grips. On the other hand, to investigate a possible domain-general associative learning between the stimuli (and not an effect related to affordance), it would be important to include a control experiment where I have a set of stimuli which is not action related, e.g., pairs of consonants – precision grip and vowels - power grip. If an association can be built between a type of letter and a specific type of grip, leading to a decrease in RT in the same way as the pair object-grip, the rationale for object affordance priming an action related to the object would not hold.

Another way to improve the experimental design would be 1) to use an index-thumb grip rather than a fingers-thumb grip as a precision grip, since it was shown that participants were more likely to select an index-thumb than a fingers-thumb grip to seize small objects in Lagacé et al. (2013) and 2) to use a grip-based responses instead of a button-press as it is more likely for participants to perceive affordances in a task-relevant manner, thus leading to a greater degree of action priming (Yu et al., 2014).

In conclusion, I found some evidence that an action primed by object affordances can modulate attention towards the action it affords, in the same way that object affordances can bias visual spatial attention toward the locations of graspable objects. However, the extent of this effect is subjected to well controlled stimuli.

Chapter 3

Stimulus-Response Processing in an Automatic Imitation Task

3.1 Introduction

Research on stimulus-response compatibility (SRC) introduced a way of studying the cognitive processes involved in detection and recognition of relevant stimuli related to a given response in the presence of irrelevant or distracting information. This is the rationale underlying the classical Stroop (Stroop, 1935) and Simon (Simon, 1969) effects. The so-called "automatic imitation" effect is also a type of SRC effect (termed here as a *congruency effect*) "in which the topographical features of task-irrelevant action stimuli facilitate similar, and interfere with dissimilar, responses" (Heyes, 2011). A close examination of the Stroop and Simon effects has shown that irrelevant inanimate stimuli can delay responding by interfering during the process of response selection and execution (Eimer, Hommel, & Prinz, 1995; Hommel, 1995, 1996; Proctor & Vu, 2006; Proctor, Van Zandt, Lu, & Weeks, 1993). Studies on automatic imitation using Simon-like tasks suggest that irrelevant movements can also interfere with response (Brass, Bekkering, & Prinz, 2001a; Catmur & Heyes, 2011; Cooper, Catmur, & Heyes, 2013; Heyes, 2011; Leighton & Heyes, 2010). However, it is unclear whether temporal dynamics of response selection, execution and inhibition follows the same pattern as for inanimate and non-social stimuli. In this chapter, I investigated the interference of a task-irrelevant stimulus (action) during response processing. I investigated the time window where response selection can be affected in an automatic imitation task. Moreover, I asked whether task-irrelevant stimuli can also interfere with response execution.

3.1.1 MODELS OF RESPONSE SELECTION AND EXECUTION

The differentiation between response selection and response execution stages is quite puzzling. The mere idea that a response is 'selected' before being executed is rather

controversial. In line with traditional cognitive theories, one would argue that response selection is resolved in a serial manner, so that I select 'what to do' before specifying 'how to do it'. The difficulty is that the concept of selection implies a decomposition of behaviour into distinct elements (actions) whose temporal sequence should be optimally orchestrated. According to this hierarchical decomposition view (see Botvinick, 2007 for a review), the perceptual system first collects sensory information to build an internal representation of the external world (Marr, 2010). Next, this information is used along with representations of current needs and memories of past experience to make judgments and decide upon a course of response (Axten, Newell, & Simon, 1973; Shafir & Tversky, 1995). The resulting plan is then used to generate a desired action, e.g., a trajectory for movement, which is finally achieved through muscular contraction (Keele, 1968; Miller, Galanter, & Pribram, 1960). This idea is in agreement with Sternberg's view (1969), which suggests that the time taken to execute a response after a stimulus is the sum of individual stage durations, so factors affecting the durations of different stages naturally have additive effects on the final response time.

In a typical choice reaction task in which each stimulus is assigned to a unique response, it is common to distinguish between three stages of processing: stimulus identification, response selection, and response execution (Robert W. Proctor, Lu, Van Zandt, & Weeks, 1994; Robert W Proctor & Vu, 2007). The stimulus identification stage involves processes that are entirely dependent on stimulus properties, which defines the duration of this stage. It concerns the peripheral sensory processes involved in the conduction of the sensory signal along the afferent pathway to the sensory projection areas of the cerebral cortex. Human electrophysiological experiments have an estimative of 140 to 200 ms needed for information processing within the primary visual cortex (Allison, Mccarthy, Nobre, Puce, & Belger, 1994; Thorpe, Fize, & Marlot, 1996). The response-

selection stage refers to those processes involved in determining which response to make to a given stimulus. It is affected by the uncertainty and number of alternatives (Hick-Hyman law; Hick, 1952; Hyman & Ray, 1953), any conceptual, perceptual or structural similarity shared by S-R (J. Miller, 1982; Robert W. Proctor & Reeve, 1985), pre-cueing (Kantowitz & Sanders, 1972) and even by S-R repetition in a sequence (Bertelson, 1961). Response execution refers to the specification of the physical response to be made and it is affected by variables such as relative S-R frequency and movement complexity. The response execution duration is primarily a function of response properties. Primary motor cortex neurons fire 5-100 ms before the onset of a movement.

Various studies on human performance and information processing have investigated the processes involved from the time of stimulus identification until the response execution, translating these broad concepts into more concrete and testable hypotheses. One common way to address this is by having another stimulus that interferes within the selection process altering, for instance, the response speed and/or accuracy (Proctor & Vu, 2006). Empirical studies, along with relatively sophisticated theoretical accounts on SRC effects, have successfully demonstrated that a task-irrelevant stimulus can delay or speed responses depending on its compatibility with the response required for the task (R. Proctor & Vu, 2006).

Typically, an imperative stimulus is presented together with a task-irrelevant stimulus that shares some feature with the required response. In the case of the original Simon task, the imperative stimuli were a high-pitched tone (1000 Hz) and a low-pitched tone (400 Hz), each presented to one ear at the time and requiring a correspondent response (say, a key press on the right or left side, respectively). The spatial feature of the imperative stimulus is task-irrelevant. Consequently, it is possible to have two different situations in the Simon task: i) the tone that requires the press of the right key is presented

to the right ear and ii) the tone that requires the press of the right key is presented to the left ear (and, conversely, for the other imperative tone). RT is shorter when there is spatial compatibility between the stimulus' irrelevant location and the response than when they are incompatible. This finding suggests that when pressing the key, participants are unable to ignore the irrelevant spatial information provided by the stimulus position. Therefore, these results support the view that an interference of the imperative stimulus' irrelevant location occurs during the stage of response selection, i.e., selecting which key to press (Kornblum et al., 1990; R W Proctor et al., 1993; Simon, 1969).

In a similar version of the Simon task, Hommel (1995, 1996) tested whether it was possible to eliminate the task-irrelevant stimulus interference by presenting it after the completion of the stimulus-response (SR) translation process. A left or right-hand key pressing response was cued before each trial, but executed only after the presentation of a Go signal, presented either on the right or the left side of the screen. The task thus provided 100% valid information about the next response (right or left), so that participants could complete the whole S-R translation in advance. Participants had 900 - 1900 ms between the cue presentation and the Go signal to prepare the response. In this sense, the Go signal acted only as a temporal mark and no stimulus had to be "translated" into a response code at that stage. Interestingly, the responses were still considerably faster when there was spatial correspondence of the Go signal and the required response. The author suggests that, although the participants should have had strong motivation to prepare the response immediately after the cue onset, both responses were held in some state of readiness until the Go signal was presented (Hommel, 1995, 1996). Eimer and colleagues (1995) added to the conclusion that the irrelevant spatial information of the Go signal activates the code of the compatible response in an automatic fashion (according to the automatic route of Kornblum's model). Indeed, both conclusions are in line with the

current models of response selection mentioned above, where it is considered that both alternative responses are competing with each other (and hence maintained in a "steady state") and the selection process is affected by a concurrent stimulus processing (the Go signal) before any response is executed.

Taken together, these studies demonstrate the different points of the process of responding where a distractor can interfere. The above discussion is framed in terms of the idea of sequential stages of processing from stimulus identification through response selection to response execution. However, this simple stage model may be oversimplified. Nevertheless, neurophysiological studies showing how the brain is functionally organized, and in particular the multiples roles of the posterior parietal cortex, suggest that the concepts of separate perceptual, cognitive and motor systems might not be appropriate for bridging neural data with behaviour (Cisek, 2007). The current predominant view is that sensory information arriving from the world is continuously used to specify several currently available potential actions, while other kinds of information are collected to select from among these the one that will be released into overt execution at a given moment (Cisek & Kalaska, 2010; Glimcher, 2001; Gold & Shadlen, 2001). Furthermore, standard diffusion models assume distinct decision and non-decision periods – including usually a motor execution period after an internal decision is reached (Yeung & Summerfield, 2012). Also, there is evidence that the brain exploits information that is in the processing pipeline when the initial decision is made to subsequently either reverse or reaffirm the initial decision, even after a movement has been initiated (Resulaj, Kiani, Wolpert, & Shadlen, 2009).

Therefore, information processing is a gradual process, based on the accumulation of noisy information over time that ends at a decision threshold that is associated with a

particular decision or choice (Roger Ratcliff, 1978; Roger Ratcliff & McKoon, 2008; Usher & McClelland, 2001; Voss, Rothermund, Gast, & Wentura, 2013).

3.1.2 RESPONSE SELECTION AND EXECUTION IN AUTOMATIC IMITATION TASKS

The SRC approach has also been used in numerous studies to demonstrate an automatic imitation effect (Brass, Bekkering, Wohlschläger, & Prinz, 2000; Catmur & Heyes, 2011; Leighton & Heyes, 2010; Stürmer, Aschersleben, & Prinz, 2000). The first study to adopt a dynamic stimulus in a SRC task to explore the mechanisms underlying the imitation of body gestures was carried out by Stürmer et al. (2000). They developed an interference task where participants had to perform a hand gesture, e.g., either a fist or by spreading the fingers apart, cued by the colour of a moving hand (imperative stimulus). However, the movement performed by the hand was always task-irrelevant and could either correspond to the required response gesture or not. On congruent trials, stimulus gesture and response gesture were the same; on incongruent trials, they differed. The results showed that participants were faster to perform a hand gesture (e.g., hand spreading) while viewing a compatible action (hand spreading) than when viewing an incompatible action (e.g., a fist). Since then, similar results have been reported by several authors (Brass et al., 2000; Brass, Bekkering, & Prinz, 2001; Press, Bird, Walsh, & Heyes, 2008; Press, Gillmeister, & Heyes, 2006; Bertenthal, Longo, & Kosobud, 2006; Liepelt, Cramon, & Brass, 2008). An important and common point to all of these studies is that the task-irrelevant stimulus does not require participants to process the identity of the observed movement. In the case of incongruent trials, where the task-irrelevant stimulus was different from the response required, processing of movement identity was clearly counter-productive with respect to task performance. Hence, the fact that both the compatible and incompatible irrelevant movement identity still had an effect on response

times is considered as evidence that this effect could be considered as an instance of automatic imitation (Catmur, 2008; Catmur & Heyes, 2011). Together, these studies provide evidence that automatic imitation (or imitative compatibility, see Catmur & Heyes, 2011) can be explained by the very same theoretical framework underlying the SRC effect.

The automatic imitation effect has been studied by means of SRC tasks within simple and choice RT designs. In a choice RT task, Brass et al. (2000) examined lifting movements of the index and middle fingers. The trials began with a left hand placed on a table from a third-party perspective. Subsequently, a number (1 or 2) appeared between the index and middle fingers, and participants were required to lift their index finger in response to the number 1 or their middle finger in response to the number 2, or vice-versa. The number appearance occurred together with a lifting of either the index or the middle finger of the stimulus hand. Participants' responses were faster in compatible trials – when the finger lifted in the background (irrelevant stimulus) was the same as the one commanded by the imperative stimulus (number) – in comparison to incompatible trials. These results indicate that if a task requires a choice to be made between two alternative actions in response to a symbolic imperative stimulus, the observation of those actions can either facilitate or reduce the motor performance, depending on their congruency, even when participants are told about its irrelevancy to the task in hand. Similar congruency effect are found in other SRC automatic imitation tasks using choice RT (Bertenthal et al., 2006; Boyer, Longo, & Bertenthal, 2012; Catmur, 2016; Catmur & Heyes, 2011; Leighton & Heyes, 2010).

Further, and in line with the study of Stürmer et al. (2000) mentioned previously, Brass et al. (2001) used a similar design as in Brass et al. (2000) but employing a simple RT task instead. They asked participants to make the same finger movement on every

trial within a block, as fast as possible, in response to the initiation of a task-irrelevant hand movement (the imperative stimulus). Therefore, the initiation of a compatible or incompatible movement displayed on the screen acted only as a "go signal" for participants to perform the action prepared beforehand. It is important to note that the imperative stimulus indicated only when to move but not what to do, with the participants not being required to process the identity of the observed movement. The results showed a pronounced compatibility effect, i.e., participants were faster when the moving finger, displayed as the go signal, was congruent to the response required in the task. Similar results were found by Press et al. (2008, 2006) and Stürmer et al. (2000). In this sense, these results challenge the view that SRC effects are only related to the response selection stage, since, similar to Hommel's findings (Hommel, 1996), the response selection requirements were minimal or were already solved at the go signal. However, considering that these studies involved SRT tasks, there is the possibility of these effect to be, actually, inertia effects. This happens when subjects switch frequently from one response to the other, so that after a switch some activation of the last response may show some inertia and transfer to the new trial, even though, objectively, this response is no longer valid (Hommel, 1996).

Hence, considering the current models of information processing and the dual-route model previously described, I suggest a possible way to evaluate whether not only response selection but also response execution could be affected by input modulation in an automatic imitation task. In brief, by either presenting an asynchronous task-irrelevant stimulus or by presenting a cue preceding the imperative stimulus, I can vary the stage of processing of one stimulus in relation to the other. Thus, I can verify if the task-irrelevant stimulus can affect response selection only or could also extend its interference to response execution. Therefore, Experiment 3.1 made use of the same choice RT experimental

design as in Brass et al. (2000) in order to assess the interference effect previously reported in the literature. Experiment 3.2 was designed to evaluate the time-course of the congruency effect by varying the stimulus onset asynchrony (SOA) between the imperative and task-irrelevant stimuli. I aimed to assess the time window in which the task-irrelevant stimulus can interfere with the response. Finally, in Experiment 3.3, by adding a cue before the imperative stimulus, I gave participants prior information about the response to be selected in order to evaluate whether the task-irrelevant stimulus can interfere with response execution in the case of pre-selected responses.

3.2 Automatic Imitation Task

Experiment 3.1

Experiment 3.1 consisted of an attempt to replicate Experiment 1 of Brass et al. (2000). In a choice reaction time task, participants were presented with an imperative stimulus (number 1 or 2). The number informed participants whether to lift their index finger or their middle finger. Participants were instructed to make this movement as fast as possible after the appearance of the imperative stimulus. Before the imperative stimulus presentation, a static hand was displayed on the screen. Shortly after the onset of the imperative stimulus, the hand performed a lifting movement of either the index or middle finger. This movement was task-irrelevant, and could be either congruent or incongruent with participant's task.

As in Brass et al.*'s* (2000) study, I expect that the task-irrelevant movement will influence participants' movements, e.g., observing a given finger movement should activate the respective congruent response and, hence, should facilitate response

initiation. Observing an incongruent finger movement should activate the incorrect response and, therefore, should lead to an interference effect. Therefore, a main effect of congruency, for accuracy and RT, should be observed. Crucially, I added two further analyses in order to explore the congruency effect in relation to other studies SRC tasks. Therefore, I increased the number of trials in relation to the original experiments to analyse the congruency effect over time and divided it into 4 blocks. Also, with a quintile analysis I aimed at analysing the distribution of RTs and I expect to observe an increased congruency effect towards the higher RTs.

3.2.1 METHODS

Participants

A total of fifteen right-handed participants were tested, 8 of whom were female. The participants' ages ranged from 19 to 35 years (Mean = 24.0). As a convention for all experiments in this chapter, participants with poor accuracy (score smaller than 3 standard deviation from the mean) were excluded from analysis and would be indicated in this section when appropriate. All participants had normal or corrected-to-normal-vision. They gave informed consent and received course credit or money (10 pounds/hour) for their time. This study and all the subsequent ones were approved by the Central University Research Ethics Committee of the University of Oxford.

Stimuli and Apparatus

A Dell Optiplex 9010 computer controlled stimulus presentation and data acquisition using E-prime 2.0 (Psychology Software Tools, Inc). Participants were seated approximately 80 cm from the screen and kept their eyes at this fixed distance by using a chin rest. The visual stimuli were the same used in Brass et al. (2000), kindly shared by the authors. Short, digitized video sequences of an animated hand were presented on a

17" screen with a frame frequency of 60 Hz. The video sequences consisted of six frames. The animated hand had a visual angle of approximately 6.5° vertically and 10° horizontally. The animated hand was positioned as to appear as a mirror image of the participant's hand, which rested on a table. The imperative stimulus consisted of a solid, coloured square, occupying ≅ 1° x 1° visual angle displaying either the number "1" or "2". The imperative stimulus was equidistantly located between the index and middle fingers, thus ensuring that spatial attention was equally allocated to both fingers and giving no information about the subsequent movement. Responses were recorded by a keyboard in which participants kept the "1"and "2" keys pressed by, respectively, the index and middle fingers of their right hand throughout the experiment, releasing one of them at the time of the response. Correct responses were defined as the upward movement of the index finger in response to the imperative stimulus "1" and upward movement of the middle finger for number "2". Participants were instructed to keep their left hand on the table. RT were calculated from the onset time of the imperative stimulus until the release of one of the keys.

Design and Procedure

The experiment consisted of a symbolic cue (number) as the relevant dimension and a finger movement as the task-irrelevant dimension. Participants were presented with a video sequence and instructed to execute either an index or a middle-finger upward movement (extension) in response to the presentation of either the number 1 or 2, respectively. Three conditions were randomly presented (see Fig. 3.1). In the baseline trials, only the numbers were presented and no finger movements were displayed. In the congruent trials, a congruent finger movement accompanied the number (e.g., the index movement was presented along with the number 1); in incongruent trials, an incongruent

finger movement accompanied the presented number (e.g., the middle finger movement was presented along with the number 1). Each trial started with a blank screen displaying a centred fixation point for 500 ms to indicate that the video sequence was about to start. The video sequences (Fig. 3.1) began with the image of a hand in a resting position. This image, which was identical for all conditions, remained visible for 560 ms. Then, a sequence of four images (each lasting, approximately, 34 ms) presented a number (the imperative stimulus) and one of the fingers at successive stages of the upward movement (except for the baseline condition, in which the hand remained motionless at the initial resting position throughout the trial). In the congruent and incongruent trials, the first of these four sequential images depicted the hand in the resting position, with the three others depicting each consecutive stage of the evolving movement. Finally, a sixth image displaying the hand back in the resting position was presented for approximately 500 ms. The overall displacement of the presented finger movement was about 2°. Between trials, a blank screen was presented for 1000 ms. Participants were instructed to respond as quickly as possible in response to the imperative stimulus (number) without compromising accuracy. The procedure comprised a total of 480 trials divided in 4 blocks. Each block (120 trials) contained the 3 different trial types randomly presented (40 baseline, 40 congruent, and 40 incongruent trials). Ten practice trials were presented at the beginning of the experiment to illustrate the task to participants and were not included in the analysis.

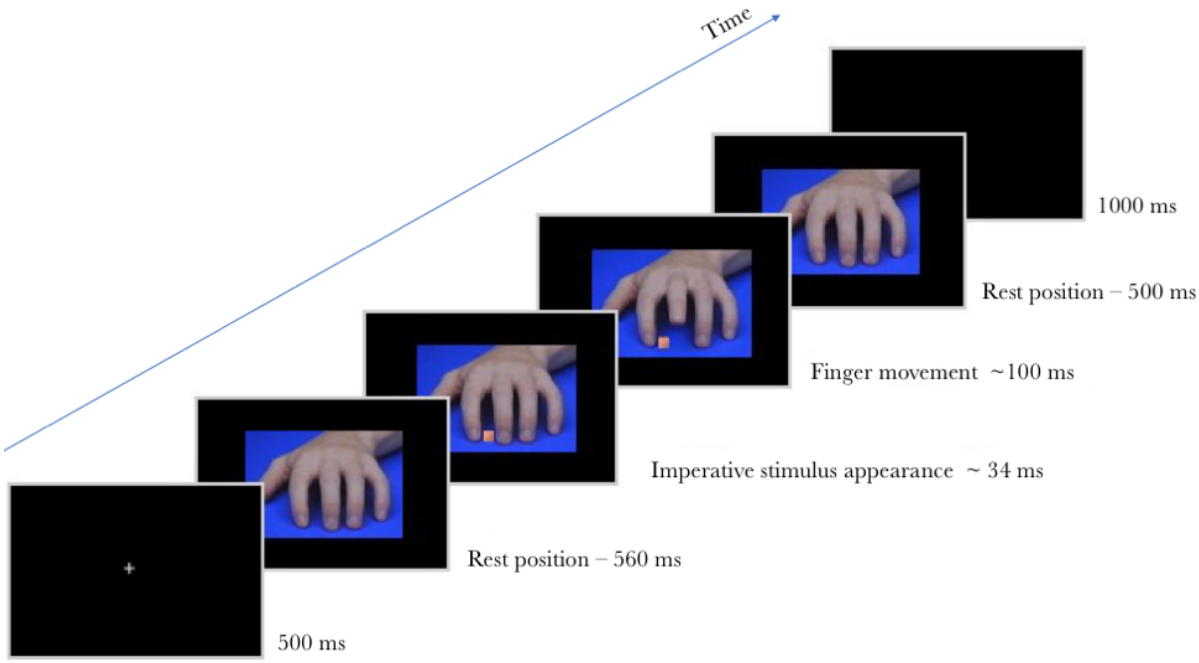


Figure 3.1. Experimental design for Experiment 3.1. The imperative stimulus (number) is a displayed between the index and middle finger with a pink background colour. Number "1" indicates the lifting of the index finger and number "2" to the middle finger. The task-irrelevant stimulus is the finger movement displayed in the background. Congruent trials are those where the number and the moving finger correspond, e.g., number 1 as imperative stimulus and index finger as the moving finger. Incongruent trials are those where the number and the moving finger are not correspondents, e.g., number 2 as imperative stimulus and index finger as the moving finger. On baseline trials, there is no finger movement in the background.

3.2.2 RESULTS

Accuracy

The mean of accuracy for each participant was calculated, separately, for all blocks and experimental conditions. The accuracy was analysed by carrying out a two-way repeated-measures ANOVA having block (1 to 4) and congruency (congruent, incongruent and baseline) as within-subject factors. As I expected, there was a significant main effect of congruency ($F_{(2,28)}$ = 10.01; p =.001; η_p^2 =.41). No main effect of block or

further significant interaction (Fs < 0.9; ps >.14). Post-hoc analyses (Newman-Keuls test) showed that on congruent trials (mean= 97.66%; SE=0.40) participants were more accurate compared to the incongruent (mean= 96.41%; SE=0.48) (p =.01) but did not differ reliably from the baseline condition (mean=97.62%; SE=0.48) (p=.90). However, they did show a significant difference between incongruent and baseline trials (p =.001) (Fig. 3.2).

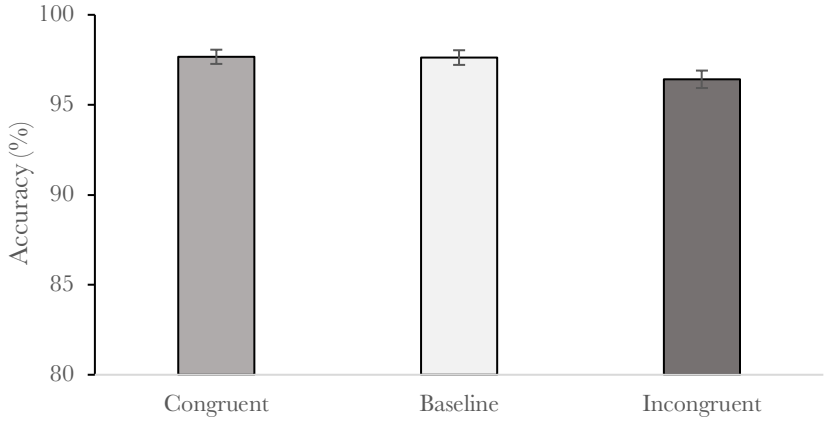


Figure 3.2. Mean percentage of correct responses in each condition (congruent, baseline and incongruent) in Experiment 1 (error bars represent the standard error of the mean).

Reaction time

The median of RTs was calculated for each participant for all blocks and conditions separately. Then, for each block and condition, the participant's individual medians were averaged in order to yield the arithmetic mean of that sample. These means RTs were analysed by carrying out a two-way repeated-measures ANOVA having block (1 to 4) and congruency (congruent, baseline and incongruent) as within-subject factors. Again, consistent with our prediction, there was a significant main effect for congruency ($F_{(2,28)}$ = 9.20; p <.001; η_p^2 =.40), but no main effect of block or a significant interaction (Fs < 1.3; ps >.140). Post-hoc analyses (Newman-Keuls test) showed that participants were

faster on congruent trials (mean= 422.43 ms; SE=11.07 ms) in comparison to both baseline trials (mean= 435.60 ms; SE=12.81) ($p < .01$) and incongruent trials (mean= 441.86 ms; SE=15.2 ms) ($p < .001$). There was no significant difference between the incongruent and baseline trials ($p = .18$) (Fig. 3.3).

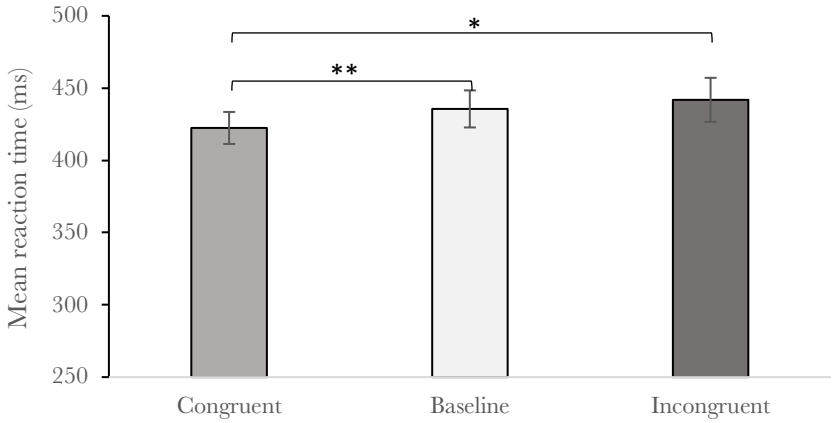


Figure 3.3. Mean RTs for each condition (congruent, baseline and incongruent) in Experiment 3.1 (error bars represent the standard error of the mean). *p<.0001; **p<.01

Distribution of Reaction times

In order to compare the distribution of reaction times across the congruency conditions, a quintile analysis was performed (Ratcliff, 1979). The distribution of each participant's RTs over the entire experiment, separately for the congruent and incongruent trials, was ordered by RT and divided into five "bins" (1 = fastest to 5 = slowest) with an equal number of trials in each bin. A 2 x 5 repeated measures ANOVA was carried out with congruency (congruent and incongruent) and quintile (1 – 5) as within-subject factors. There was a main effect of congruency ($F_{1,14} = 25.83$; $p < 0.001$; $\eta_p^2 = 0.61$). Also, as expected, there was an interaction between quintile and condition ($F_{4,56} = 17.00$; $p < 0.0001$; $\eta_p^2 = 0.42$). Post-hoc analyses (Newman-Keuls test) showed that the congruency effect (the difference between the RTs in the incongruent and congruent

conditions) did not reach significance for the first quintile (mean=2.86 ms, SE=2.14, p=0.568) but became larger and significant as RTs increased, from quintile 2 (mean=11.45 ms, SE=3.25) to 5 (mean=55.43 ms, SE=11.48) (Fig. 3.4).

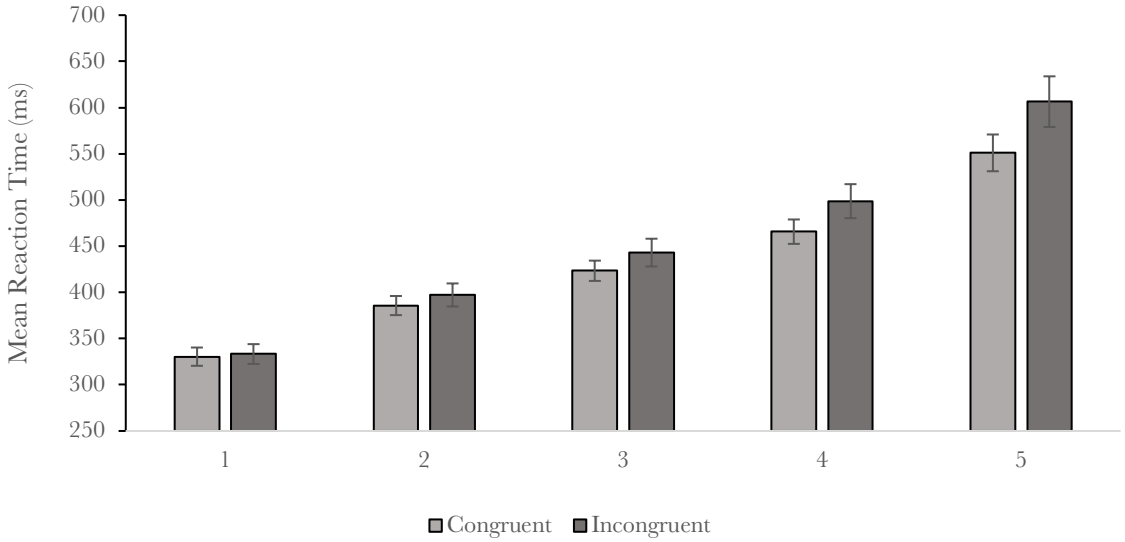


Figure 3.4. Mean RT of congruent and incongruent conditions across the five quintiles (1 = fastest RTs, 5 = slowest RTs) in Experiment 3.1 (error bars represent the standard error of the mean).

3.2.3 DISCUSSION

The significant main effect found for congruency, observed in both accuracy and RT measures, indicates a consistent congruency effect with a higher percentage of correct responses and shorter RTs in the congruent condition compared to the incongruent one. This effect provided evidence of a compelling influence of the observed finger movement on the action executed by the participant, even when this visual stimulus is totally irrelevant for the task. These results are consistent with the original study reported by Brass et al. (2000) and with other previous studies discussed above, allowing us to validate the experimental design to be used in the subsequent experiments.

The analysis of block and quintile yielded an interesting result. First, although Bertenthal, Longo, & Kosobud, (2006) showed that the size of the congruency effect may be reduced along the course of a block, it is important to note that they used a design in which blocks alternated between finger and symbol conditions. Also, participants responded by imitating the finger tapping movement in a single RT task. The lack of difference among blocks in the present experiment allows us to conclude that there is no evidence that the congruency effect substantially decreases across trials and, therefore, cannot be explained by some kind of inertia effect from one block to the other (Hommel, 1996). The quintile analysis showed that the congruency effect becomes larger for slower responses, indicating that the process underlying this effect becomes more influential over time (Brass et al., 2001). Catmur & Heyes (2011) demonstrated similar RT dynamics using SRC automatic imitation tasks, even when spatial compatibility was controlled. Experiment 3.1, therefore, confirmed that the effects I found, based on accuracy, RT and RT distribution, are consistent with a robust congruency effect. Hence, Experiment 3.2 aimed at investigating more deeply the time course of the congruency effect and its relationship between response selection and the processing of task-irrelevant stimuli.

3.3 Effects of Stimulus-Movement Interval Offset

Experiment 3.2

Experiment 3.2 sought to investigate the time window in which the task-irrelevant stimulus can interfere with response. I used the same stimuli and task as Experiment 3.1, with the exception that a manipulation of the task-irrelevant stimulus onset timing was included. By employing four different onsets, I could assess how the different stages of responding to the imperative stimulus is affected by a task-irrelevant movement.

Catmur (2008), using outward (abduction) movements in an automatic imitation task, demonstrated that the congruency effect is not significant until the simultaneous presentation of the imperative and task-irrelevant stimulus. The congruency effect peaks, actually, when the task-irrelevant stimulus is presented before the imperative stimulus. This means that task-irrelevant stimulus interference is greater when it is presented before participants know what action to perform (i.e., before the imperative stimulus display). When the imperative stimulus was presented before (160 and 80 ms), the congruency was very small (around 5 ms). Therefore, this temporal dynamic rises an important question: if response selection starts after the imperative stimulus presentation, what is the limit of offset the task-irrelevant stimulus can still interfere with response?

Experiment 3.1 showed that congruency effect increases as RTs increases. Thus, if the task-irrelevant stimulus interferes with the process of response selection, I should observe an increase on RTs as the task-irrelevant stimulus onset increases. Experiment 3.2 main goals were to evaluate the time window during which the task-irrelevant stimulus can still interfere with response and how the congruency effect would evolve across time. Hence, I expected to have significant main effects of congruency and stimulus-movement interval (SMI). Also, and more important, I expected to have an interaction between these two factors, showing the modulation of the congruency effect by SMI, especially the small ones.

An important aspect of Experiment 3.2 is the breakdown of the congruency effect, by analysing congruent, incongruent and baseline trials. Thus, our experimental design allows us to better explore the role of the contingency between imperative and task-irrelevant stimuli on the process of selecting the response.

3.3.1 METHODS

Participants

A total of twenty-three right-handed participants were tested. Three participants had to be excluded due to poor accuracy. To keep consistency, I continued collecting data until I reach the same sample size as the previous study. The final sample consisted of twenty participants, 13 of whom were female. The participants' ages ranged from 20 to 29 years (Mean = 23.0).

Design and Procedure

The procedure was basically the same as in Experiment 3.1, with the following exceptions. I varied the offset between the imperative stimulus and the start of the finger. This was done by varying the interval between the presentation of the number and the start of the finger movement, which now could be 0 ms, 68 ms, 136 ms or 272 ms (in Experiment 3.1 this interval was fixed at 34 ms). I chose intervals smaller than those used by Catmur (2008) to try to detect interference at the very beginning of the response selection stage. For the baseline condition the design remained the same, since there is no finger movement on these trials. The experiment had 432 trials divided in two blocks with the four SMIs equally and randomly distributed between the three types of trials.

3.3.2 RESULTS

Accuracy

The mean of accuracy was calculated, for each participant, for the two congruencies and the four SMIs separately. Accuracy was analysed by carrying out a 2 x 4 repeated-measures ANOVA having congruency (congruent and incongruent) and SMI (0 ms, 68 ms, 136 ms, 272 ms) as within-subject factors. There was a main effect of

congruency ($F_{(1,19)}$ = 19.70; p = .000; η_p^2 =.55), where participants had a significantly higher accuracy for the congruent condition (mean= 93.5%; SE=1.55) compared to the incongruent condition (mean= 90.97%; SE=1.74), and a main effect of SMIs ($F_{(3,57)}$ = 3.540; p = .021; η_p^2 =.18). Post-hoc analyses (Newman-Keuls test) showed that participants had a lower accuracy for an SMI of 272 ms (mean= 85.37%; SE=2.03) when compared to all other SMIs (p<0.05). No significant interaction between congruency and SMI was found (F< .50; p > .68) (Fig. 3.5). Since the difference between congruencies was small and there was no interaction with SMI, I only analysed the baseline for RT (see below).

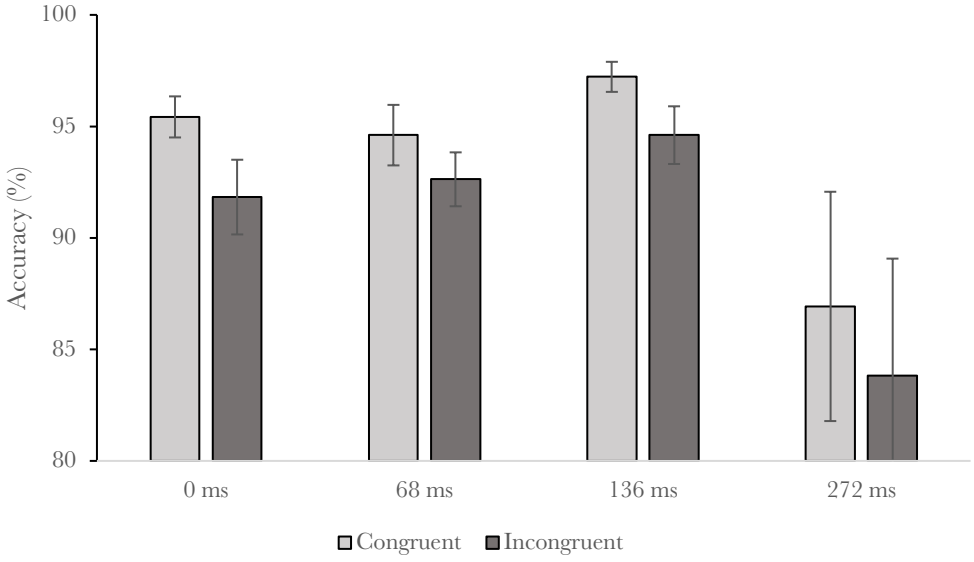


Figure 3.5. Mean percentage of correct responses for the three congruencies (congruent, baseline and incongruent) and the four inter-stimulus intervals in Experiment 3.2 (error bars represent the standard error of the mean).

Reaction time

After removing incorrect responses, the median of RTs was calculated for the two congruencies and four intervals, separately, for each participant. The RTs were analysed

by carrying out a 2 x 4 repeated-measures ANOVA having congruency (congruent and incongruent) and SMI (0 ms, 68 ms, 136 ms, 272 ms) as within-subject factors. Consistent with our predictions, the results replicated those from Experiment 3.1, revealing a significant main effect of congruency ($F_{(1,19)} = 54.0$; $p = .000006$; $\eta_p^2 = .80$), showing that participants were faster on congruent trials. There was also a main effect of SMI ($F_{(3,57)} = 8.25$; $p = .0002$; $\eta_p^2 = .38$). Post-hoc analyses (Newman-Keuls test) revealed that the first two smallest SMIs did not differ from each other ($p = .98$) but both were different from the two greatest SMIs ($ps < .05$). No further significance was found between levels of SMI. However, the key result is the significant two-way interaction of condition with SMI ($F_{(3,57)} = 4.51$; $p = 0.005$; $\eta_p^2 = .24$). Post-hoc analyses (Newman-Keuls test) revealed that the congruency effect occurred for the two smallest SMIs (0 and 68 ms, $p < .002$), but not for the largest ones (136 and 272 ms, $p > .33$). Importantly, the analysis of congruent trials across all SMIs showed that participant's RTs increased progressively. The increase of 5 ms from SMI 0 ms to 68 ms did not reached significance ($p = .53$). However, from SMI 68 ms to 136 ms the increase was of 15 ms ($p = .02$) and of 19 ms from SMI 136 ms to SMI 272 ms ($p = .003$). In incongruent trials participant's responses were very steady, participant's responses at SMIs 0, 68 and 136 ms showed no significant difference among them ($p > .60$) but, at SMI 272 ms, responses were slower than all the other ones ($p < .05$) (see Fig. 3.6).

In order to explore further the origin of the congruency effect, I included into the analysis the baseline data as a level of the congruency factor. However, this forced us to run four separate ANOVAs analyses (one ANOVA for each different SMI) since the baseline trials, by design, did not include SMIs levels, not yielding a full factorial design. Yet, in order to protect against inflation in the Type I error, I adjusted downward the threshold for significance level (α) of the separate ANOVAs by means of the Bonferroni

correction. Four one-way ANOVAs, one for each SMI, were carried out having congruency as a factor with 3 levels now (congruent, incongruent and baseline). The analyses showed an effect of congruency for SMI 0, 68 and 272 ms ($F>14.0$; $p<.006$; $\eta_p^2 >.32$). The one-way ANOVA for SMI 136 ms revealed no differences among the congruencies ($F<2.38$; $p>.11$; $\eta_p^2> .13$). Pairwise comparisons between congruent and incongruent trials in relation to the baseline revealed that the congruency effect in the first two SMIs was more likely due to a facilitation by the congruent trial (congruent faster than baseline, $p<.001$) rather than a cost by the incongruent (incongruent slower than the baseline, $p>.60$). Moreover, the results revealed no significant cost across all SMIs ($p>.17$), apart from SMI 272 ms, where participants were on average 18 ms slower than the baseline ($p=.006$). Surprisingly, there was also a cost at SMI 272 ms associated with the congruent trials, where participants were on average 16 ms slower than the baseline ($p=.03$). No further significant difference was found ($p>.22$).

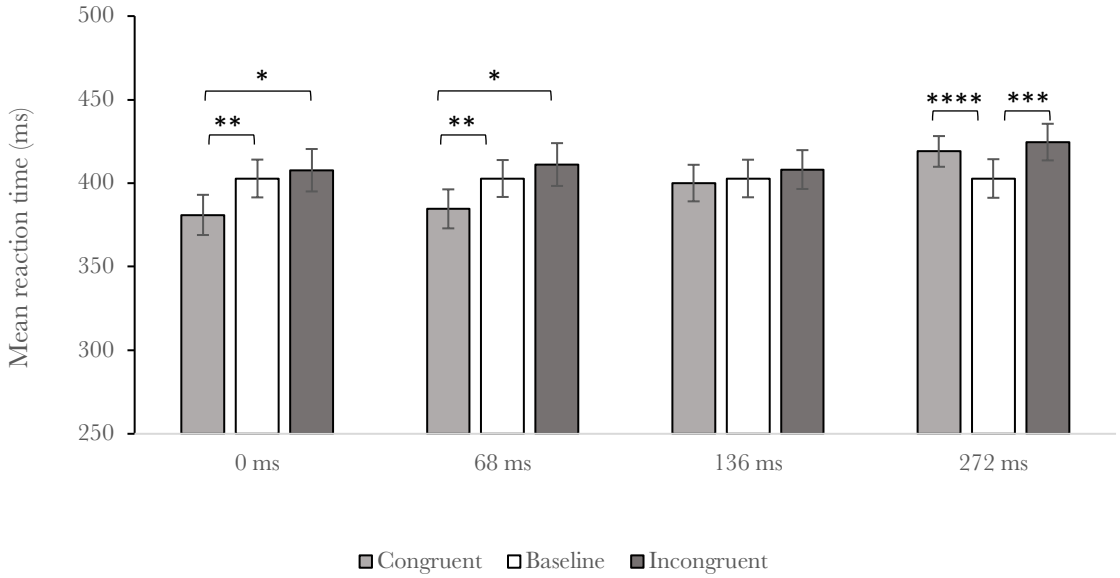


Figure 3.6. Mean RT for the three conditions (congruent, baseline and incongruent) and the four SMIs in Experiment 3.2 (error bars represent the standard error of the mean). *p<.0001; **p<.001; ***p<.01; ****p<.05.

3.3.3 DISCUSSION

The results show a consistent congruency effect for accuracy and RT measures. Crucially, this effect was modulated by the interval between the presentation of the imperative and the task-irrelevant stimuli. Hence, the analysis yielded some interesting results. First, although the congruency effect occurred across all SMIs for accuracy measures, it only occurred on the two smallest SMIs for RTs. One would expect that, if the task-irrelevant stimulus can still interfere with the process of response selection at the 272 ms SMI in relation to accuracy, this would happen also for RT measures. However, although response occurred later in the SMI of 272 ms, the difference between the two congruencies is not statistically significant, yielding no congruency effect in the last two SMIs. Actually, the interaction between congruency and SMI for RT measures indicates that the size of the congruency effect changed over the four SMIs, as would be expected considering that this effect depends on the contingency between the imperative and task-irrelevant stimuli (Catmur, 2008; Hommel, 1993, 1994).

The analysis of the temporal dynamics of congruent and incongruent trials separately and in relation to the baseline gave us other important results. The significant difference between congruent trials and the baseline was restricted to the first two SMIs (21 ms for SMI 0 ms and 18 ms for SMI 68 ms). Specifically, the results showed that the congruency effect in these intervals is due to a facilitation from the task-irrelevant stimulus. Moreover, the lack of difference between incongruent trials and the baseline showed no evidence of the idea of a cost caused by the task-irrelevant stimulus on those SMIs. These results suggest that the task-irrelevant stimulus can facilitate response selection within a short time interval (between 0 ms and 68 ms in this experiment). After this window, there is an interval (~136 ms) where this stimulus does not facilitate response

selection. Interestingly, however, there was a cost associated to the SMI 272 ms for congruent **and** incongruent trials. At this interval, participants were also significantly less accurate for both congruent and incongruent trials, compared to the baseline, which indicates that this is not a case of speed-accuracy trade-off effect. Also, the increase of RTs in congruent trials across SMIs was such that, at SMI 136 ms the difference between congruent trials and baseline did not reach significant difference and, at SMI 272 ms, this continuous RT rise was enough to exceed baseline RTs significantly. It is important to note, however, that the increase in RTs for congruent trials was constant across all SMIs but, for incongruent trials, it only increased significantly at SMI 272 ms. This lack of modulation of the RTs for incongruent trials in the first three SMIs and its later occurrence only at SMI 272 ms is rather surprising. Together with the cost associated to the congruent trials at SMI (~272 ms), our results suggest that after a longer SMI, a task-irrelevant stimulus can interfere negatively regardless its congruency with the required response.

Experiment 3.2 therefore confirmed that a task-irrelevant stimulus can interfere with response selection even within a delay of 68 ms in relation to the imperative stimulus, detailing the findings of previous studies (Catmur & Heyes, 2011). Also, our results suggest that this interference is due to a facilitation on congruent trials. However, the findings regarding the negative interference in a long SMI for both congruencies open the question of whether it is possible that task-irrelevant stimuli can also interfere with response execution. Experiment 3.3 aimed to answer this question by using the same experimental task, but including a valid cue before the imperative stimulus. Our aim was to investigate whether prior information about the response to be executed, excluding, therefore, the response selection stage, would still produce a congruency effect.

3.4. Effects of Cued Response in a CRT task

Experiment 3.3

In the previous two experiments, the task-irrelevant stimulus was presented during the interval between the presentation of the imperative stimulus and the processing of response. According to sensorimotor information processing models, during this interval, the response is selected from a response repertoire, initiated and, finally physically executed (Sanders, 1980). Therefore, if the congruency effect has its origin at the response selection stage, one can argue that congruency effects should not occur any more after response selection has been completed. Indeed, this question can be investigated by distinguishing interference in response selection and execution using SRT tasks (Cracco et al., 2018; Hommel, 1996).

Studies involving SRT tasks with abstract stimuli produce correspondence effects of about 2 ms ±6 (Hommel, 1996). However, several studies on automatic imitation did find a congruency effect using SRT tasks (Brass et al., 2001; Cook, Press, Dickinson, & Heyes, 2010; Heyes, Bird, Johnson, & Haggard, 2005; Kilner, Hamilton, & Blakemore, 2007; Kilner, Paulignan, & Blakemore, 2003). In these studies, a pre-defined response is required in relation to a go-signal, which is usually a movement congruent or incongruent in relation to the response. Hence, the pre-defined response should eliminate the response selection stage and, consequently, the interference can be considered somewhat at the execution stage in SRT tasks. However, the only study to offer an explanation considering action-perception processing models is Brass et al. (2001), using the stimulus and response common code instead of sequential models. They argue that, because of the common coding, predefining a response does not prevent the response from being influenced by

the irrelevant stimulus during the response execution process. Still, in a standard SRT task, only one response is applicable and active throughout a certain number of trials. Participants are likely to hold only one response in readiness, and consequently a small impact of activation from the alternative response is expected (Hommel, 1996). Hence, sequential effects (Bertelson, 1961), e.g., when the enhanced performance is a consequence of a repetition (or alternation) of a response or a stimulus in preceding trials, should be considered.

Therefore, in Experiment 3.3 I used a CRT task, similar to Experiments 3.1 and 3.2, to ask whether anticipated and fully valid information about the next response to be executed (a cue) would interfere with the congruency effect. Although a CRT task was used, the addition of a cue before the imperative stimulus makes this task comparable to the automatic imitation SRT tasks. However, even in a cued CRT task, participants have to switch from one response to the other, so that after a switch some activation of the last response may show some inertia and transfer it to the new trial, even when this response is no longer valid. Thus, this design provides a way to explore the transitory residual effect that might favour repetitions and certain types of switches, allowing us to investigate sequential effects.

Participants were informed that a cue, at the beginning of each trial, would inform them about the required response. They were instructed that a response should be initiated as quickly as possible after the presentation of the imperative stimulus. Cues were only valid, therefore giving the participants absolute certainty about the response to be executed. With three different intervals between the presentations of the cue and the imperative stimulus, I wanted to ensure participants would have enough time to complete the response selection/preparation. In this case, the presentation of the imperative stimulus after the valid cue could be considered as a go-signal and, consequently, the point

which response initiation will take place. Therefore, if the assumptions of the sensorimotor approach hold true, I expected to find either no congruency effect in any given interval or, a congruency effect explained by sequential effects. On the other hand, the existence of congruency effect, independent of a sequential effect, would favour the assumptions of the IM approach, showing that action effect codes were modulated by the task-irrelevant stimulus before response execution takes place.

3.4.1 METHODS

Participants

Twenty participants took part in Experiment 3.3, 12 of whom were female. The participants' ages ranged from 20 to 30 years (Mean = 23.4).

Design and Procedure

The experimental design was similar to Experiment 3.1 with some changes added in order to evaluate response selection and anticipatory effects in the presence of a cued imperative stimulus. Letters with no direct meaning ("W", "K" and "N") were used as cues. On an initial black screen, a centrally displayed letter "W" or "N" indicated which imperative stimulus (1 or 2) would be presented. Letters "W" and "N" were randomly presented and stimulus assignments were counter-balanced across participants. Catch trials, indicated by letter "K", were inserted to ensure that they were paying attention to the cues. In these trials, participants had to withhold their responses and wait until the next trial. The cues were randomly presented for 200, 500 or 800 ms, followed by the presentation of the right hand in a resting position. The hand image remained visible for 560ms and was followed by the presentation of the imperative stimulus and the sequence of task-irrelevant finger movement in the same way as in Experiment 3.1. Therefore, the

cue-imperative stimulus interval (CSI) was the time of cue presentation plus 560 ms from the initial frame with the hand at rest position, in total 760, 1060 and 1360 ms. Participants were asked to pay attention to the cues and informed they indicated, with 100% certainty, which response would be required. They were asked to respond as quickly as possible and as soon as the imperative stimulus was presented. Congruent, incongruent and catch conditions totalled 288 trials (96 trials for each one) divided in 2 blocks. Also, the interval between the presentation of the imperative stimulus and the initiation of the finger movement (the task-irrelevant stimulus) was now fixed at 0 ms, the shortest SMI used in Experiment 3.2 and the one where the congruency effect was stronger.

3.4.2 RESULTS

Accuracy

The mean of accuracies was calculated, for each participant, for congruent and incongruent trials and for each CSI, separately. Accuracy was analysed by carrying out a 2 x 3 repeated-measures ANOVA having congruency (congruent and incongruent) and CSI duration (700 ms, 1000 ms, 1300 ms) as within-subject factors. I found a significant main effect of congruency ($F_{(1,19)}$ = 8.48; p = .009; η_p^2 =.32), showing that participants were more accurate in congruent (mean=98.84%, SE=.27) than incongruent trials (mean=97.98%, SE=.45). There was also a main effect of CSI ($F_{(2,38)}$ = 6.72; p = .003; η_p^2 =.27). The interaction between congruency and CSI did not reach statistical significance ($F_{(2,38)}$ = .12, p= .88; η_p^2 =.006). Post-hoc analyses (Newman-Keuls test) showed that participants were less accurate at the longest CSI 1300 ms (mean=98.80%, SE=.29) when compared to the other intervals (p< .01). No significant accuracy difference was found between CSI 700 and 1000 ms (p=.78) (Fig. 3.7).

Reaction time

After removing incorrect responses, the RTs were analysed by carrying out a 2 x 3 repeated-measures ANOVA having congruency (congruent and incongruent) and CSI (700 ms, 1000 ms, 1300 ms) as within-subject factors. Again, I observed a significant main effect for both factors: congruency ($F_{(1,19)}$ = 10.16; p = .005; η_p^2 =.36), showing that responses were faster in congruent trials (mean= 342.87 ms, SE=20.40) when compared to incongruent trials (mean=373.92 ms, SE=26.16), and CSI ($F_{(2,38)}$ = 26.50; p = .0001; η_p^2 =.59). Similar to accuracy measures, their interaction did not reach statistical significance ($F_{(2,38)}$ =.7; p= .47; ; η_p^2 =.04). Post-hoc analyses (Newman-Keuls test) showed that the shortest CSI 700 ms had the slowest RT (mean=393.1 ms, SE= 4.6) when compared to the other intervals (p< .0001) (Fig. 3.8).

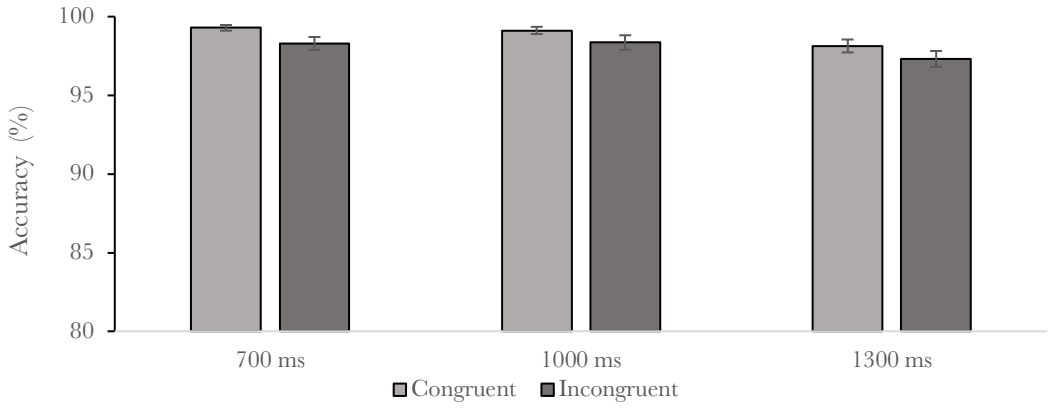


Figure 3.7. Mean percentage of correct responses for both conditions (congruent and incongruent), and the three CSIs in Experiment 3.3 (error bars represent the standard error of the mean).

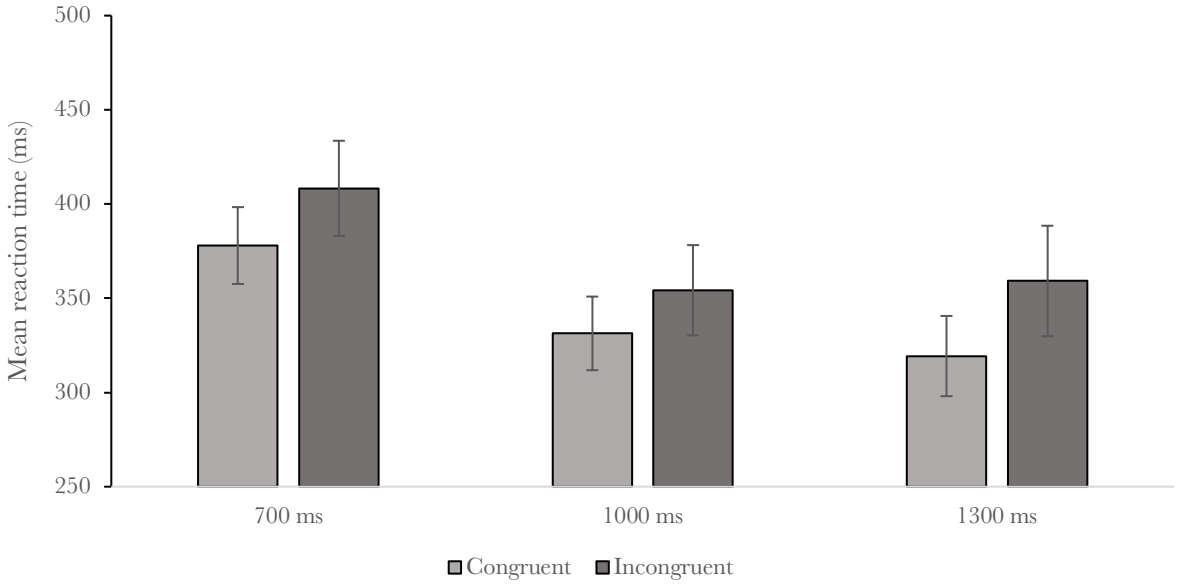


Figure 3.8. Mean RT for both conditions (congruent and incongruent), and the three CSIs in Experiment 3.3 (error bars represent the standard error of the mean).

Sequential effects

In order to analyse whether the response in a given trial can be modulated by the repetition or alternation of the stimuli presented in the previous trial, I mapped all the possible combinations of two trials in a sequence considering both congruencies and imperative and task-irrelevant stimuli (see figure 3.9). Therefore, a sequence of two trials with the same congruency relationship, e.g., a congruent trial followed by another congruent trial, allows **only** two types of repetition between stimuli: full repetition (when both imperative and task-irrelevant stimuli are repeated) and a no repetition (when both imperative and task-irrelevant stimuli alternate). On the other hand, an alternation of congruencies, e.g., a congruent trial followed by an incongruent trial, allows **only** partial repetitions, i.e., a task-irrelevant repetition (when imperative stimulus changes and task-irrelevant repeats) or an imperative repetition (when imperative stimulus repeats and task-irrelevant changes). The confounding of the two critical factors (congruency relationship and full-partial repetition) is not simply an avoidable methodological flaw but a basic

characteristic of the task due to its two-choice design. The use of the term "repetition" is arbitrary, and it can be used interchangeably as opposite to "alternation"; for instance, a "full repetition" sequence also refers to a "no alternation" sequence. Likewise, when the sequence contains an alternation of congruencies, e.g., a sequence of congruent and incongruent trial, the repetition/alternation of stimuli is always partial and, therefore, an "imperative repetition" also refers interchangeably to a "task-irrelevant alternation".

	$C^{P}_{1,1}$	$C^{P}_{2,2}$	$I^{P}_{1,2}$	$I^{P}_{2,1}$
$C^{C}_{1,1}$	full repetition	no repetition	imperative repetition	task-irrelevant repetition
$C^{C}_{2,2}$	no repetition	full repetition	task-irrelevant repetition	imperative repetition
$I^{C}_{1,2}$	imperative repetition	task-irrelevant repetition	full repetition	no repetition
$I^{C}_{2,1}$	task-irrelevant repetition	imperative repetition	no repetition	full repetition

Figure 3.9. Illustration of all possible repetitions of the two stimuli from a sequence of two trials in Experiment 3.3. Each trial is represented by a letter and two indexes. Letters C and I represent congruent and incongruent trials, respectively. Superscript indexes P and C represent the trial position (P= previous and C= current trial). Subscript indexes 1 and 2 represent the fingers displayed as stimulus (1=index and 2=middle finger). The first index represents the imperative stimulus and the second, the task-irrelevant stimulus. The repetition of a given congruency between two trials ($C^{P}_{x,y}\, C^{C}_{x,y}$ or $I^{P}_{x,y}\, I^{C}_{x,y}$) can generate a full repetition (when imperative and task-irrelevant stimuli are also repeated) or a no repetition (when imperative and task-irrelevant stimuli alternate). The alternation of congruencies ($C^{P}_{x,y}\, I^{C}_{x,y}$ or $I^{P}_{x,y}\, C^{C}_{x,y}$) can generate a task-irrelevant repetition (when imperative stimulus changes and task-irrelevant repeats) or an imperative repetition (when imperative stimulus repeats and task-irrelevant changes).

Therefore, to investigate sequential effects and their relationship with the congruency effect found in Experiment 3.3, RTs were analysed by carrying out a 2 x 3 x 4 repeated-measures ANOVA having congruency (congruent and incongruent), CSI (700 ms, 1000 ms, 1300 ms) and repetition type (full repetition, no repetition, imperative repetition and task-irrelevant repetition) as within-subject factors. Consistent with the previous RT analysis, I observed a significant main effect of congruency ($F_{(1,18)}$ = 13.15; p = .002; η_p^2 =.43) and CSI ($F_{(2,36)}$ = 39.73; p = .0001; η_p^2 =.70). The results were in line with the previous RT analysis, showing faster responses in congruent trials when compared to incongruent and the slowest RT for the shortest CSI 700 ms when compared to the other two intervals. However, no main effect of repetition type was found ($F_{(3,54)}$ = .71; p = .24; η_p^2 =.09). Crucially and consistent with our main prediction, there was a reliable interaction between congruency and repetition type ($F_{(3,54)}$ = 4.21; p = .03; η_p^2 =.25). Post-hoc analyses (Newman-Keuls test) revealed, importantly, a congruency effect for trials generated by no repetition (30 ms, p=.03), imperative (29 ms, p=.04) and task-irrelevant repetition (49 ms, p=.007), but none for trials generated by a full repetition (8 ms, p=.13). No significant difference within the same congruency across repetition types was found (F<1, p>.78) (Fig. 3.10). Pairwise comparison revealed difference sizes of congruency effects across repetition types: task-irrelevant repetition yielded the greatest congruency effect (p=.03) while full repetition yielded the smallest (p=.01) when compared to all the other ones. There was no difference between no repetition and imperative repetition (ps>.2)

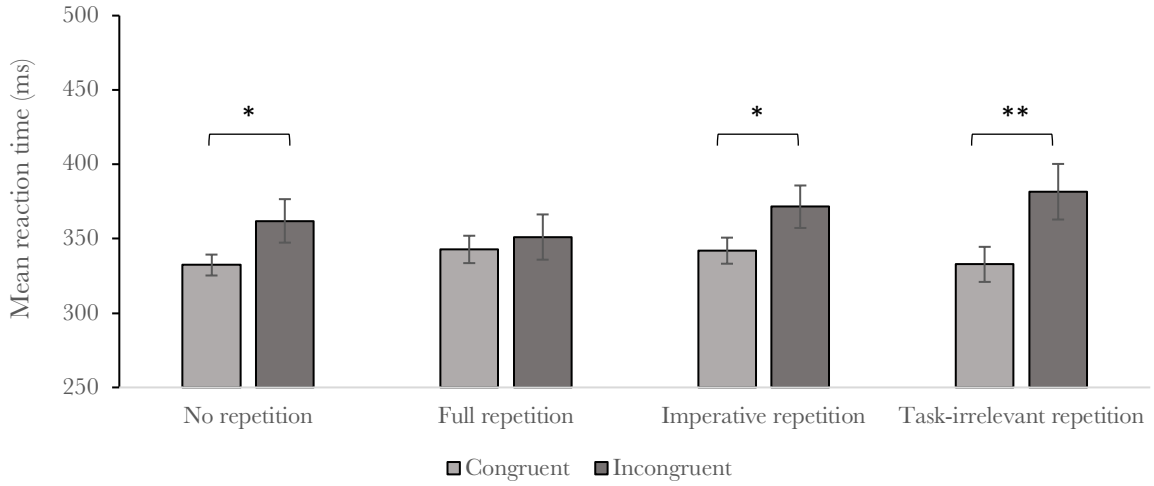


Figure 3.9. Mean RT for both conditions (congruent and incongruent), and the four repetition types (no repetition, full repetition, imperative repetition and task-irrelevant repetition) in Experiment 3.3 (error bars represent the standard error of the mean). *p<.05; **p<.01

3.4.3 DISCUSSION

Experiment 3.3 sought to investigate whether previous information about the next response to be executed would interfere with the congruency effect in a classical choice RT automatic imitation task. I also explored the origin of the congruency effect by analysing sequential effects.

Crucially, a robust congruency effect was observed that did not vary reliably across CSI conditions, lending support to the idea that task-irrelevant stimulus interference prevails even when participants could fully complete the required response selection. Although the possibility that the existence of catch trials (no-go trials) led participants to adopt a more conservative response criterion, there is evidence showing that this impact is not sufficient to abolish congruency effects (Hommel, 1995, 1996). By amply varying the time between the cue and the imperative stimulus as well as by giving participants complete knowledge as to the action to be executed, I have gone beyond the process of response selection, invading the (possibly early) process of response execution.

Considering that the cue was always informative, I assume that, especially at the largest interval, participants would have already made their response selection and were fully prepared to respond (or withhold their response, in case of catch trials). The fact that the task-irrelevant stimulus can interfere after a response had been selected, even at the longest interval, is clearly demonstrated by the consistent significant difference in RTs between the congruent and incongruent trials observed across all CSIs (Fig. 3.8).

Because all the cues were informative, participants knew what they should do at least 700 ms before the imperative stimulus. In this sense, the imperative stimulus was acting merely as a "go-signal". However, if I consider that action planning involves different stages, the control of some aspects of the response could occur even as the action proceeds after the movement has been initiated (Maslovat, Klapp, Jagacinski, & Franks, 2014). So, it is possible that holding the response until the "go-signal" does not allow response selection to be fully completed, permitting some interference of the task-irrelevant stimulus at its later stages. Nevertheless, I cannot discard the possibility of a *continuum* between the processes of response selection and response execution (Brown, Friston, & Bestmann, 2011; Clark, 2013). In this sense, it could be the case that the process of selecting the appropriate response was, at its latest stages, overlapping the early stages of response execution.

The analysis of sequential effects provided further explanation for the origins of the congruency effect. The interaction between congruency and repetition type gave evidence of a modulation of the congruency effect by the sequence of trials. There was no significant difference between congruent and incongruent trials (8 ms) on trials with a full repetition of both stimulus features, where the response to be executed does not change from one trial to the other. Therefore, in the case of full repetition of incongruent trials,

it is possible that the repetition of the task-irrelevant and, consequently, its inhibition, facilitates response of current trial, leading to a faster RT.

The greatest congruency effect was found in trials where the imperative stimulus alternated and the task-irrelevant stimulus was repeated (for instance, $C^{P}_{1,1}$ $I^{C}_{2,1}$ or $I^{P}_{1,2}$ $C^{C}_{2,2}$). This alternation benefit is consistent with the studies with non-social stimuli where the interval between the previous response and the stimulus from the actual trial is around 500 ms or longer (Bertelson, 1961; Proctor & Vu, 2006). Here, the crucial point is that, because the imperative stimulus alternates, the task-irrelevant stimulus changes its valence (from inhibition to activation, for instance) from one trial to the other, while remaining the same stimulus. In trials with no repetition, the same imperative stimulus alternation occurs, but the congruency effect is significantly smaller. Therefore, our results suggest that the greatest congruency effect can be better explained by the change of valence of the task-irrelevant stimulus across trials instead of the response inertia transferred to the new trial. In trials where there is an alternation of congruencies between trials ($C^{P}_{x,y}$ $I^{C}_{x,y}$ or $I^{P}_{x,y}$ $C^{C}_{x,y}$) but the imperative stimulus remains the same, the task-irrelevant stimulus changes its valence from one trial to the other, as it also changes the stimulus. In this case, the results showed an intermediate congruency effect, similar to no repetition trials.

3.5 General Discussion

The set of experiments described in this chapter aimed to investigate the temporal dynamics of the automatic imitation effect. After being able to replicate the congruency effect in our own experimental setup (Experiment 3.1), I adapted the original design from Brass et al. (2000) by varying the interval between the imperative and task-irrelevant stimuli and by adding an informative cue before the imperative stimulus. The present

experiments demonstrate the temporal aspects of task-irrelevant stimulus interference on not only the response selection (Experiment 3.2), but also on response execution (Experiment 3.3).

There is some debate whether automatic imitation is a specialized form of spatial stimulus-response compatibility, with no difference from other long-term S-R associations (Boyer et al., 2012). Considering that our set of experiments did not control for spatial compatibility (because congruent hand stimuli were always also spatially compatible, and incongruent stimuli were always spatially incompatible), I cannot exclude the possibility that our results apply to effects of spatial cues rather than action cues, i.e. that task-irrelevant spatial cues can interfere with response execution. However, prior experiments controlling spatial compatibility (Brass et al., 2001; Catmur & Heyes, 2011; Press et al., 2008; Cooper et al., 2013) indicate that SRC effects in this finger lifting experimental design and similar ones have, indeed, an imitative compatibility component. Brass et al. (2001) demonstrated a larger congruency effect when the experimental design combined spatial and imitative compatibilities compared to a modified version which excluded spatial compatibility. Catmur (2008) showed that both compatibility effects build up and then decay over time, following the onset of the irrelevant movement stimulus. She suggests that the difference between the time courses is due to spatial information being processed more quickly, leading to a compatibility effect that builds up earlier than the automatic imitation effect. In her hand abduction experimental design, the congruency effect is maximal when the task-irrelevant stimulus is presented around 80 ms before the imperative stimulus, and decays when both stimuli are presented together. The spatial congruency effect showed a more constant size across the variation of stimulus offset.

In Experiment 3.2 I presented the task-irrelevant stimulus with a delay ranging from 0 to 272 ms in relation to the imperative stimulus. Therefore, our results allowed us

to address the stages of the response selection process where the task-irrelevant stimulus can still interfere. Also, by including baseline trials, the nature of the congruency effect could be explored in terms of facilitation and costs.

Usually, evidence from the literature shows that the congruency effect is due, at least in part, to a negative interference (cost) rather than positive (facilitation) when it is compared to a baseline condition (Bertenthal, Longo, & Kosobud, 2006b; Brass et al., 2000; Gillmeister, Catmur, Liepelt, Brass, & Heyes, 2008; Heyes, 2011). The task-irrelevant stimulus interference is mainly discussed in terms of response selection and its effect due to the activation of the automatic route of Kornblum's model (Kornblum et al., 1990). The activation of the intentional route by the presentation of the imperative stimulus, together with the activation of the automatic route by the presentation of the task-irrelevant stimulus, leads to an interference of the process that starts with selecting the appropriate response and ends with the response execution. Because the SRC effect happens only when there is at least some contingency between the imperative and the task-irrelevant stimulus, the time interval between these two stimuli needs to be short (see Hommel, 1993, 1994). Interestingly, however, Experiment 3.2 showed a decay of the congruency effect at SMI 136 ms mostly due to an increase of the RT for congruent trials, while the RTs for incongruent trials did not show any significant difference across the four SMIs. A similar result was obtained by Experiment 3.1 where the SMI was fixed at 34 ms. I suggest that the period between 0 to 68 ms is dedicated to solving the competition of responses, and it is vulnerable to interference. That is why trials where the process of response selection does not involve inhibition and reorganization, i.e., congruent trials, the activation of the automatic route by the task-irrelevant stimulus can speed up the process if presented in an interval between 0 ms and 68 ms (from the imperative stimulus display).

Together, the results from Experiments 3.1 and 3.2 are the only ones that allow us to address the question of positive and negative interference, either because of a direct comparison with baseline or a difference on the temporal dynamics of congruent and incongruent trials. Hence, the present results indicate, at least for RT measures, that the congruency effect is due to a facilitation. No evidence of a cost was found.

Experiment 3.3 explored more closely the stages of information processing during an automatic imitation task. By giving previous information of the response required I aimed at investigating the idea that task-irrelevant stimulus affects the process of response execution. The addition of a cue anticipated the process of response selection in such way that the imperative stimulus did not have to be entirely processed at the moment it was presented. Instead, the choice of which response to prepare could be done by the time the cue was presented and the imperative stimulus was a mere signal to warn participants to respond. Also, the variation of CSI duration allowed us to investigate the different levels of response selection reached by the time of the imperative stimulus display. Assuming that, with a CSI of 1300 ms, participants could have fully selected the appropriate response, the congruency effect observed at this interval suggests that the presentation of a task-irrelevant stimulus affects later stages of information processing. Additionally, the sequential effects showed that, in addition to some response inertia can be carried-over while alternating responses, the change of valence of task-irrelevant interference can also affect response selection.

In conclusion, our experiments allow us to draw some conclusions about when task-irrelevant stimuli interfere during the process of responding. I demonstrated that the competition for response alternatives and its selection lasts until participants have an ultimate signal to execute the action response, and the automatic imitation effect operates

not only during response selection but also response execution. However, future studies on automatic imitation should investigate to what extent interference/facilitation occurs during response selection instead of, actually, exclusively during response execution.

Chapter 4

The Modulation of Automatic Imitation by a Prominent Self

4.1 Introduction

In social interactions, it is crucial to share and distinguish the representation of the self and other people. In perspective taking for instance, the representation of our own perspective must be inhibited in favour of representation of the other's perspective. The failure in controlling others-motor related representations over our own results in automatic imitation, which indicates the degree of which an observer's motor system reflects the action of another individual. Decety & Sommerville (2003) argues that self-awareness and agency are crucial components for directing these self-other representations. Crucially, during automatic imitation studies (see Experiment 3.1, Chapter 3), when participants observe an action that is incongruent with the response to be performed, self-awareness and agency are essential to ensure a correct performance.

The aim of this chapter is to explore the role of self and others-related information in the process of action inhibition in an automatic imitation task. I first review studies that show how self information can modulate other cognitive processes and then discuss the role of self-related information in automatic imitation. In the experiments described below I try to understand whether a prominent self stimulus could modulate the automatic imitation effect as a function of the interaction with different agents.

4.1.1 PERCEIVING THE SELF

There are a few studies demonstrating that self-relevant information is more perceptually salient than that of others (Gronau, Cohen, & Ben-Shakhar, 2003; Sui, He, & Humphreys, 2012; Sui & Humphreys, 2015a). Sui et al., (2012) demonstrated that giving a neutral stimulus greater personal significance has effects on visual selection equivalent to altering perceptual salience. They used an associative learning procedure in

which participants were instructed to arbitrarily associate three different shapes with three different labels, for instance, square to "you" (the participant), triangle to "friend" and circle to "stranger". Participants judged whether the presented shape-label pair matched the given instruction or not. Reaction times and d-prime measures indicated that participants rapidly labelled a neutral stimulus with self-relevance, showing a robust advantage for self-labelled compared to other- labelled stimuli. This study is important because it uses neutral stimuli like geometrical shapes instead of own-name and own face, which carry great familiarity and, therefore, are naturally more salient. Furthermore, Sui & Humphreys, (2015d) used the same experimental design to distinguish the relations between self-bias and reward bias. They associated different reward values (£8, £2, £0) with particular shape-label pairs. Self shape-label pairs always received no reward, while friend shape-label pairs received high reward and stranger shape-label pairs low reward, or the reverse (friend - low reward; stranger - high reward). Despite receiving no reward, responses to self-related pairs were still advantaged relative to those to low-reward stimuli and did not differ from those to high-reward items.

Self-relevant stimuli are also powerful cues for attention that can enhance sensory responses and reduce uncertainty in decision-making. Liu, He, Rotsthein, & Sui (2016) used self- or other-faces as a central cue prior a letter target in a study where participants had to judge the orientation of the target. The face changed its orientation dynamically so that it turned either to the location where the target would appear or to a location on the opposite side. The results showed that the self-face acted as a stronger attentional cue than the faces of other people. Tao, Zhang, Li, & Geng (2012) demonstrated similar result even when the awareness for faces was minimized by the use of a continuous flash suppression.

Self-related information was also found to influences other cognitive processes like memory (Turk, Cunningham, & Macrae, 2008), facial processing (Devue & Brédart, 2008), judgments (Hu et al., 2016; Watson, Dritschel, Obonsawin, & Jentzsch, 2007) and imitation (Wang & Hamilton, 2013). Sui, Liu, Mevorach, & Humphreys (2015) suggest that once a personal association is formed, it can modulate the saliency of stimuli and subsequently impact on visual selection. Therefore, self-association could actively direct attention in the environment by altering the social saliency of stimuli.

4.1.2 THE AUTOMATIC IMITATION EFFECT AND THE SELF

As reviewed above, self-related information has a greater relevance to an individual, and it can interfere with several behaviours. Currently, evidence points to a role of self-related information in reinforcing individual's own intentions and also in enhancing self-other discrimination (Brass, Ruby, & Spengler, 2009; de Guzman, Bird, Banissy, & Catmur, 2016; Jackson & Decety, 2004; Mergan, 2016; Obhi & Hogeveen, 2013; Sowden & Catmur, 2015; Spengler, Brass, Kühn, & Schütz-Bosbach, 2010; Spengler, Von Cramon, & Brass, 2009).

In an imitation-inhibition task, Spengler et al. (2010) instructed participants to emphasize their action intention against a tendency to copy other's behaviour under heightened and normal self-focus. During high self-focus, induced either by performing the task with mirror self-observation or after self-referential judgments, participants showed reduced imitative tendencies. In settings with a normal self-focus, e.g., with a mirror reflecting the participant's side, the tendency to imitate was higher. The authors suggest that in a situation with augmented self-focus, action-control mechanisms can be enhanced online, leading to a modulation of automatic mirroring responses by preventing unintentional copying tendencies. Indeed, people with a tendency to display a greater self-

focus and reduced concern for others (narcissists) are an important group to explore in the context of imitation tendencies. Indeed, Obhi, Hogeveen, Giacomin, & Jordan (2014) showed that individuals with high scores on subclinical narcissism are less prone to imitate. In a version of the automatic imitation task of Brass et al. (2001), they instructed participants to respond to symbolic cues displayed with videos of congruent or incongruent actions. They found that participants with high scores on narcissism has a reduced congruency effect. The authors suggest the inhibition of imitation found in these participants comes from an ability to discriminate internally generated motor representations from those triggered by observing another person's action. However, one can argue, for instance, that people who are high on narcissism may show a smaller congruency effect not because they are better distinguishing self-other representations but because they pay less attention to information regarding others (and/or more attention to information about them).

Wang & Hamilton (2013) used pro/antisocial primes to measure the modulation of the automatic imitation effect when participants are primed with first or third-person sentences. They manipulated the self-relatedness of the pro/antisocial primes, e.g., from a third-person perspective - "Greg encourages others to be friends with Lauren", "Joe cruelly bullied Stephanie about her weight problem" and from a first-person perspective, by changing the first character with 'I' or 'we', e.g., "We encourage others to be friends with Lauren". After completing a Scrambled Sentences Test, participants had to respond to an imitation-inhibition task similar to Brass et al. (2000) (see Chapter 3). Their results showed that prosocial primes enhance imitation only when the social primes are self-related whereas antisocial primes enhance imitation only when the social primes are self-unrelated. Nonetheless, van Baaren, Maddux, Chartrand, de Bouter, & van Knippenberg (2003), using a more ecological study, with participants engaged in a real interaction with

confederates, showed that when participants were primed with self-relevant words like *I*, *me*, and *mine*, they imitated the confederate (rubbing his face or shaking his foot) more than when primed with control words like *he*, *him*, and *his*.

The studies reviewed above indicate that self-related information is highly significant and can capture attention in a relatively automatic manner, modulating performance when attention is required. They also indicate that the automatic imitation effect can be enhanced or lessened depending on how self-related information is processed. Thus, the direction of prime-to-behaviour effects depends on where and how primes are directing attention, especially when it involves self-related information. Still, the results are mixed and there is no clear evidence of how prominent self-related information modulates the tendency to copy others' motor behaviour. Currently, studies exploring the role of the "self" in modulating the automatic imitation effect employ the concept of self through an indirect dimension, for instance, by showing participants their own names (Mergan, 2016), priming with their own image (Spengler, von Cramon, & Brass, 2010) or using sentences from a first-person perspective (Leighton, Bird, Orsini, & Heyes, 2010; Wang & Hamilton, 2013). Then, the "self-biasing stimulus" is combined with an automatic imitation task that typically involves Stimulus-Response Compatibility designs, where response interference (measured by accuracy and reaction time) is used as an indication of imitation tendencies. However, self-processes operate at multiple levels (Decety & Chaminade, 2003) and, therefore, it is important to specify how each "self-dimension" can help to understand the modulation of automatic imitation. The studies reviewed above used dimensions such as self-focus, first-perspective and self-image as a prime to test its effect on the execution of the imitation task. Nevertheless, it is not clear in which process of imitation those primes are acting. Here, I sought to understand

whether self-related stimuli, incorporated directly into the imitation task rationale (as opposed to the indirect prime), can modulate particularly the processing of the stimulus that is imitated/inhibited. Moreover, I used different degrees of self-related information, i.e., the self and different others (highly familiar others: a friend and an unfamiliar other: a stranger).

In the present series of three experiments, I asked whether including a prominent self-related stimulus within an automatic imitation task would affect performance as a function of the social relevance of the viewed action—i.e., when the agent of the task-irrelevant movement is explicitly informed (or not). I used the same SRC choice reaction time design from Brass *et al.* (2000) to address the question about automatic imitation. In order to produce a perceptual self-bias, I adapted the paradigm introduced by Sui et al. (2012) based on a simple associative matching procedure. In that task, as described above, participants were asked to apply labels referring to different people to specific shapes. Here, I created a similar label (self, friend, stranger) and colour (red, blue and green) association task to be performed before the automatic imitation task. Once the perceptual self-bias was established, participants executed the automatic imitation task where the agent of the task-irrelevant movement was (in)directly suggested by the colour of the stimulus background, (i.e., using the same colours from the labels of the perceptual matching task). Importantly, in Experiment 4.1 participants performed the automatic imitation task with different background colours, but **no explicit** instruction about the agent of the task-irrelevant movement was given. In Experiment 4.2, prior the task, participants **were explicitly given** information about the relationship of the background colours and the agent of the task-irrelevant movement, which matched the perceptual matching task. In Experiment 4.3, I used the same rationale as in Experiment

4.2 with the addition of a set of stimuli in which spatial compatibility effects were dissociated from imitative congruency. This experiment was done in order to verify whether the modulation of the automatic imitation effect (if any) would persist when detaching spatial compatibility from imitative congruency effects. The use of the term compatibility for spatial relationships and congruency for imitative relationships was adopted to facilitate the comparison. Thus, considering that a response is always executed with participant's right hand, an index finger movement could be presented on the left side of space by a left hand (imitative congruent and spatially compatible) or on the right side of space by a right hand (spatially compatible but not imitatively congruent).

Firstly, it was expected that the automatic imitation effect in Experiment 4.1 would be smaller in the presence of self-related colour compared to stranger-related because there was no specification regarding whether and which dimension of the "self" should be taken into account. Specifically, I expected that a stimulus inducing a self-bias would reduce automatic imitation effects by enhancing self-focus, as shown in previous studies (Mergan, 2016; Spengler, von Cramon, et al., 2010; Wang & Hamilton, 2013). Secondly and most importantly, I predicted that if the specific agency dimension of the "self" plays a different role during imitation, in Experiment 4.2 self-related information would capture participants' attention to the task-irrelevant stimulus strongly enough to interfere with responding. More specifically and different from Experiment 4.1, mean reaction times should be smaller when the agent of the observed action is the "self" and the action to be performed is the same as the observed one, since there would be high congruency between participants' motor intentions and the action observed. On the other hand, when there is a conflict between the action to be performed and the action observed (incongruent trials), mean reaction times should be greater, since participant's motor intentions will be different from their "own hand" task-irrelevant movement. Also, if our hypothesis holds

true, I should expect a different modulation of the automatic imitation effect when it is detached from spatial compatibility, since this type of design is known for yielding smaller automatic imitation effects (Catmur & Heyes, 2011; Cooper, Cook, Dickinson, & Heyes, 2013; Heyes & Ray, 2004).

4.2 Colour Perceptual Matching task

Self-bias task

The study of Sui et al. (2012) provides evidence that a newly established self-relevant visual association affects performance in simple perceptual matching task. Their shape-matching task shows that associating a stimulus to the self modulates its subsequent perceptual processing. This modulation was demonstrated by a faster RT and higher accuracy for matching shapes to the label self, relative to when the shapes were linked to familiar others, an unfamiliar person, or a neutral label. Here, I created a similar association task using three different colours instead of shapes. Using the same labels (you, friend and stranger), I assigned each one to a colour (red, green or blue) to obtain a similar visual association. After performing this task, I expected that participants would carry over the colour-label association to the next task, the automatic imitation experiment. Although the research reported in this chapter comprises three different automatic imitation experiments, the colour matching task that participants performed first was always the same. Therefore, I describe below the common colour matching task and its unified analysis, considering participants of all automatic imitation experiments together.

I expected to find similar effects to those found in the shape matching task Sui et al. (2012): The results should show a faster response and higher accuracy (measure as d-

prime) to the matching pair related to the self in comparison to the friend and stranger, creating a so-called self-bias when processing the aforementioned colours.

4.2.1 METHODS

Participants

In total, ninety right-handed participants were trained (thirty for each of the following automatic imitation experiments), 65 of whom were female. The participants' ages ranged from 18 to 35 years (Mean = 23.02). All participants had normal or corrected-to-normal-vision. They gave informed consent and received course credit or money (10 pounds/hour) for their time. This study and all the subsequent ones were approved by the Central University Research Ethics Committee of the University of Oxford.

Apparatus and Material

A Dell Optiplex 9010 computer controlled stimulus presentation and data acquisition using E-prime 2.0 (Psychology Software Tools, Inc). Participants were seated approximately 80 cm from the screen and kept their viewing distance fixed using a chin rest. One of three possible coloured squares (3.8° x 3.8° in green, blue or red) was presented above a white fixation cross (0.8° × 0.8°) at the centre of the screen. The word *you*, *friend*, or *stranger* (3.1°/3.6° × 1.6°) was displayed below the fixation cross. The distance between the centre of the coloured square or the word and the fixation cross was 3.5°. Responses were recorded by a keyboard in which participants pressed either "H" or "J" with their right hand.

Design and Procedure

The stimulus on each trial comprised a coloured square and a label presented on a light grey background. Participants had to judge whether the pairing of colour and label matched a given association (e.g., Is the red your friend?). The association was established by the experimenter. Before the experiment starts, participants were presented to the arbitrary association of named colours (green, blue and red) to the labels you, a best friend (named by the participant), and a stranger (named by the participant from a list of names). For example, a participant was informed: "Mary [the stated best friend of the participant] is represented by the colour blue; you by the colour red; and Peter [a name chosen for from a list to name the stranger] by the colour green". The association of the three colours to the self, friend, or stranger conditions was counterbalanced across participants. Each trial started with the presentation of a central fixation cross for 500 ms. Subsequently, a pairing of a colour and a label was presented for 100 ms. The pairing could conform the established association previously or it could be a recombination of a label with a different colour, with the colour–label pairings being generated at random. The next frame showed a blank for a variable time ranging from 800 to 1200 ms. Participants were expected to judge whether the colour was correctly assigned to the person by pressing one of the two response buttons ("matching" or "non-matching") as quickly and accurately as possible within this timeframe (to encourage immediate responding). Feedback (correct or incorrect) was given on the screen for 500 ms at the end of each trial. Participants were informed of their overall accuracy at the end of each block. Each participant performed three blocks of 120 trials following 12 practice trials, where self, friend, stranger, and re-paired stimuli occurred equally often in a random order. Thus, there were 60 trials in each condition (self-matched, self-nonmatching, friend-matched, friend-nonmatching, stranger-matched, and stranger-nonmatching).

4.2.2 RESULTS

Accuracy

To test for a self-prioritization effect when processing the colours, accuracy was analysed using a signal detection approach. Correct responses shorter than 200 ms were excluded from the analysis, eliminating less than 1% of the trials overall. Performance in each match condition was combined with the same colour nonmatching condition to form a measure of d-prime, e.g., green-self (match condition) and green-friend (nonmatching condition). The data were then analysed using a 3x3 mixed design ANOVA with label (you, friend and stranger) as a within-subjects factor and experimental group (4.1, 4.2 and 4.3) as between-subjects factor. The results showed a main effect of colour label ($F_{(2,176)}$ = 57.71, p= .0001, η^2=0.40) and, importantly, no main effect of group or interaction between the two factors (Fs<1). Post-hoc analyses (Newman-Keuls test) showed that the d-prime for trials with the "self" label was significantly higher compared to the label "friend" (p<.0001) and "stranger" (p<.0001). Also, the labels "friend" and "stranger" differed significantly from each other (p=.006).

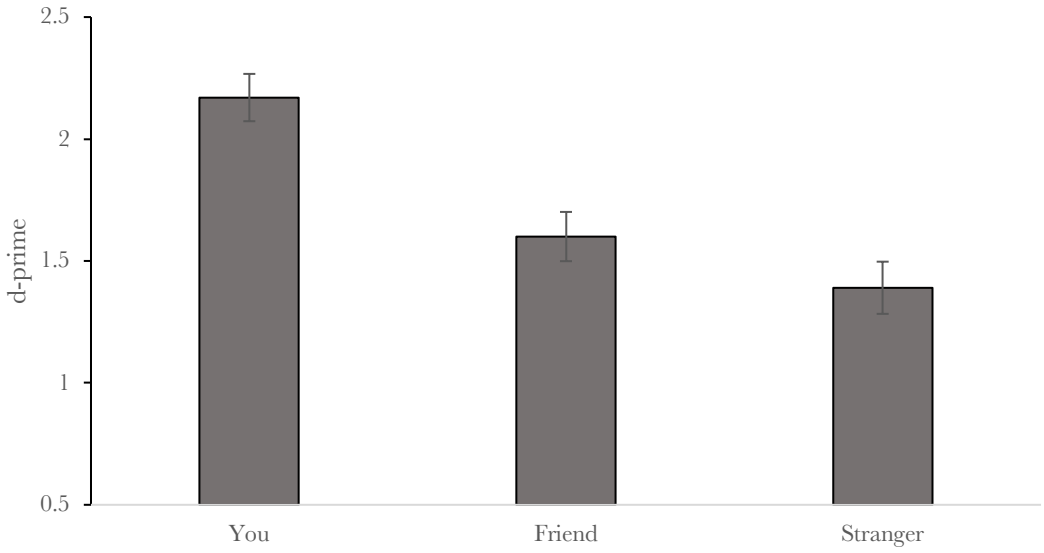


Figure 4.1. d-prime measure for each label for the colour matching task.

Reaction time

Errors were excluded from the RT analysis. The median RT for both matching judgment conditions (matched vs. nonmatching), the three labels and the three experiments were calculated for each participant of each experimental group. A 3x3x3 repeated measures ANOVA was carried-out having condition and label as within-subject factors and experimental group as between-subject factor. The results showed a significant effect of label ($F_{(2, 178)} = 48.82$, $p < .00001$, $\eta^2=0.35$) and condition ($F_{(1,89)} = 227.44$, $p < .00001$, $\eta^2=0.71$). Post-hoc analyses (Newman-Keuls test) showed an overall difference between the label "self" and "friend" (p=.0009), between "self" and "stranger" (p=.0002) and between "friend" and "stranger" (p=.0019). Also, the matching condition was faster than the non-matching conditions (p=.0001). Further, there was an interaction between condition and label ($F_{(2, 178)}=75.08$, p= .00001, $\eta^2=0.45$). Post-hoc analyses showed that RTs for the three labels were significant different from each other (p<.00002) in the matching conditions but no significant difference among the labels was found in the non-matching condition (p>.08).

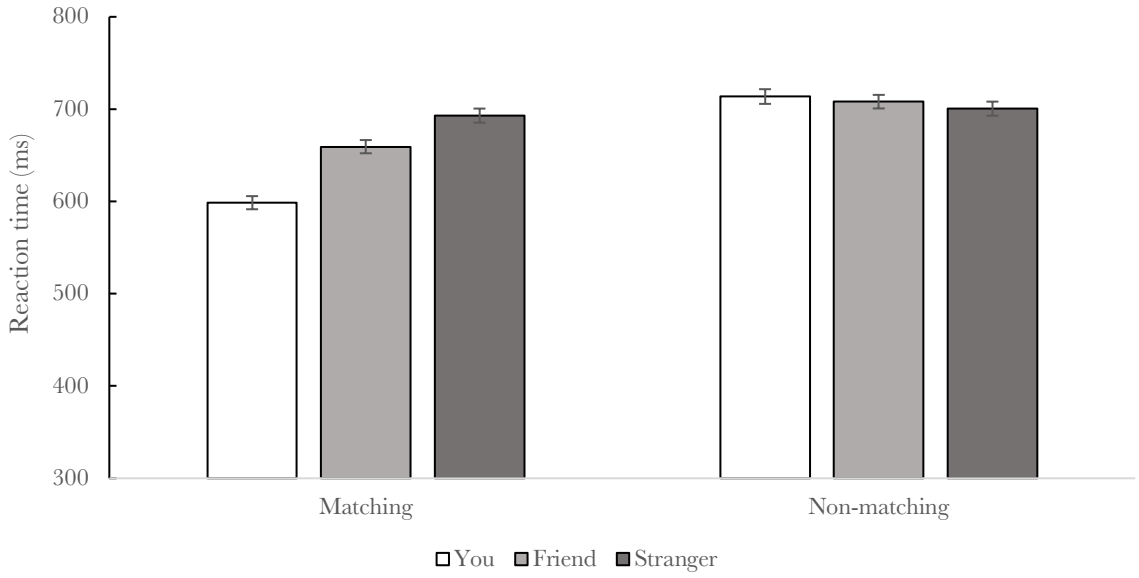


Figure 4.2. Interaction between label and matching judgment. Mean reaction times for matched and non-matched trials as a function of label (self, friend, or stranger).

4.2.3 DISCUSSION

I adapted the experimental design from Sui et al. (2012) in order to replicate the effects of the social salience of self-related information in a simple perceptual matching task. Participants associated labels for themselves (you), other familiar person (friend), or an unfamiliar (stranger) with colours and then immediately judged whether subsequent label–colour pairings matched. Our colour matching task showed results similar to other studies where a similar experimental design was used (Stolte, Humphreys, Yankouskaya, & Sui, 2015; Sui et al., 2012; Sui, Sun, Peng, & Humphreys, 2014; Sui & Humphreys, 2015b, 2015d). The higher d-prime and faster RTs in trials where the matching pair involved the label "self" indicate that participants were better at differentiating label-colour associations containing self-related information than when other familiar or an unfamiliar person information was presented. This advantage related to the processing of the "self" is discussed in terms of enhancing the stimulus enough to modulate ongoing matching tasks (Cunningham, 2016; Glyn W Humphreys & Sui, 2016; Sui & Humphreys, 2015c).

Importantly, by combining the results of the colour matching task performed by participants of the three subsequent experiments, I could demonstrate that there was no difference among those experimental groups, indicating that the three groups learned the perceptual association in a corresponding way. Hence, I can assume that participants from the three following experiments started the automatic imitation task with a perceptual bias towards colour information related to the "self", referred henceforth as "perceptual self-bias". Therefore, the following described experiments sought to test whether the perceptual self-bias would be carried over to an automatic imitation task and modulate action congruency effects.

4.3 Automatic imitation under perceptual self-bias

Experiment 4.1

In Experiment 4.1 I sought to investigate whether the automatic imitation effect can be modulated by perceptual self-bias carried over from the prior perceptual matching task. I adapted the automatic imitation task used in Experiment 3.1 (Chapter 3) by combining it with the colours labelled in the perceptual matching task. New stimuli were created using three different coloured backgrounds matching the colours of the labels. Therefore, the task-irrelevant stimulus was presented in three different scenarios, based on the colour of the background. Considering that the base of the automatic imitation effect relies on a self-other distinction mechanism, and that self-related information can modulate perceptual processing, I expected that the automatic imitation effect would be modulated by the perceptual bias towards self-related information. Specifically, our aim was to test whether participant's perceptual self-bias would be carried over and interfere with the processing of the task-irrelevant stimulus (moving finger). I expected to find the overall effect of congruency and, most importantly, an interaction between congruency and colour association, showing a smaller congruency effect when the task-irrelevant stimulus is presented combined with self-related information.

4.3.1 METHODS

Apparatus and Material

Similar apparatus and material used in Experiment 3.1 were used for the present experiment. The video sequences of the animated hand were created having the stimulus parameters from Brass et al. (2000) as reference, using a Nikon, D51 camera (18-55mm

Nikkor lens) and three different coloured backgrounds. The colours used were exactly the same as in the self-bias task for the labels "you", "friend" and "stranger". Responses were recorded by a keyboard in which participants kept the "1"and "2" keys pressed by, respectively, the index and middle fingers of their right hand throughout the experiment, releasing one of them at the time of the response.

Design and Procedure

The experimental design used was similar to Experiment 3.1, with the following modifications. There were only two conditions (congruent and incongruent). Each condition could be presented in three different scenarios, i.e., the stimuli could be presented with a red, green or blue background colour. Each colour was associated with one of the labels from the perceptual matching task (you, friend and stranger). The sequence of stimuli and their durations in an example trial are shown on Fig 4.3. The procedure comprised a total of 300 trials with the two congruencies and the three colour-labelled background equally distributed (50 You congruent, 50 You incongruent, 50 Friend congruent, 50 Friend incongruent, 50 Stranger congruent and 50 Stranger incongruent). Participants were informed that the perceptual matching and automatic imitation tasks were unrelated. Ten practice trials were presented at the beginning of the experiment to illustrate the task to participants and were not included in the analysis. RTs were calculated from the onset time of the imperative stimulus until the release of one of the keys. Incorrect responses in the automatic imitation task were defined to be errors when the key released ("1" or "2") did not correspond to the imperative stimulus. At the end of the task, participants were asked whether they could remember the colour-label associations from the perceptual matching task for control purposes.

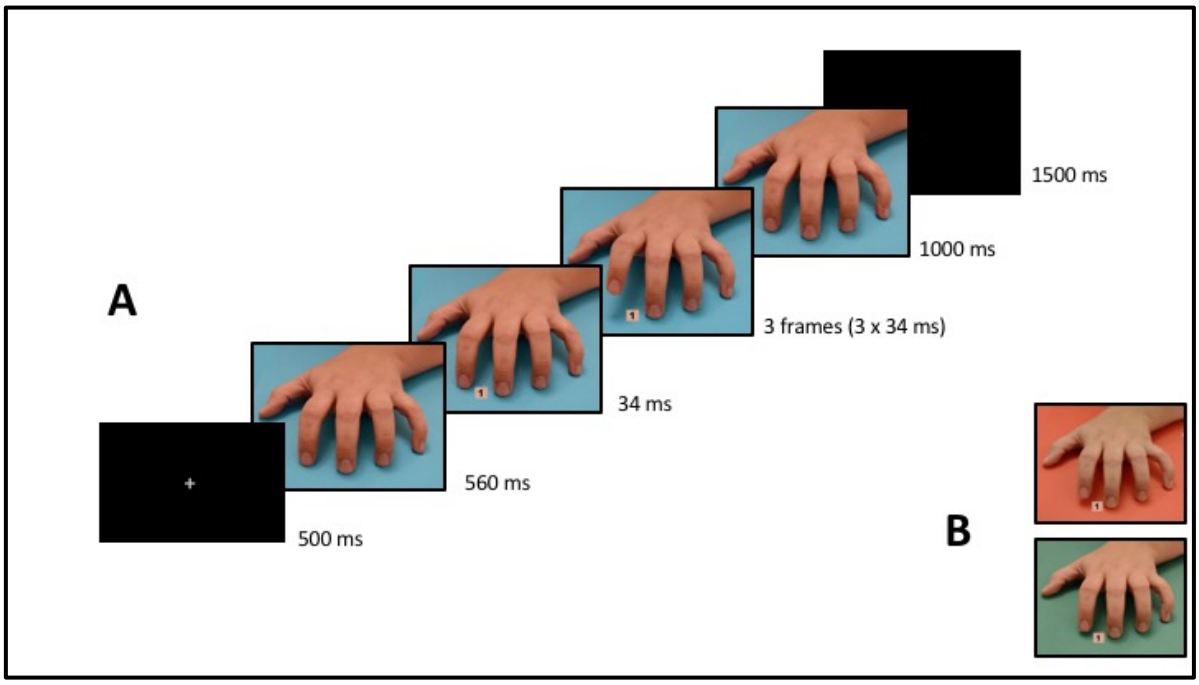


Figure 4.3. A - The sequence of stimuli in each trial in Experiment 4.1. The figure shows a congruent condition with the task-irrelevant stimulus (hand) displayed in a blue background. B - The two alternative background colours (red and green).

4.3.2 RESULTS

Accuracy

Mean accuracy was calculated for all conditions and labelled backgrounds for each participant. Accuracy was then analysed using a 2x3 repeated-measures ANOVA having condition (congruent and incongruent) and labelled background (you, friend and stranger) as within-subject factors. There was a main effect of congruency ($F_{(1,29)} = 17.65$; $p = .0001$; $\eta_p^2 = .38$), showing that participants had higher accuracy in congruent trials compared to incongruent trials. Importantly, there was no main effect of labelled background ($F_{(1,58)} = 2.56$; $p = .11$; $\eta_p^2 = .07$) and the interaction between congruency and labelled background did not reach statistical significance ($F_{(2,58)} = 3.7$; $p = .55$; $\eta_p^2 = .03$) (Fig. 4.4).

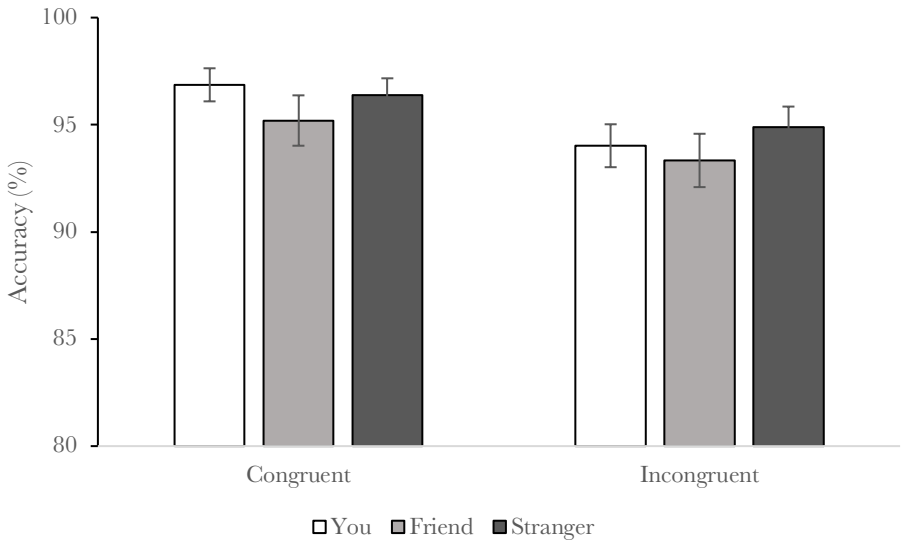


Figure 4.4. Mean of correct responses in each condition (congruent and incongruent) for each label (you, friend and stranger) in Experiment 4.1 (error bars represent the standard error of the mean).

Reaction time

The median of RTs was calculated for each participant for all conditions and labelled backgrounds separately. Then, for each condition and labelled background, the participants' individual medians were averaged in order to yield the arithmetic mean of that sample. A 2x3 repeated measures ANOVA was carried-out having congruency (congruent and incongruent) and labelled background (you, friend and stranger) as within-subject factors. A significant main effect of condition was found ($F_{(1, 29)}$= 34.10, p < .001, η^2=.54), showing that participants were faster in congruent trials compared to incongruent trials. Importantly, the effect of labelled background did not reach significance ($F_{(2, 29)}$=.32, p= .723 η^2=.01). Contrary to what I expected, the interaction between condition and labelled background did not reach statistical significance ($F_{(2, 58)}$=1.69, p= .194, η^2=.05) (Fig. 4.5). Also, to test for an unpredicted colour effect, I also carried-out an 2x3 repeated measures ANOVA having congruency and colour (red, green

and blue) as within-subject. Indeed, the colour effect was not significant ($F_{(2,58)}$= 1.66, p =.198, η^2=.05).

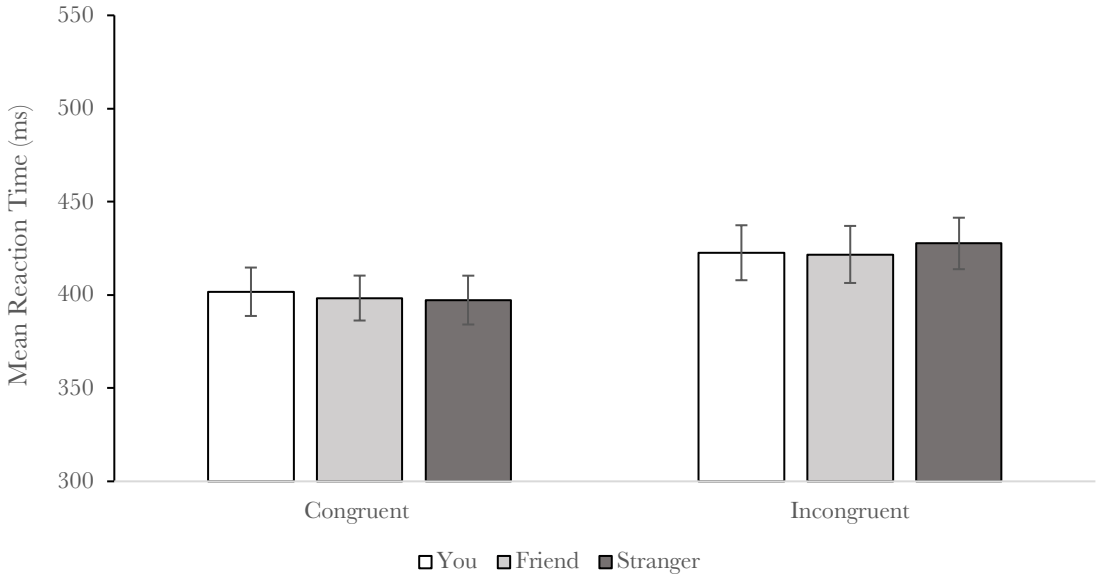


Figure 4.5. Mean RTs for each condition (congruent and incongruent) and each label (you, friend and stranger) in Experiment 4.1 (error bars represent the standard error of the mean).

Distribution of Reaction Times

Considering that the congruency effect in this type of automatic imitation task is greater for slower responses, I used a quintile analysis (Ratcliff, 1979) to further investigate the relationship between the congruency effect and labelled background. The distribution of each participant's RTs over the entire experiment was ordered by response speed, considering each of the three labelled background and both congruencies, and subsequently divided into five "quintiles" (1 = fastest to 5 = slowest) with an equal number of trials in each one. The congruency effect (RT on incongruent – RT on congruent trials) was then calculated for each of the five quintiles. This allowed measurement of the size of the congruency effects across the range of slowest to the fastest RTs, providing an insight

into the relative strength of each label over time. I carried-out a 3x5 repeated measures ANOVA with labelled background and quintile (1 – 5) as within-subjects factor. The analyses revealed no main effect of labelled background. Most importantly, there was an interaction between labelled background and quintile ($F_{(8,232)}$=2.26; p=.024; η^2=.07) (Fig. 4.6). Post-hoc analyses (Newman-Keuls test) showed that labelled background modulated congruency effects at longer RTs. In accordance to what I predicted, the congruency effect for the labelled background "you" was significantly smaller compared to "stranger" from quintile 3-5 (p<.04). The labelled background "you" was also different from "friend" (p=.001) in quintile 5, but no difference was found between "friend" and "stranger" (p=.90). No further comparison between labelled backgrounds reached statistical significance (p> .87).

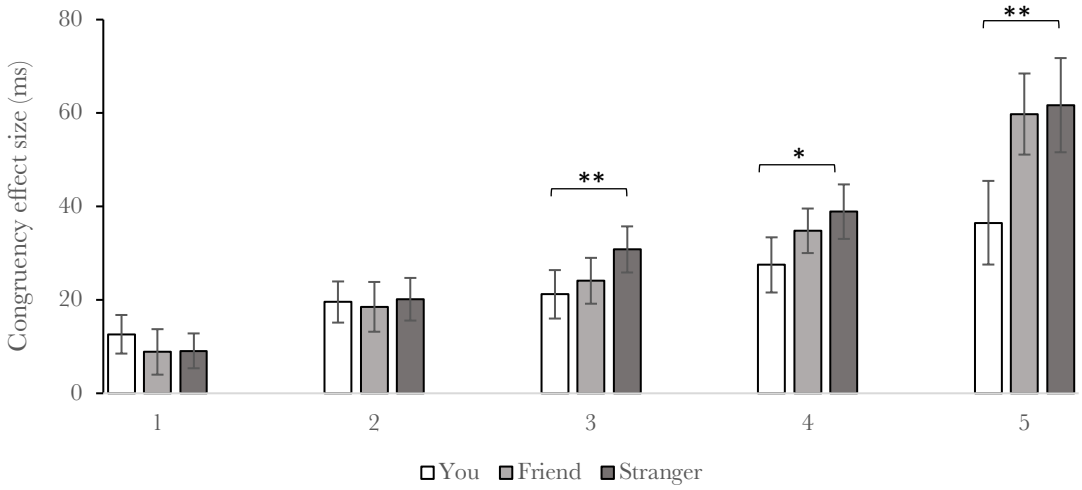


Figure 4.6. Mean of the congruency effect for each labelled background across all the five quintiles in Experiment 4.1 (error bars represent the standard error of the mean). *p=.04; **p=.03.

Colour-label association recollection

All participants were able to recover with 100% of accuracy the three colour associations from the self-bias task for all three labels.

4.4.3 DISCUSSION

Experiment 4.1 sought to test whether the perceptual self-bias from a preceding perceptual matching task would be carried-over enough to modulate the response during the automatic imitation task. The accuracy and the overall RT analyses did not show an interaction between labelled background and congruency effect. However, further exploration of the data, considering the distribution of RTs over time, provided evidence of modulation of automatic imitation by a perceptual self-bias. In the slowest quintile of RT data, the congruency effect was smaller in trials with reference to "self" when compared to trials with reference to "stranger". Our results suggest that perceptual self-bias enhanced some kind of self-control process that is critical to reinforce current internally produced action intentions against task-irrelevant stimuli. In contrast, stranger-related information might have lessened self-control processes during the automatic imitation task, since it showed a greater congruency effect. However, I did not know exactly how participants used the colour-label information when responding to the automatic imitation task. It is possible, for instance, that abstract self-related information (the background colour) enhanced a motor self-focus and, therefore, participants could better control external distracting information.

Therefore, in order to further test the role of perceptual self-bias in the process of responding to the imperative stimulus (and inhibit copying the task-irrelevant stimulus), in Experiment 4.2 I reinforced the colour-label perceptual relationship and added sense of agency. Participants were explicitly required to establish an agency relationship

between the person associated to a given colour and the hand of the task-irrelevant movement while responding to the imperative stimulus. If the modulation of the automatic imitation effect is due to a heighted self-focus when responding, participants' performance should not be affected when facing conflicting information in incongruent trials, i.e., when the "self agent" executes a different action from the intended one.

4.4 Automatic imitation with an explicit agent

Experiment 4.2

The results from Experiment 4.1 revealed a modulation of the automatic imitation effect by perceptual self-bias, weakening the effect in the presence of self-related information when compared to information related to a stranger. In Experiment 4.2 I sought to test whether an explicit relationship between the labelled background and the agent of the task-irrelevant movement would enhance the congruency effect on trials where the task-irrelevant movement agent is the "self" compared to trials with a "stranger" agent. Vastano, Pozzo, & Brass (2017) stress the importance of correspondence and coherence between own intentions and the integration of the observed action-related information for the experience of agency. Therefore, I assume that on trials where the agent is the "self", participants should expect a consistency between their intentions and the observed task-irrelevant movement. However, given the perceptual self-bias and the explicit agency relationship, I expected that participants would perform worse in trials where the agent is the "self" and the task-irrelevant stimulus is incongruent, leading to a greater congruency effect. Accordingly, trials with other familiar or unfamiliar information should result in a smaller congruency effect, since the inconsistency between the participant's intentions and the observed task-irrelevant movement would not be as

highlighted and conflicting in comparison with trials containing information about the self.

4.3.1 METHODS

Design and Procedure

Experiment 4.2 follows the same experimental design as Experiment 4.1 except for the instructions regarding the association between the labels and colours of the perceptual matching task. At the beginning of the experiment, participants were informed that the perceptual matching task they had just performed was related to the next one. They were asked to remember the colour-label association from the perceptual matching and the information was reinforced when necessary, i.e., it was reviewed when participants could not recollect one of the associations correctly. Participants were asked to pay attention to the colour of the background where a hand would be displayed. They were informed that the background colour indicated who was the owner of the hand displayed, using the association of the prior task as reference. Next, participants were given the instructions of the automatic imitation task. They were asked to respond to the imperative stimulus as fast and accurately as possible and, also, to identify the agent of the task-irrelevant movement. Following this task, they were asked "Whose hand did you see previously?". The keys "Y", "F" and "S" were used as equivalence of "you", "friend" and "stranger" respectively. Participants used their left hand to respond to this question so they did not change the position of their right hand used in the primary, speeded match/nonmatch decision. Participants had up to 4000 ms to indicate the colour-identity and were instructed to give priority to accuracy. Trials in which participants responded incorrectly to the question regarding the agent of the movement were excluded from

analysis (less than 1%), and these responses were not analysed further. Data analysis instead focused on accuracy and RT for the correct judgment.

4.4.2 RESULTS

Accuracy

Accuracy was analysed using the same procedure as in Experiment 4.1. Again, there was a main effect of congruency ($F_{(1,29)}$ = 19.5; p =.0001; η_p^2 =.40), showing that responses in the congruent condition were more accurate compared to the incongruent condition (p =.0006) (Fig. 4.7). There was no statistically significant main effect of labelled background ($F_{(1,58)}$ = .88; p =.41; η_p^2 =.03) nor a significant interaction ($F_{(2,58)}$=.20; p =.81; η_p^2 =.007).

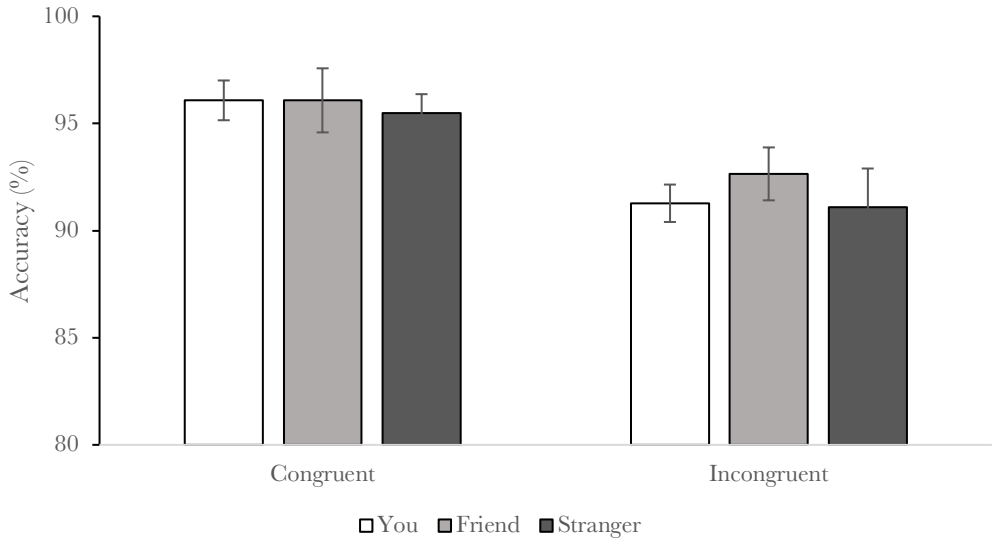


Figure 4.7. Mean of correct responses in each condition (congruent and incongruent) for each labelled background (you, friend and stranger) in Experiment 4.2 (error bars represent the standard error of the mean).

Reaction time

The same analysis procedure as in Experiment 4.1 was used. A significant main effect of congruency was found ($F_{(1, 29)}$= 37.42, p = .00001, η^2=.56), showing that in

congruent trials participants were faster compared to the incongruent trials. The main effect of labelled background was not significant ($F_{(2, 58)}$=1.31, p= 0.277, η^2=.043) (Fig. 4.8). Importantly, there was an interaction between condition and labelled background ($F_{(2, 58)}$=6.21, p= 0.003, η^2=0.17). Pairwise comparisons showed that the congruency effect for trials with the labelled background "you" was significantly smaller (22 ms) when compared to trials with "stranger" (44 ms, p=.001). Trials with the labelled background "friend" also showed a smaller congruency effect (32 ms) when compared to "stranger" (p=.026). Labelled backgrounds "you" and "friend" did not show a statically significant difference (p=.17). Crucially, post-hoc analyses (Newman-Keuls test) showed that the difference in the congruency effect relies on the difference among incongruent trials rather than the congruent. The results showed that participants were faster in incongruent trials when the labelled background was "you" compared to "stranger" (p=0.01). The difference among incongruent trials with the labelled background "friend" compared to "you" or "stranger" did not reach statistical significance (p>0.390). For congruent trials, there was no difference among labelled backgrounds (p>.32). I also carried-out a 2x3 repeated measures ANOVA having congruency and colour as within-subject to test for an unpredicted colour effect. Indeed, the colour effect did not reach statistical significance ($F_{(2,58)}$= .97, p =.382, η^2=.03).

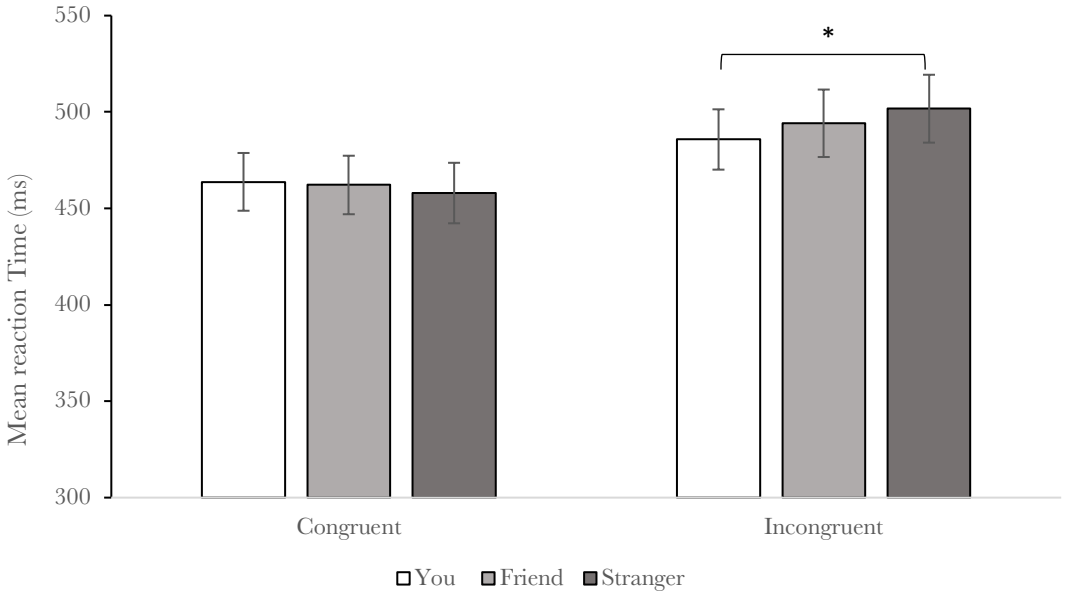


Figure 4.8. Mean RTs for each condition (congruent and incongruent) and each label (you, friend and stranger) in Experiment 4.2 (error bars represent the standard error of the mean). *p=.01.

Distribution of Reaction Times

I carried-out a 3x5 repeated measures ANOVA on the RT congruency effects with labelled background and quintile (1 – 5) as within-subjects factor. The analyses revealed a main effect of labelled background ($F_{(2,58)}$=3.73; p=.030; η^2=.11). Most importantly, there was no interaction between labelled background and quintile ($F_{(8,232)}$=.37; p=.93; η^2=.01) (Fig. 4.6). Post-hoc analyses (Newman-Keuls test) showed that the congruency effect with labelled background "you" was significantly smaller compared to "stranger" (p=.01), and "friend" was smaller than "stranger" (p=.03). There was no significant difference between "you" and "friend" (p=.88).

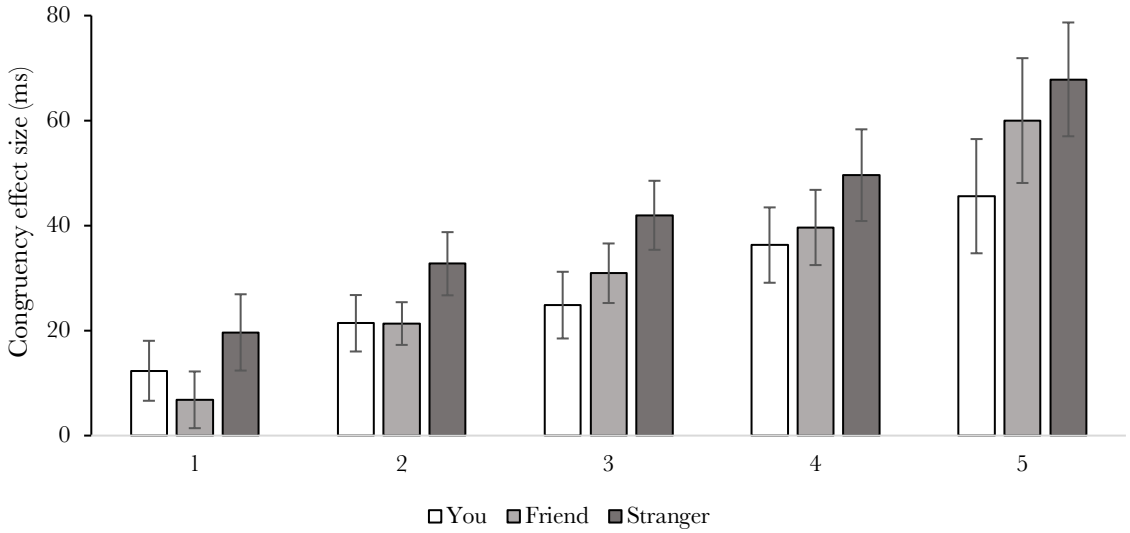


Figure 4.9. Mean of the congruency effect for each labelled background across all the five quintiles in Experiment 4.2 (error bars represent the standard error of the mean).

Combining Experiment 4.1 and 4.2

To test for a global effect between Experiment 4.1 and 4.2, I added an additional factor of experiment (agent explicitness), whose main effect can be tested as well as its interaction with the remaining factors (congruency and labelled background). Therefore, I carried-out a 2x3x2 mixed design ANOVA having congruency and labelled background as within-subjects factors and experiment (4.1 and 4.2) as a between-subjects factor. The results revealed an effect of experiment ($F_{(1,58)}$= 9.95, p =.003, η^2=.14), showing that Experiment 4.1 had faster RTs (mean= 416.8 ms, SE=13.6) compared to Experiment 4.2 (mean= 477.5 ms, SE=13.6). There was also a main effect of congruency ($F_{(1,58)}$= 71.00, p =.0001, η^2=.550), showing that congruent trials had faster RTs (mean= 432.8 ms, SE=9.11) compared to incongruent (mean= 461.6 ms, SE=10.38). No main effect of label was found ($F_{(2,116)}$= .74, p =.47, η^2=.01). Importantly, the interaction between label and congruency was highly significant ($F_{(2,116)}$= 7.40, p =.001, η^2=.113). Pairwise comparisons confirmed that the congruency effect for trials with the label "you" was significantly

smaller (21 ms) when compared to trials with the label "stranger" (37 ms, p=.0001). Also, the congruency effect for trials with the label "friend" was significantly smaller (27 ms, p=.005) when compared to trials with the label "stranger", but the difference with label "you" did not reached statistical significance (p=.16). The factor of experiment did not interact with congruency (p=.26) or label (p=.44).

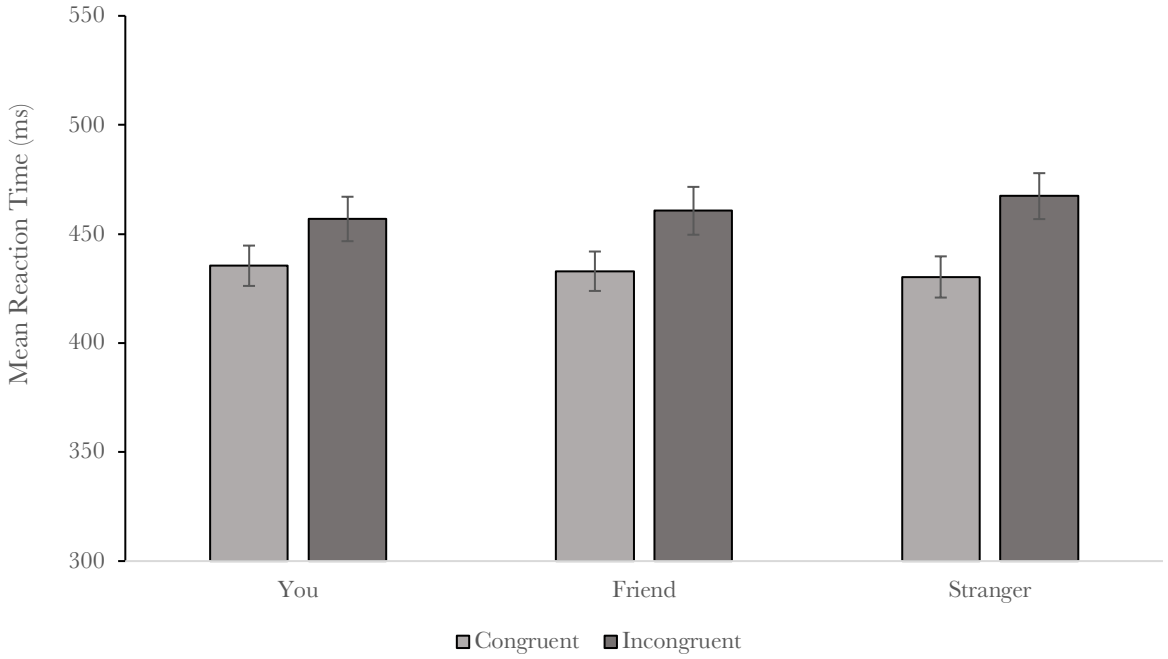


Figure 4.10. Mean RTs for each condition (congruent and incongruent) and each labelled background (you, friend and stranger) of the combined data from Experiment 4.1 and 4.2 (error bars represent the standard error of the mean).

4.3.3 DISCUSSION

Experiment 4.2 addressed the modulation of automatic imitation by a prominent self stimulus via establishing an explicit relationship between the labelled background and the agent of the task-irrelevant movement. I expected that participants would face a great conflict during incongruent trials with the "self" as agent due to the task-irrelevant movement being different from the intended one, leading to a greater congruency effect. In trials where the agent is a "friend" or a "stranger" this conflict should not be as strong

because no a priori correspondence between the participant's own intentions and the observed action was expected.

Importantly, our results pointed in the opposite direction. The congruency effect for trials with the label "you" was significantly **smaller** than the label "stranger", the same direction of effect seen in Experiment 4.1 in which there was no explicit manipulation to encourage participants to treat the background colour as indicating who was the owner of the hand displayed. Moreover, the difference in the congruency effect relies on the difference among incongruent trials rather than the congruent trials. Results from Experiment 4.2 showed that participants' performance was not modulated differently as a function of their "own" or "another hand" executing the same action they intended to execute (congruent trials). Instead, when the action seen was different from the one they had to execute (incongruent trials), the "stranger's hand" had, surprising, a stronger effect on participant's performance compared to their "own" hand.

Participants had a slower RT compared to Experiment 4.1, which could be explained by a working memory load, since participants had to keep the information of another task - who was the movement's agent - throughout the trial. This was verified by the high accuracy of responses to the question "Whose hand did you see previously?". Also, the slower RTs can help explain why the interaction between congruency and quintile was not significant. Since the automatic imitation effect and its modulation is greater at slower RTs, the first quintile of the RT's distribution was already slower enough to show the modulation.

Taken together, Experiments 4.1 and 4.2 showed that the colour-label association built during the self-bias task was enough to modulate participant's perception of the task-irrelevant stimulus, and it was independent of the agent explicitness. Crucially, the results of Experiments 4.1 and 4.2 are based on an experimental design where participants saw

the opposite hand being used and, consequently, the "imitative" response would also be spatially compatible with the movement (e.g., observed left-index finger movement would be on the left side, compatible with participant's right hand index-finger side). Thus, considering the overlap between automatic imitation and spatial compatibility effects that occurs in both experiments, in Experiment 4.3 I asked whether the "you"- vs. "stranger"-related information would still modulate the automatic imitation effect when this confound is controlled. Specifically, I wanted to test whether both effects are modulated by self-related information in the same manner. Therefore, I created stimuli that allowed us to control for spatial compatibility effects and isolate them from automatic imitation.

4.5 Controlling for spatial compatibility

Experiment 4.3

Experiment 4.3 follows the same experimental design as Experiment 4.2 with the addition of the spatially-controlled hand stimulus. In Experiments 4.1 and 4.2, the spatial and anatomic perspective were overlapping, e.g., the task-irrelevant index finger displayed in the background was on the left side of the space, as was the participant's (right-hand) index finger. This spatial compatibility is known to interfere positively with the automatic imitation effect. Therefore, I sought to determine whether the modulation of the congruency effect by self-related information found in Experiments 4.1 and 4.2 is due to spatial compatibility or an automatic imitation effect. Considering that the two effects have different dynamics, e.g., imitative congruency follows a different time course from spatial compatibility (Catmur & Heyes, 2011), I expected to find a smaller congruency effect and a greater label modulation in trials where spatial compatibility did not overlap with imitative congruency.

4.5.1 METHODS

Apparatus and Material

The same apparatus and material as in Experiment 4.2 were used here with the addition of an extra set of stimuli showing a right hand from a third-person perspective. The videos were created by reflecting the images of the left hand (from Experiment 4.2) in the y-axis and were identical to the videos with the left hand in all other respects. Therefore, the stimuli consisted of an animated hand that was positioned either with a spatially compatible relationship, i.e., a left hand where the index finger is presented on the left side of space, and with a spatially incompatible relationship, i.e., opposing anatomical and spatial relationships, such as a right hand where the index finger is presented on the right side of the space (top row of Fig. 4.11).

Design and Procedure

The experimental design was very similar to Experiment 4.2, where the agent of the task-irrelevant stimulus movement was explicit. However, Experiment 4.3 had, in addition to the imitative congruency between imperative stimulus and participant's response, two different types of trials regarding the spatial compatibility between task-irrelevant stimulus and participant's response. Spatially compatible trials consisted of a left hand displayed in a third-person perspective (as in Experiment 4.2) where spatial relationships align with the spatial relationships regarding the participant's response perspective, e.g., an index finger displayed on the left side of space and a participant's' index finger response required (left side of the space, right hand). Spatially incompatible trials consisted of a right hand displayed in a third person perspective where spatial relationships do not align with the spatial relationships regarding the participant's

response perspective, e.g., an index finger displayed on the right side of space and a participant's' index finger response required (left side of the space, right hand).

Therefore, to maintain numbers of trials per condition, Experiment 4.3 involved 336 trials with two types of compatibility (spatially compatible and spatially incompatible), two congruencies (imitatively congruent and imitatively incongruent) and three different labels (you, friend and stranger) equally distributed. Trials were sampled in a random sequence with no replacement. Trials where participants responded incorrectly to the question regarding the agent of the movement were excluded and were not further analysed (less than 1%).

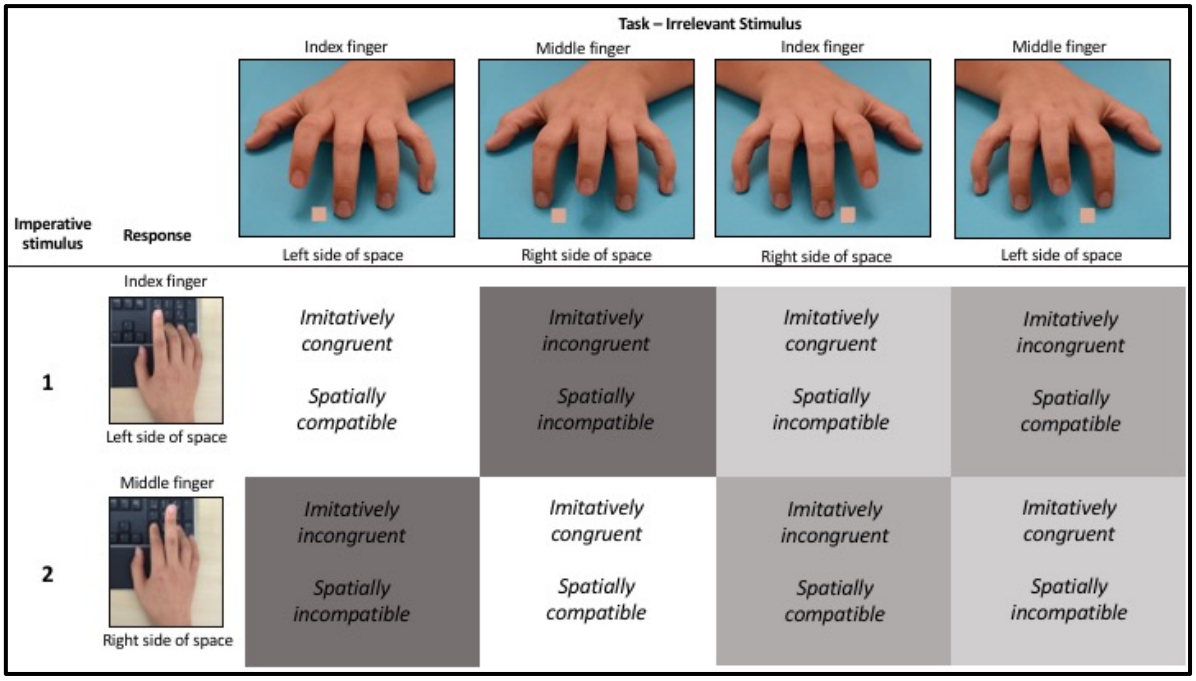


Figure 4.11. Imitative and spatial relationship of trial types used in Experiments 4.3. Responses were always made with the right hand. The four trial types are indicated by different levels of shading.

4.5.2 RESULTS

Accuracy

Mean accuracy was calculated for all spatial compatibilities, congruencies and labelled backgrounds for each participant. Accuracy was analysed using a 2x2x3 repeated-measures ANOVA having spatial compatibility, imitative congruency and labelled background as within-subject factors. There was a main effect of imitative congruency ($F_{(1,29)}$ = 12.11; p =.002; η_p^2 =.30), indicating that participants had a higher accuracy in congruent trials compared to incongruent trials. There was also a main effect of labelled background ($F_{(2,58)}$ = 4.25; p =.02; η_p^2 =.128) where pairwise comparison indicated a higher accuracy for trials with the labelled background "you" compared to trials with "stranger" (p=.02). There was no main effect of spatial compatibility ($F_{(1,29)}$ = .11; p =.73; η_p^2 =.004). Importantly, there was a significant interaction between spatial compatibility and congruency ($F_{(1,29)}$ = 14.51; p =.001; η_p^2 =.33). Pairwise comparison revealed that there was a congruency effect only on trials that involved spatially compatible stimuli (p<.001) but not on trials with spatially incompatible stimuli (p=.32) (Fig. 4.12). The interaction between congruency and labelled background was not significant ($F_{(2,58)}$ = 2.15; p =.12; η_p^2 =.06). No further interaction reached statistical significance (p>.08).

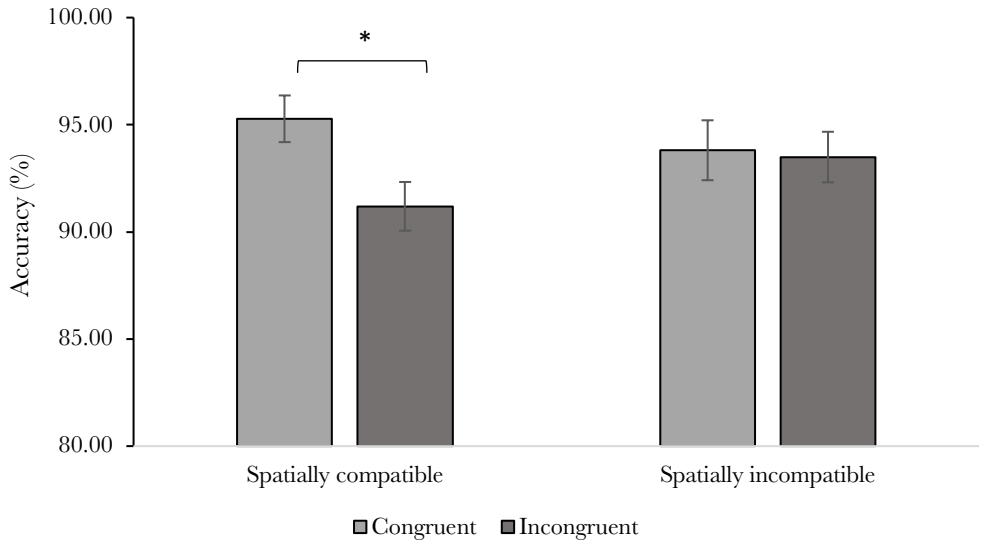


Figure 4.12. Mean accuracy for both spatial compatibilities in each congruency condition (congruent and incongruent) in Experiment 4.3 (error bars represent the standard error of the mean). *p<.001

Reaction time

RTs were analysed using a 2x2x3 repeated-measures ANOVA having spatial compatibility, congruency and labelled background as within-subject factors. There were no main effects of spatial compatibility ($F_{(1,29)}$=.01; p =.97 1; η^2=.00) or congruency ($F_{(1,29)}$=2.19; p =.15 1; η^2=.07). There was, however, a main effect of labelled background ($F_{(2,58)}$= 3.35; p = .04; η^2=.10). Post-hoc analyses (Newman-Keuls test) showed that in trials where the label was "you", participants were faster (mean= 475.88 ms; SE=13.93) than in trials with the label "stranger" (mean=482.45 ms; SE=14.56). Crucially, there was an interaction between spatial compatibility and congruency ($F_{(1,29)}$= 84.0; p< .0001; η^2=0.74). Pairwise comparison showed that there was congruency effect for trials with spatially compatible stimuli (29 ms) and a reversed congruency effect for trials with spatially incompatible stimuli (-20 ms) (Fig. 4.13). The interaction between congruency and labelled background was not significant ($F_{(2,58)}$ = .86; p =.42; η_p^2 =.02). No further interaction was found (p> .31). I also carried out a 2x2x3 repeated measures ANOVA

having compatibility, congruency and colour as within-subject to test for an unpredicted colour effect. The colour effect was not significant ($F_{(2,58)}$= .0075; p =.978; η^2=.002).

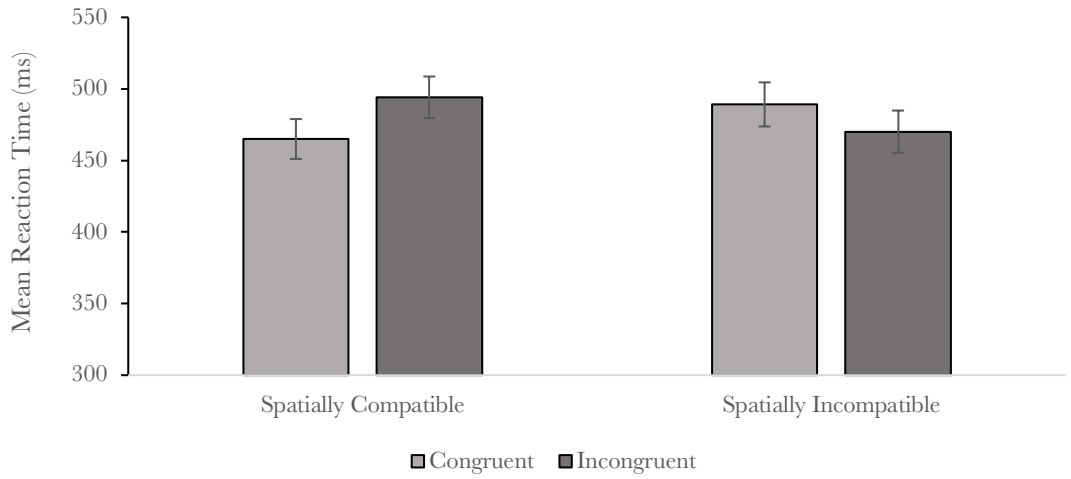


Figure 4.13. Mean RTs for each imitative congruency condition (congruent and incongruent) for both spatial compatibilities in Experiment 4.3 (error bars represent the standard error of the mean).

Distribution of reaction times and congruency effect

Following the same rationale to analyse the congruency effect across reaction time quintiles, I calculated the imitative congruency effect for each spatial compatibility condition, labelled background, and for each of the five quintiles. I carried-out a 2x3x5 repeated measures ANOVA with spatial compatibility, labelled background and quintile (1 – 5) as within-subjects factor. Consistent with the previous analysis, there was a main effect of spatial compatibility ($F_{(1,29)}$=47.18; p=.0001; η^2=.62), showing that in trials where the task-irrelevant stimulus was spatially compatible, the congruency effect was greater compared to spatially incompatible trials (where the congruency effect was negative). Post-hoc analyses (Newman-Keuls test) showed that at the slowest RTs (quintile 5), participants had an overall congruency effect significantly larger than all the others (p< .038). This can be explained by the interaction between spatial compatibility and quintile

($F_{(4,116)}$=3.44; p=.011; η^2=.10). Pairwise comparisons showed that in the first four quintiles (1-4), the congruency effect differed between spatial compatibilities (p=.0001). However, the most interesting result is that in the slowest RT bin the congruency effect was numerically positive for both spatial compatibilities and, therefore, not differ reliably between the two spatial compatibilities (p=.56) (Fig. 4.14).

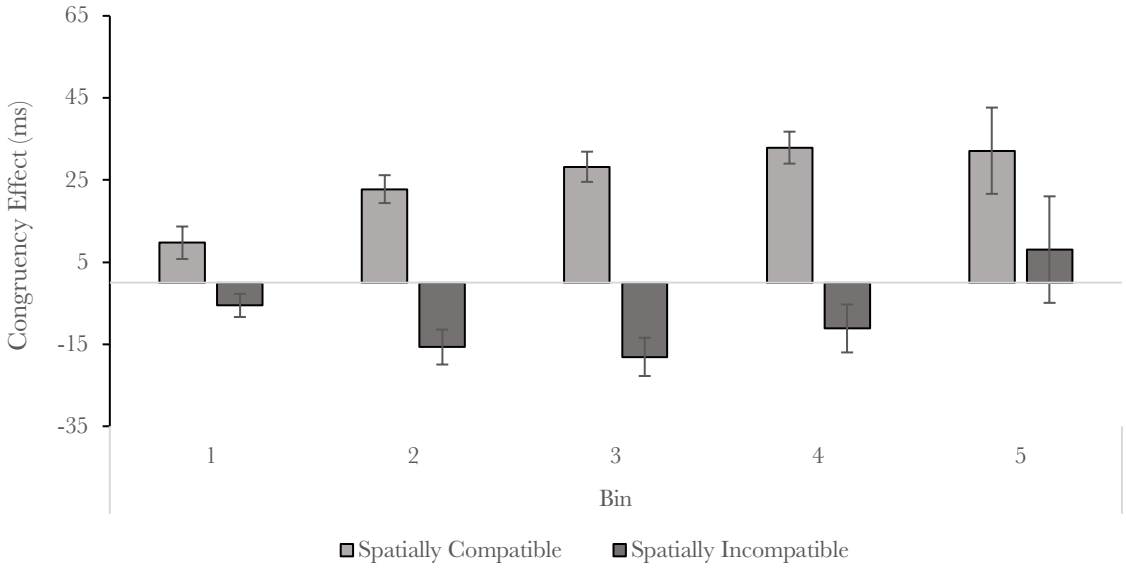


Figure 4.14. Size of the congruency effect for the two spatial compatibilities across the five quintiles (1 = fastest RTs, 5 = slowest RTs) in Experiment 4.3 (error bars represent the standard error of the mean).

Although the previous analyses show a main effect of labelled background, this factor did not show a significant interaction with other factors and, therefore, it limits any conclusion regarding the congruency effect being modulated by the labelled backgrounds, as shown by Experiment 4.1 and 4.2. However, as seen previously, this modulation occurs mostly at the slowest RTs and, it is possible this effect did not have enough power to be shown in this experimental design. Interestingly, in a qualitative analysis of the pattern of distribution of the congruency effect for "you" and "stranger" across all quintiles (Fig. 4.15), it is possible to see that, in the two slowest RT bins, the congruency effect for the labelled background "you" starts to increase and, finally becomes positive at quintile 5

(15.8 ms). This increase of the congruency effect in spatially incompatible trials means that participants started to respond faster to congruent stimuli in comparison to incongruent stimuli. It also means that the automatic imitation effect started to overcome the spatial compatibility effect. This pattern starts to occur to the labelled background "stranger" later at quintile 5, but it is still not enough to become positive (-11 ms).

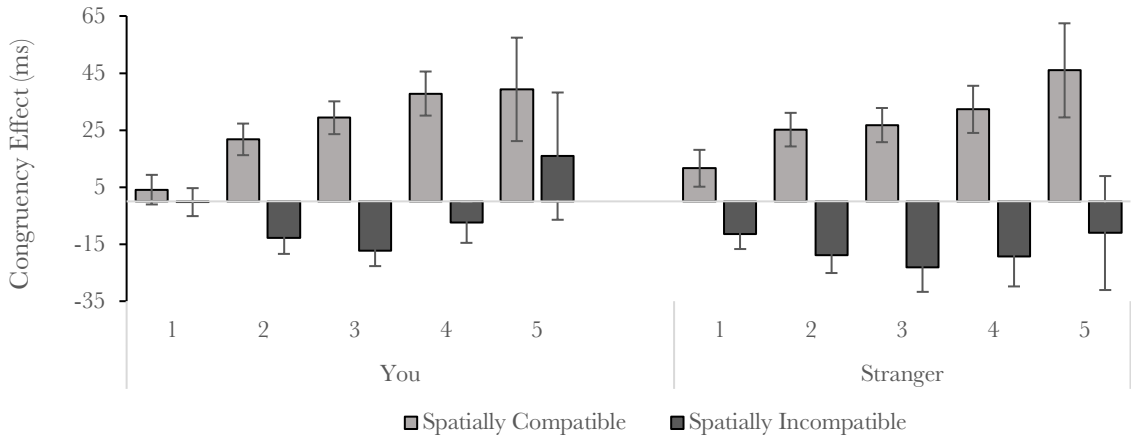


Figure 4.15. Size of the congruency effect for the two spatial compatibilities across the five quintiles (1 = fastest RTs, 5 = slowest RTs) showing labelled background "you" and "stranger" in Experiment 4.3 (error bars represent the standard error of the mean).

4.5.3 DISCUSSION

Experiment 4.3 investigated whether the modulatory effect of agency on automatic imitation would persist when controlling for spatial compatibility. Analysis of accuracy data showed an imitative congruency effect only on trials where there was also spatial compatibility. RT measures, on the other hand, did not show a main congruency effect. In terms of self-related information, participants were more accurate in trials with the labelled background "you" compared to "stranger". Nonetheless, participants were faster in spatially compatible trials and when the labelled background was "you" compared to "stranger". Overall, spatially compatible trials were more accurate and faster

when compared to spatially incompatible trials. I did not replicate the results from Experiments 4.1 and 4.2 regarding the difference in the congruency effect for labelled backgrounds "you" and "stranger". A quintile analysis was carried-out to further explore the congruency effect dynamics but the labelled background effect was not found in this analysis either. It was possible, however, to show that the imitative congruency effect increased as RTs increased in spatially compatible trials and it remained almost constant in spatially incompatible trials (around 0 ms). Further, a significant decrease of difference between the two spatial compatibilities regarding the congruency effect occurred only at the slowest RTs. A qualitative analysis of the data suggests that self-related information may play a role at the slowest RTs and the modulation of the congruency effect depends on spatial compatibility as well. However, this conclusion can only be made very tentatively given the lack of statistical significance of the relevant contrasts in the analysis.

4.6 General Discussion

The set of experiments described in this chapter investigated whether a perceptual bias towards the self, built through the perceptual matching task, could modulate the processing of a task-irrelevant stimulus and, therefore, modulate the automatic imitation effect. I used a perceptual learning approach (Sui et al., 2012) in which participants associated labels for themselves (i.e., you), a familiar person (i.e., friend), or an unfamiliar person (i.e., stranger) with colours, and then immediately judged whether subsequent label–colour pairings matched. The three experimental groups demonstrated a substantial advantage for matching colours to a self-related label relative to when the colours were linked to familiar others and/or to an unfamiliar person. This advantage was supported by a distinct RT–accuracy distribution relative to other conditions and

generally in an improved d-prime. There was an advantage also for associations to familiar others (best friend) when compared with associations to unfamiliar person (stranger), although this effect was less robust than the self-advantage. The effects of the enhanced perceptual salience of self-related information was then tested in a subsequent automatic imitation task.

The automatic imitation task, adapted from Brass et al.'s (2001) experimental design, displayed a hand with a task-irrelevant moving finger in a background coloured with one of the three colours used in the self-bias task. Participants were not informed (Experiment 4.1) or were explicitly instructed (Experiments 4.2 and 4.3) about the relationship between the agent of the task-irrelevant finger movement (themselves, the best friend or the stranger) based on the associations from the self-bias task. Experiment 4.3 tested whether this modulation would be independent of spatial compatibility. I expected that adding the colours to the stimulus background, each one related to one of the labels, would enhance the task-irrelevant stimulus, when the colour-label association was explicit but not when it was not mentioned to participants. The important point is that on incongruent trials with self-related information, the enhanced stimulus conflicts with participants own intentions, i.e., their "own" moving hand makes a movement different from the intent one. In trials with information related to a "friend" or a "stranger", this conflict would be minimised by reduced or absent expectation of correspondence and coherence between the actions of two people. Therefore, greater task-irrelevant processing would lead to a greater interference when responding to the imperative stimulus and, thus, a greater congruency effect in the "self" condition.

Our results showed that a significant perceptual bias was carried-out from the self-bias task as evidenced by Experiment 4.1 and 4.2. It provided a modulation of the automatic imitation effect and it was stronger when it was reinforced each trial, through

a probe question regarding the agency of the finger movement. However, different from what I predicted, participants had a greater automatic imitation effect when presented with information about the "stranger" in comparison to information about the "self". Interestingly, when dissociating spatial compatibility from the imitation effect (Experiment 4.3), this modulation was not clear, even though trials with self-related information had overall faster RTs.

In line with previous evidence that the imitative congruency effect increases as RTs increases (Caroline Catmur & Heyes, 2011), most of our findings reached significance at the slowest RTs. Indeed, in Experiment 4.1, the difference in the congruency effect between "you" and "stranger" reached statistical significance only in the slowest RT quintile. It is also in the last quintile that the difference of both effects addressed in this chapter, automatic imitation and spatial compatibility, became clearer (Experiment 4.3). Importantly, but still speculative, is the dissociation of those effects in trials with self-related information earlier than in trials with stranger-related information. In quintile 5, on trials with spatially incompatible stimuli and with self-related information, the congruency effect is positive (congruent trials faster than incongruent) and is more than 26 ms greater than the congruency effect in trials with stranger-related information. It means that, when presented with information about the "self", participants had a greater automatic imitation effect and managed to overcome the spatial compatibility effect, which would lead them to respond faster to ipsilateral stimuli instead of the anatomically congruent one. Moreover, when presenting participants with stranger-related information, it seems that there was a tendency to the same effect, but the results did not reach statistical significance and are still inconclusive. In the following, I discuss the implications of each of these findings.

It is difficult to differentiate whether the sense of agency contributed to the effects I found regarding the congruency effect and the label "you" and "stranger". In Experiment 4.1 I had a clear interaction between the congruency effect and the labels when I looked at the slowest RTs. In contrast, Experiment 4.2 had an overall significant interaction. One can argue that the sense of agency enhanced the interaction effect and, therefore, it is essential to modulate the congruency effect. However, Experiment 4.2 had overall slower RTs and, a plausible cause could be because of the greater working memory load necessary to respond to the question about the agent's movement. It is possible that adding the sense of agency in a question slowed responses favouring the interaction significance rather than causing it.

Also, according to the literature (Caspar, Cleeremans, & Haggard, 2015; Sidarus & Haggard, 2016; Vastano et al., 2017; Wenke, Fleming, & Haggard, 2010) conflict in the action selection process induced by an incongruent stimulus disrupts the course from action intention to action execution and is related to decreased agency ratings. One could argue that in our study participants were aware of who was the agent in congruent trials with the self-referenced colours, however, they did not recognize themselves as the agent in conflicting situations. In contrast, stranger-related trials do not contain the experience of controlling the task-irrelevant action, and, therefore, the sense of agency is not present at all. Nonetheless, the congruency effect was smaller in trials with self-related information compared to stranger-related colour associations. Therefore, our results suggest that, even with the sense of agency reduced in incongruent trials, self-related information still plays a role during action selection during conflicting situations. This is especially important in the context of the self-other distinction, providing evidence of a control-inhibition mechanism that goes beyond agency. It would be important, however, to test this hypothesis using a similar experimental design including baseline conditions, so it could

be determined whether the prominent-self modulation occurs facilitating (congruent trials) or delaying response (incongruent trials).

Furthermore, the faster RTs in trials with self-related information suggest that that enhanced self-focus/awareness does not reduce the processing of task-irrelevant stimulus by focusing on the imperative stimulus. If this was true, in congruent trials, there should be a difference between trials with self or stranger-related information in the same way as in incongruent trials. However, our results showed no difference in congruent trials across the labelled backgrounds.

Importantly, our results are in accordance with those found by Spengler et al. (2010), where they directed attention towards the self before the actual task was presented. However, differently from Spengler et al. (2010), our results showed that the control of imitative tendencies occurs even when the source of self-related information is highly conflicting with immediate intentions (cued by the imperative stimulus). Thus, one possibility is that the modulation of the congruency effect by self-related information is based on self-focus/awareness rather than task-irrelevant movement's agency and the conflict it induces. Accordingly, in trials with friend or, mainly, stranger-related information, self-focus is not enhanced and, therefore, participants have less control on inhibition of imitative tendencies. Interestingly, these results are consistent with functional brain imaging data (Spengler, Von Cramon, & Brass, 2009), where it was revealed that there are overlapping brain circuits of self-referential thoughts and mentalizing processes with the ability to execute their own motor intention under a condition of motor contagion.

Lastly, Experiment 4.3 raised an important question about whether self-other related information plays different roles when modulating the inhibition of imitative and overlearned responses. There was a small numerical trend towards a weaker effect of

spatial (in)compatibility when responding to self-related compared to stranger-related information. However, the lack of statistical significance for the interaction of congruency and labelled background does not allow us to safely conclude any special modulation. Further studies where general spatial attention is controlled (e.g., towards imperative/task-irrelevant stimulus) might provide insight into how self-related information can direct visual attention in two spatially different scenarios.

In conclusion, the present findings demonstrate that a simple self-referential stimulus, such as new self-colour associations can be effective in triggering self-focus in an imitation-inhibition task, privileging self-related information. The consequence of this is a reduced congruency effect for observed actions on self movement. The consequence of this self-focus in the present studies was a reduced sensitivity to observed movements (as shown by a reduced imitative congruency effect), rather than as an increased tendency to treat observed movements as self-generated (which should increase the imitative congruency effect).

Chapter 5

General Discussion

The research presented in this thesis has investigated perception-action coupling in terms of the modulation of response selection and execution processes by the perception of object affordances, automatic imitation and action agency. The current chapter will tie together the findings and their theoretical implications, while also considering limitations of the research presented. I first summarize the experimental findings presented in the previous chapters and will explore how these findings can help to answer the research questions outlined in the introduction. Further, the limitations regarding those findings will be flagged and future avenues to explore will be suggested.

5.1 Experimental findings

The work presented in this thesis addressed a number of questions regarding the modulation of response processes due to perception-action coupling when we interact with the environment and other people. I explored how studying different ways of priming an action can inform our understanding about how perception and action are coupled. These questions were investigated by combining actions primed by object affordances and actions primed in a social context, through imitation.

The experiments in Chapter 2 sought to investigate the automaticity of the action priming effect and its relationship with the awareness of object affordances. Different from the classical studies on object affordances, I addressed this relationship through attentional effects to avoid SRC effects as a confound. In Experiment 2.1, I asked whether the object-affordance relationship needs to be explicit to direct visual attention towards an action-related stimulus in a perceptual discrimination task. The result suggested that, at least for error rates, when the relationship between an object and its action-related stimulus is explicit, affordances can elicit an attentional bias towards a representation of

the action that a recently seen object affords. RT measures, on the other hand, did not reach statistical significance. An unexpected interaction between object size and compatibility, with the predicted effects only observed reliably when the primes were small objects requiring a precision grip, raised questions about the type of target used and a possible sub-optimal target/distractor stimulus set. Because the majority of trials were compatible, it was not possible to establish if the observed effect was due to a real object-affordance influence on visual attention or a contextual cueing effect.

In Experiment 2.2 I tried to circumvent this issue by varying the predictability of the object-grip corrected correspondence pair. The experiment was divided into three groups based on the predictability of the target being presented surrounding (or not) an affordance-congruent hand grip image. The rationale was to distinguish a congruency effect, brought about by an affordance relationship, from a contextual cueing (predictability) effect, where the association between the two visual stimuli is simply based on a highly frequent contingency. The compatibility effect was, again, confirmed by error rates measures. Interestingly, a common feature present in all conditions in the three groups, regardless of predictability, was a shorter RT when the picture surrounded by the target was a precision grip, what I referred to as a "precision grip stimulus effect". The results from the 50:50 group were crucial to analyse the congruency effect because contingency learning should have virtually no role, since the proportions of congruent and incongruent trials were equal. Indeed, this group was the only one to show a significant compatibility effect for small objects. In the 80:20 group, the positions of most of the targets could be predicted based on a contingency **and** action priming effects. However, surprisingly, no compatibility effect for either object size was found. The 20:80 group, where I expected a smaller compatibility effect (if any), showed a significant inverse

compatibility effect in trials with large objects, favouring the precision grip stimulus effect but, crucially, this pattern did not occur in trials with small objects.

Taken together, the results of Chapter 2 indicate that object affordances can direct attention to action-related images depicting congruent actions, resulting in improved accuracy (but inconclusive effects on RT) when a visual search target appeared next to those action images. An important point of this investigation is that, here, no similar action or spatial compatibility is required in the visual search task, so that the imperative stimulus and its correspondent response is not related to any kind of action representation the object could prime. Instead, I measured object priming via attentional modulation towards a task-irrelevant stimulus. In this way, the results demonstrate perception-action coupling in terms of object affordances biasing visual search, independent of the confounding effects of SRC relationships.

Chapter 3 focused on the temporal aspects of automatic imitation investigating the stage of information processing at which the interfering effect of viewing a response-incongruent action takes place. Experiment 3.1 defined, based on Brass et al. (2000), the experimental design model for the subsequent experiments. I varied the stage of processing of one stimulus (e.g., an observed task-irrelevant action) in relation to the other (the imperative stimulus) in order to determine the temporal windows where response selection and execution can be affected. Experiment 3.1 found results consistent with the original study reported by Brass et al. (2000), providing evidence of a compelling influence of observed finger movements on the action executed by the participant, even when this visual stimulus is totally irrelevant for the task. Experiment 3.2 demonstrated the stages of the response selection process where the task-irrelevant stimulus can still interfere as well as the nature of this interference. The results showed a decay of the congruency effect when an interval of 136 ms or longer separated the onset of the imperative stimulus and

observed action, mostly due to an increase of the RT for congruent trials. Together, the results from Experiments 3.1 and 3.2 allowed me to address the question of positive and negative interference, either because of a direct comparison with baseline condition with no observed movement (Experiment 3.1) or a difference in the temporal dynamics of congruent and incongruent trials. The results showed, at least for RT measures, that automatic imitation effects were more consistently observed in terms of a facilitation effect from congruent observed actions rather than a cost when observed actions are incongruent with required responses. Experiment 3.3 explored more closely the stages of information processing during an automatic imitation task. Here, trials were initiated with a cue, giving participants 100% valid information about which response would be required. The idea was to anticipate the process of response selection in such way that the response could be selected beforehand. In Experiment 3.3, the task-irrelevant stimulus interference was found to prevail, resulting in a significant automatic imitation congruency effect, even considering that participants could fully complete the required response selection before onset of the imperative stimulus. The results suggest that I have gone beyond the process of response selection, invading the limits of response execution. In this sense, Chapter 3 demonstrated that the automatic imitation effect interferes not only with response selection but also with response execution, therefore providing new evidence of the reach of perception-action coupling effects. However, I cannot discard the possibility of a *continuum* between the processes of response selection and response execution. In this sense, it can be the case that the process of selecting the appropriate response was, at its latest stages, overlapping the early stages of response execution. These findings support the idea of a strong coupling between the perception of an action and the processes of preparing to respond. The selection and execution of a response are subject to a continuous flow of information that can modulate its final results.

In Chapter 4 I asked whether a prominent self stimulus could modulate the processing of task-irrelevant observed movements and, therefore, modulate the automatic imitation effect. To induce self-bias, I used the paradigm introduced by Sui et al. (2012), based on a simple associative matching procedure between colours and labels corresponding to self, a familiar other person and a stranger. A subsequent automatic imitation task was performed with no explicit agent of the task-irrelevant finger movement (Experiment 4.1) and in a situation where the agent of an observed finger movement was explicitly instructed (Experiment 4.2). The important point in this study was the type of processing in incongruent trials with self-related information. In these trials, the observed action stimulus conflicts with participants own intentions, i.e., their "own" moving hand makes a movement different from the intended one. The results showed that the colour-label association built during the self-bias task was enough to modulate participants' perception of the task-irrelevant stimulus independent of agency awareness. Participants' performance was affected when the action seen was different from the one they had to execute (incongruent trials). Specifically, the "stranger's hand" had the strongest effect on participant's performance. In Experiment 4.1, where overall task RTs were shorter, this effect only appeared in an analysis of the distribution of the congruency effect across 5 bins. In Experiment 4.2, with slower overall RTs, the effect was more clearly apparent across RT bins, and again showed a smaller congruency effect for trials with the self label than with the label "stranger". Importantly, in Experiment 4.3, where spatial compatibility was dissociated from imitative compatibility, the results suggest that participants were less affected by spatial (in)compatibility when responding to self-related compared to stranger-related information. However, the lack of statistical significance does not allow us to safely conclude any special modulation.

Taken together, these findings argue for a strong relationship between perception and action affecting the response process. Actions can be primed by the perception of either object affordance properties or by the perception of actions performed by others.

5.2 Limitations

The preceding section summarises the results of the experiments presented in this thesis. However, limitations of this research should be acknowledged, including relating to unexpected details of the results observed as well as the overall methodology adopted. A first and clear limitation comes from Chapter 2, where the predicted effects of attentional capture by primed action-related stimuli was only observed for one of the stimulus types used. The mixed results for large objects and power grip, in contrast to the clear effects observed for small objects and precision grips, argue for a better controlled set of stimuli where the correspondence between object and grip could be maximized. The pre-selection of the object-grip pairs was done based on a real interaction with the object, whereas the experiment accesses a declarative relationship established by the participants. Since there will always be a chance for discrepancy between what we judge an object affords and its real affordances in a specific context, this experiment should have made the object affordances explicit by the same way the object-grip pairs were selected, i.e., the selection should have been done based on the answers to the same question done during the experiment. Furthermore, the object and grip stimuli presented some overlapping features regarding specificity. Some objects, like a flask, for instance, can afford a precision grip if it is handled by the lid, or a power grip, if handled by the bottle. Also, the power grip can be seen as an early stage of the precision grip. Therefore, the extent of our conclusions regarding the coupling between the affordance of an object and

its correspondent action are limited. The evidence of a congruency effect found to the pair small object – precision grip should be interpreted with caution and the effects found for the pair large object – power grip analysed considering each experiment individually.

The results from Chapter 3, suggesting an effect of a task-irrelevant observed action not only on response selection but also on response execution, can be interpreted only for tasks where imitative and spatial compatibilities are directly combined. This is a limitation that was addressed on Chapter 4, which used the same automatic imitation rationale. Although there is evidence that automatic imitation and SRC effects are different (Catmur & Heyes, 2011; Cooper, Catmur, et al., 2013), it is not possible to disentangle both effects within the experimental design used in Chapter 3, even if the results clearly demonstrate that task-irrelevant stimuli can interfere with response execution in some way. It can be the case that it only occurs when I have SRC potentiating the automatic imitation effect.

The results from Chapter 4 clearly demonstrate that automatic imitation effects can be modulated as a function of self-related information. However, it is not possible to understand to what extent self-related information exerts this influence by facilitating vs. interfering with a response (when congruent or incongruent, respectively). The experimental design did not contain baseline trials to allow for this comparison. Also, it is important to consider that agent-related stimuli were generated in a perceptual matching task that resulted in a self-bias, i.e., an advantage for self-labelled compared to other-labelled stimuli. Therefore, our conclusions should be taken cautiously due to the fact that the self-related stimulus, i.e., the colour, was already processed differently from "friend" and "stranger" stimuli. It is possible that our results reflect a smaller congruency effect in trials with self-related stimulus as a function of its perceptual bias rather than its concept of self.

In Experiment 4.3, it was possible to see a difference between the two spatial compatibilities regarding the congruency effect more across the first four RT quintiles. The lack of difference at the fifth quintile can only suggest that both compatibilities have different temporal dynamics, consistent with previous literature. Therefore, it is not possible to infer conclusively whether self-related information plays a role at the slowest RTs independently of spatial compatibility.

It would be interesting to see to what extent the present findings can be applied to a broader context than the specific set of tasks and actions considered in the experiments of this thesis. An important point is that here I considered effects limited to movements driven by stimuli and not voluntary initiated. The effect of actions primed by affordances could be addressed in a more ecologically valid design where actions and affordances are embedded in natural environments with self-initiated movements. Also, actions priming action execution should also be addressed including movements of different effectors, e.g., arm and feet movements. Further, these effects could be contrasted considering other motor domains. For instance, the motor theory of speech perception (Galantucci, Fowler, & Turvey, 2006; Möttönen & Watkins, 2009) offers a robust framework to test the extent of action execution modulation by action perception. Considering that speech recognition may critically depend on identifying the articulatory movements that are used to produce the speech signal, an important question is to what extent action execution (production of speech) can be affected by the perception of similar actions.

An important analytical aspect that might have had a relevant impact on our results is statistical power, which depends on several crucial empirical factors such as experimental design, variance in sampled data, effect sizes and sample sizes. Here, relatively small effect sizes in some experiments as well as a reduced number of participants in some experimental groups may have contributed to statistically significant

effects not being detected due to low statistical power. This analytical difficulty impacts negatively the detection of significant main effects and the detection of interactions even more so (Zar, 2010).

On the other hand, across our experiments, accuracy data (which are confined to lie on a scale between 0 and 100%) were measures prone to ceiling effects, increasing the likelihood of violations the assumptions of the Analysis of Variance approach used (such as normality and homoscedasticity), possibly leading to spurious significant effects. This means that accuracy measures are not sensitive indicators of experimental effects and, for this reason, more confidence should be placed in RT data than in accuracy data.

5.3 Theoretical Implications

There is a longstanding debate about the boundaries and commonalities involving perception and action. Traditional cognitive theories argue for sequential processing from perception to action (Sternberg, 1969): The perceptual system first collects sensory information to build a representation of the external world (Marr, 2010); next, this information is combined with representations of current needs and memories of past experience to make judgments and decide upon a course of response (Axten et al., 1973; Shafir & Tversky, 1995); the resulting plan is then used to generate a desired action, e.g., a trajectory for movement, which is finally achieved through muscular contraction (Keele, 1968; Miller, Galanter, & Pribram, 1960). In contrast, several perspectives such as Gibson's theory of perception, sensorimotor theories, ideomotor theories and predictive coding theory suggest a strong coupling between perception and action. Consistent with the latter perspectives, throughout this thesis I have provided evidence that the perceptual

and action systems are intimately connected, not only at the individual level but also at the social level.

In the experiments presented in this thesis, the relationship between perception and action was demonstrated by the finding that object affordances can direct attention towards its correspondent action. Crucially, the results from Chapter 2 demonstrated that object affordances not only affect participants' responses, but also can direct attention towards visual representations of a related action. This broad influence of affordances clearly shows the recursive nature of the perception-action coupling, consistent with the predictive coding theory: The perception of affordances generates internal expectations about how to interact with the object, priming its related action. Once this action is primed, enhanced sensorimotor representations selectively bias bottom-up sensory information relevant to those actions via attentional modulation, leading to a reduction of prediction errors.

The results regarding automatic imitation effects further extend the findings of Catmur (2008) about the temporal dynamics of the automatic imitation effect. By decomposing the congruency effect, the results provided a better understanding of the role of the contingency between imperative stimuli and task-irrelevant observed actions on the process of selecting and executing a response. The results also provided insights about the stage at which observed actions can modulate response processing. The fact that task-irrelevant stimuli can interfere with response execution opens a debate about its interference on response selection and also about the information processing models used to explain this effect. Therefore, the results can be better explained considering the ideomotor theory, which postulates that during the presentation of the imperative stimulus, a response image is generated. Also, observing an action evokes a response image as well. Therefore, even when the response was already selected, the congruency

between the action seen and the action to be performed should facilitate response execution by activating the actual response image, whereas an incompatible action should interfere with response execution.

The results of self-related information processing in an automatic imitation task provide important evidence that the self-concept can be built through abstract perceptual association and it is enough to modulate the processing of a task-irrelevant observed movement. Crucially, the results demonstrate that this modulation is different as a function of the agent of the task-irrelevant action. Also, the results indicate that self-related information reduces sensitivity to observed movements as a consequence of self-focus (and a possible heightening of participants' own intentions) and it is in accordance with the literature. Interestingly, it was possible to demonstrate that self-focus occurred even when participants were instructed to consider observed movements as self-generated. Considering the automaticity of the automatic imitation effect, the addition of self-related information in the context of the task demonstrates that automatic imitation is, nevertheless, subject to modulation. According to Heyes (2011), participants' intentions can modulate the magnitude of automatic imitation effects by influencing the processing of the task-irrelevant stimulus (input modulation) and by influencing the extent to which motor activation of a corresponding response is inhibited (output modulation). These modulations can only occur in the intentional route (based on a dual-route model). However, it is not possible to modulate an automatic imitation effect by changing the extent to which activation of the task-irrelevant stimulus representation results in activation of the response representation (automatic route). Therefore, the coupling of perception and action in the automatic imitation effect is dependent on its inputs and outputs.

Taken together, the results reveal the extent of perception-action coupling: Its effects were demonstrated in terms of objects priming actions based on their affordances, and observed actions priming action execution; in terms of effects on perception (attention directed towards action-related stimuli) as well as response processes at different levels (selection and execution); and in terms of both spatial and effector codes.

5.4 Future Directions

There are some methodological points that might guide future studies. Chapter 2 showed the importance of a standard and normalized set of stimuli in order to compare different studies. The question regarding the "precision grip effect" could be resolved by having an experiment where the visual features of each grip are controlled. Therefore, it can be determined whether the precision grip has special features that make it more salient than the power grip. More broadly, future research could explore the generality of the attentional effects observed in Chapter 2, to test whether they can be generalised across stimulus types with different affordances (e.g., a chair, which broadly affords seating), across different task contexts (natural environments), and across different types of action beyond the specific hand configurations studied so far (e.g., using different effectors).

The current thesis has used only behavioural measures to study the relationship between perception and action. A next question would be whether similarities found on the behavioural level are also reflected in neural measures. The results described in Chapter 3 could provide a better understanding of each stage within the motor control process where automatic imitation can interfere. However, this approach would benefit from a combination of electroencephalography and functional magnetic resonance

imaging, providing information about the response temporal dynamics and its neural substrates. Moreover, it would be important to address the functional connectivity of areas related to motor control, action perception and agency in order to understand the basis for a shared representational system of perceived and internally planned actions. This would shed light into the mechanisms that allow inhibition of automatic imitative behaviour in situations where an observed action leads to the activation of a motor representation that is not intended.

The modulatory effect of the automatic imitation effect through a prominent self-stimulus indicates a modulation towards an enhanced focus on participants own intentions. However, it would be interesting to distinguish this effect from a special effect of the self and its rewarding and familiar nature. Taken together, future studies should address how perception-action coupling is dependent on the context in which it is embedded, i.e., to what extent it is sensitive to an individual's intentions, stimulus familiarity and emotional states and beliefs.

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Appendix 1

PRE-SELECTION OF OBJECT IMAGES - EXPERIMENT 2.1 AND 2.2

A pre-selection was made in order to choose everyday objects that could afford either power or precision grips. A set of 33 everyday objects were displayed on a table. Participants (n = 27) were asked to grasp and move each object at the time from one side of table to another as quickly as possible (the session was taped for subsequent analysis). When the object was grasped with the aid of the thumb and the tips of the other fingers with no contact with the palm, it was considered a precision grip. When the object was grasped with all five fingers contacting the palm or the whole surface of the fingers, it was considered a power grip (Lagacé et al., 2013). Table 1 shows the list of objects tested and the percentage of the grip selected. The objects that were grasped by using a given grip by more than 90% of the total of participants were considered to afford that specific grip. Twenty objects were selected, 10 affording power grip and 10 affording precision grip, (**boldface** entries on Table 1). In addition, objects were categorized as either large (larger than 10cm) or small (smaller than 5 cm). Figure A1 shows the images of the objects used in the experiments.

Table 1. Everyday objects tested and the relative occurrence of each type of grip.

Object	Power Grip (%)	Precision Grip (%)
battery	3.7	96.3
brush	18.5	81.5
button	0.0	100.0
clip	0.0	100.0
clothes peg	0.0	100.0

coin	0.0	100.0
corkscrew	100.0	0.0
dice	0.0	100.0
flask	96.3	3.7
hair brush	92.6	7.4
key	0.0	100.0
locker	14.8	85.2
match stick	0.0	100.0
mobile phone	100.0	0.0
multiplug adaptor	100.0	0.0
nail cutter	25.9	74.1
nut	0.0	100.0
pen	85.2	14.8
pill	0.0	100.0
pin	0.0	100.0
remote control	100.0	0.0
ring	0.0	100.0
salad tong	100.0	0.0
scissor	100.0	0.0
screw	11.1	88.9
spoon	29.6	70.4
stapler	100.0	0.0
sunglasses	96.3	3.7
flash drive	0.0	100.0
toothbrush	25.9	74.1

toothpaste tube	88.9	11.1
torch	77.8	22.2
tweezers	3.7	96.3
watch	92.6	7.4

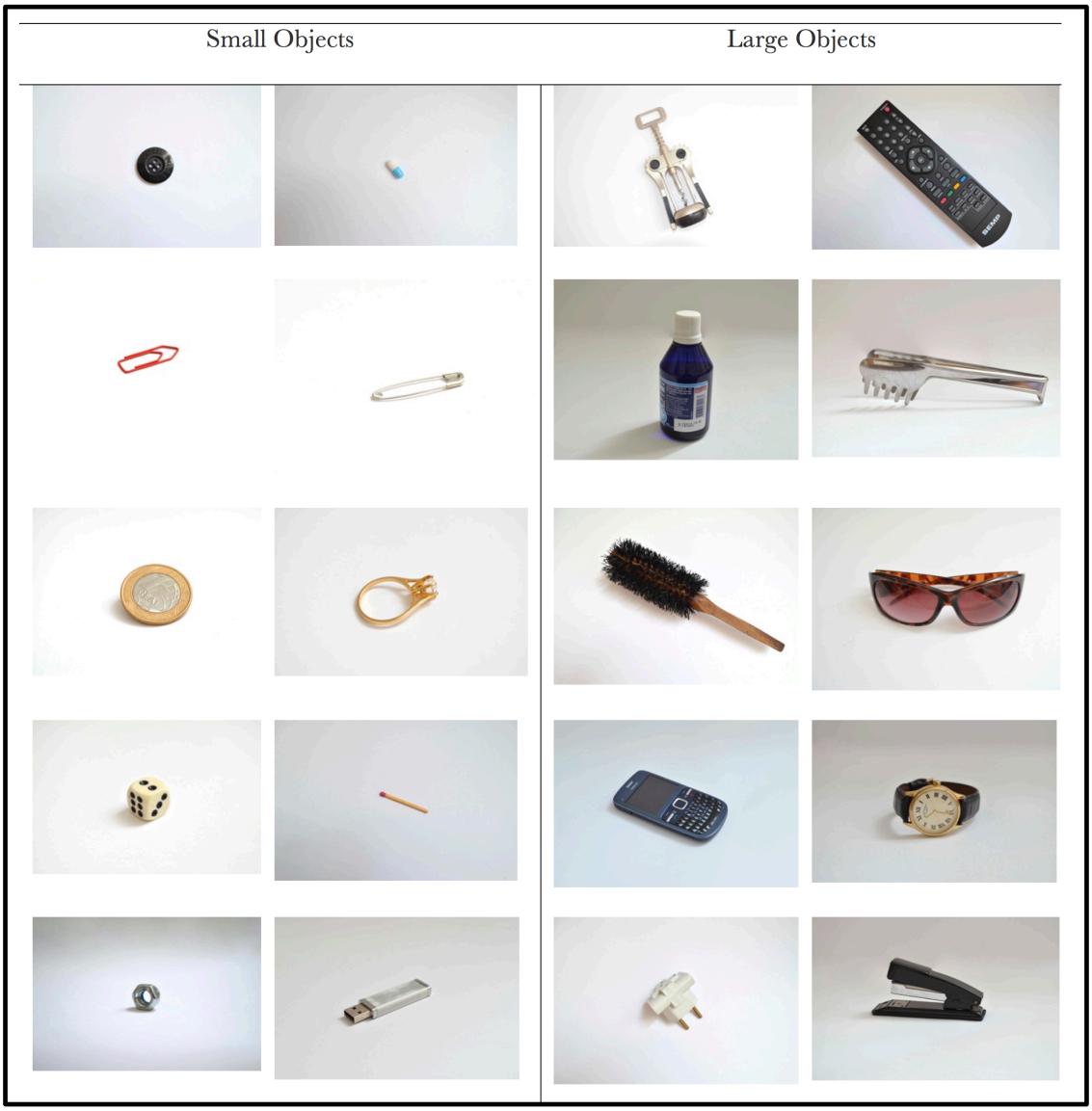


Figure A1. Images of the objects selected for the experiments.