Visuomotor associations with highly manipulable objects: Effects of task and social context

by

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Thesis
Submitted to Flinders University
for the degree of

Doctor of Philosophy

College of Education, Psychology and Social Work
October 2017

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Summary

Interacting successfully with the physical world is a fundamental skill for any animal. These interactions require tight coordination between vision and action processes, including rapid transformation of visual information into motor commands. To account for our remarkable ability to interact with the physical environment, modern cognitive neuroscience research has investigated how the human brain codes the objects around us. In particular, there is a drive to understand how sensorimotor processes and experience influence how we perceive the external world and how conceptual knowledge is acquired and stored within the brain. This thesis aimed to increase our understanding of these processing by addressing the following primary research question: In what ways are highly manipulable objects perceived and represented in motor terms in the human brain?

The first chapters of the thesis introduce different theoretical perspectives on perception and cognition, including 'embodied' theories of higher-order cognitive processes and Gibson's motor theory of visual perception. I review evidence from cognitive neuroscience and experimental, cognitive psychology that demonstrates motor neural resources are activated when highly manipulable objects are perceived and recognised. I introduce uncertainties surrounding the nature and role of this motor activation, which form the basis of the experimental work in this thesis.

The remaining chapters detail experiments I conducted during my PhD, followed by a General Discussion. The thesis comprises a series of behavioural, object perception studies in which the action-relevant feature of object handle orientation (left/right) was

manipulated. First, I investigated how a concurrent, unimanual motor task affected naming of lateralised objects to determine how competition for neural motor resources might impair object recognition. Results were inconsistent, both across my experiments and also compared with the published literature, and were therefore inconclusive. Accordingly, as a methodological adjunct, I investigated the convergent validity of vocal and manual response times in order to rule out inconsistencies owing to potential measurement problems associated with vocal responses. Results from a simple, attentional cueing paradigm suggested strong convergent validity between vocal and conventional, key-press responses. Next I investigated stimulus-response compatibility between left/right object handles and left/right key press response times. This well-established congruency effect (*handle effect*) is generally thought to reflect grasp-related motor activation. Alternatively, however, the effect can also be explained by abstract spatial compatibility between visually salient handles and lateralised manual responses. Three experiments ruled out this alternative explanation for the handle effect and have been published in the *Journal of Experimental Psychology: Human Perception & Performance*. The final experimental chapter describes a novel paradigm in which two humans perform an object recognition task in close proximity of one another. These experiments demonstrated that the handle effect can be modulated within shared, social space. I have proposed that this modulation relates to the way that near-body space is coded for both social- and physical environment-interactions. This chapter has been published in *Attention, Perception, & Psychophysics*.

This thesis makes several contributions to our understanding of manipulable object coding and related visuomotor processes. First, findings highlight the limitations in using a dual-task, behavioural methodology to test the role of motor neural resources on object identification. Second, addressing the alternative explanation for the handle effect makes an obvious, important contribution to the relevant published literature. Third, results from my novel, social paradigm open considerable scope for future research into how social and space coding processes affect our interactions with the physical environment.

Overall, these findings suggest that implicit motor activation evoked by manipulable objects represents an interplay between visuomotor processing of affordances, as well as internally stored motor information, acquired as function of our bodies' capabilities and experience. Object-related motor information is activated flexibly in line with behavioural goals, responding quickly to environmental factors including social cues and context. This rapid exchange and integration of information undoubtedly accounts for our remarkable skill in interacting with the physical world.

Listing of figures

This thesis is dedicated to Jonathan Tickle, and in loving memory of June Johnson.

Acknowledgements

Sincere thanks must go to many people without whose support this thesis would not have been written:

Professor Mike Nicholls – thank you for taking a chance on me. Thank you for welcoming me as an unknown quantity so wholeheartedly into your lab. I feel incredibly fortunate to have completed my PhD in such a fun and supportive environment. I have learned so much from you and truly appreciate all the help, advice and time you have given me over the last four years. Thank you for always encouraging me and allowing me to make the most of every opportunity.

Dr Owen Churches – thank you for the enthusiasm, support, advice, and fun. You genuinely delighted in my successes and commiserated my failures. You always had a kind word and a sympathetic ear for me when I needed it. I don't know how I would have made it through the hard times without your sincere understanding, encouragement and unequivocal belief in my abilities. You are raising two very lucky daughters.

Dr Nicole Thomas – thank you for helping me as though I were one of your students. From the very beginning you were so generous with your time and advice, even though you had no official, professional obligation to me. Thank you for believing in and championing me as a young researcher and for everything you have done to aid my future success. Thank you also for your genuine friendship and endless personal support, especially in this last year that was so hard for us both. Thank you for the fun

times – thank you for Florida! It was a whale of a time that I know we will never forget. Bring on VSS 2017! Maybe they will be ready for us this time (probably not though).

The Brain and Cognition Lab – thank you, Ali, Ancret, Blake, Dan, Ellie, Nathan and Sophie for the friendship, laughter and support. Special thanks to Ancret, for the coffees and counsel, and for the help you were never too busy to provide. Thank you, Dan – a.k.a. my separated-at-birth twin – for the dank memes, Simpsons references, daily fits of laughter and peanut butter cups. Thank you, Ali, for your generous and genuine support, love and insightful counsel. It is truly a privilege to call you a friend. Thank you, Nathan, for your help, especially when I first joined the lab, and for the comedic relief. You could always raise my spirits when they were low.

Friends and family – thank you, Jonny. This has been tough on us in a lot of ways but regardless I know that your support of this work never wavered. You made sure I had everything I needed to achieve this goal and I will never forget what you have given me. This thesis is dedicated to you. Thank you, Maria, Jenelle, Jason, Ellie, Laura and the quiz team, for Wednesdays. Thank you, Leslie, for your endless support and encouragement. Thank you, Amelia, my loudest cheerleader. Thank you, Marissa and Stephanie, for your love and support. Thank you, Chris and Christine, for your love and for Oliver, who is my light in the dark. Last, sincere and endless thanks go to the other Dr Saccone, Gino, and to Kate, for everything.

Declaration

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Research from this thesis is published in the following peer-reviewed articles:

Saccone, E. J., Churches, O., & Nicholls, M. E. R. (2016). Explicit spatial compatibility is not critical to the object handle effect. *Journal of Experimental Psychology: Human Perception and Performance,* 42(10), 1643-1653. doi:10.1037/xhp0000258

Saccone, E. J., Szpak, A., Churches, O., & Nicholls, M. E. R. (2017). Close interpersonal proximity modulates visuomotor processing in shared, social space. *Attention, Perception, & Psychophysics*, doi: 10.3758/s13414-017-1413-7

Research from this thesis has also been presented at the following conferences:

Saccone, E. J., Szpak, A. L., Churches, O., & Nicholls, M. E. R. (May 2017). *Support for modulation of visuomotor processes in shared, social space: Non-human distractors do not influence motor congruency effects relating to object affordances.* Poster to be presented at the 17th Annual Meeting of the Vision Sciences Society. Florida, USA.

Saccone, E. J., Szpak, A. L., Churches, O., & Nicholls, M. E. R. (Apr 2017). *Support for visuomotor modulation in shared, social space: Non-human distractors do not influence object affordance motor congruency effects.* Poster to be presented at the 43rd Australasian Experimental Psychology Conference. Melbourne, Australia.

Saccone, E. J., Szpak, A. L., Churches, O., & Nicholls, M. E. R. (May 2016). *Affordance perception in socially contracted peripersonal space.* Poster presented at the 16th Annual Meeting of the Vision Sciences Society. Florida, USA.

Saccone, E. J., Szpak, A. L., Churches, O., & Nicholls, M. E. R. (Mar 2016). *Socially contracted peripersonal space affects object affordances.* Poster presented at the 43rd Australasian Experimental Psychology Conference. Melbourne, Australia.

Saccone, E. J., Churches, O., & Nicholls, M. E. R. (Sept 2015). *Abstract spatial coding and affordance influences on the object handle orientation effect.* Oral presentation at the International Conference on Spatial Cognition. Rome, Italy.

Saccone, E. J., Churches, O., & Nicholls, M.E.R. (Apr 2014). *A one handed motor task differentially affects naming of objects with aligned and unaligned handles.* Poster presented at the 41st Australasian Experimental Psychology Conference. Brisbane, Australia.

The work has also been communicated in the following seminar:

Saccone, E. J. (Apr 2014). The object of my attention: The role of action-relevant properties in object recognition. Colloquium, School of Psychology, Flinders University, Adelaide, Australia.

Signed ....

Elizabeth J. Saccone

Introduction

The introduction of this thesis, consisting of three chapters, presents theoretical perspectives on perception and cognition. Chapter 1 discusses the role of the body in cognition and briefly reviews 'embodied' theories of higher-order cognitive processes. The purpose of this chapter is to provide a theoretical background for studying the brain's representation of highly action-relevant objects, and the nature and role of associated neural motor activity. Chapter 2 reviews Gibson's (1979) motor theory of visual perception and contemporary evidence of motor-based distinctions and functioning of the visual system, which supports a role of the body in cognition and, therefore, embodied theories generally. This chapter highlights evidence specifically relating to visual perceptual processes, and introduces the concept of "affordances", both of which are critical to the experimental work within this thesis. In Chapter 3 I review evidence from cognitive neuroscience and experimental, cognitive psychology that demonstrates motor neural resources are activated when highly manipulable objects are perceived and recognised. I introduce uncertainties surrounding the nature and role of this motor activation, which form the basis of the experimental work in this thesis. The specific aims of the thesis are outlined at the end of Chapter 3.

Chapter 1: The role of the body in cognition

Humans have a remarkable, seemingly effortless ability to interact with the physical world. For centuries, philosophers and scientists have considered how the human body, with its unique physical and sensory capabilities, might contribute to how we perceive, internally represent, and reason about the external world (Barsalou, 1999). Indeed, this *mind/body problem* has been considered and informed by the philosophies of Plato and Aristotle, the views of rationalists such as Descartes and Kant, and theories of empiricists like Locke and Hume. This debate continues in contemporary cognitive neuroscience as researchers strive to understand how cognition, action and perception are related or even unified within the brain.

Under *cognitivist* views, perception (input) and action (output) are entirely separate and peripheral to the working of the mind, that is, cognition. This view reflects the classic dichotomy of mental and physical states. The computer science revolution of the 1960s inspired enthusiasm in these approaches around and after this time, as did a backlash to behaviourism (Glenberg, 2015). Among others (Fodor, 1983; Marr, 2010), Newell and Simon's (1976) Physical Symbol System Hypothesis provides a quintessential example of a cognitivist model of cognition. Under these views, the brain is conceived as an information processing machine that is computing an abstract problem. Cognition is seen as algorithms operating on meaningless, abstract or amodal symbols. Action is simply the result of cognition and perception of the world is detached from how the world is represented in the brain.

In the tradition of the mind/body problem, these cognitivist theories co-existed with evidence and opinions opposing the physical and mental state dichotomy. These alternative theories espoused, either explicitly or implicitly, a refusal to see the body and its sensorimotor capabilities as only secondary or subservient to the mind. For example, Piaget's (1954) cognitive developmental theory is founded first and foremost in early sensorimotor development gained through experiencing the physical world. Merleau-Ponty (1964) argued for an important role of perception of the external world in the development of cognition and consciousness. Particularly influential, Gibson's (1979) *Ecological Approach to Visual Perception* comprised a motor-based view of perception, hypothesising that perception and action were fundamentally inseparable processes.

These types of theories were useful in addressing the primary criticism of cognitivist approaches, the symbol grounding problem (Harnad, 1990; Searle, 1980). To summarise this issue, if cognition is a closed system, entirely separate from perception and action, and comprised only of abstract, meaningless symbols, how is meaning ever attributed to these symbols? In explaining this problem, Dove (2011) provides the example of trying to learn a foreign language using only a dictionary written entirely in that language. Theories that endorsed a role of the body and its physical states in cognition and perception provided a theoretical solution to this problem.

Reviewed in more detail in the following chapter, advances in neuroscience in the late 20th century prompted a serious reconsideration of the role of the motor system in cognition (Garbarini & Adenzato, 2004). Single-cell recordings in the non-human primate cortex led to ground-breaking insights into the neural organisation and functioning underlying visual processing. These studies provided evidence of neurons that code both visual and motor properties of stimuli including actionable objects (Jeannerod, Arbib, Rizzolatti, & Sakata, 1995; Rizzolatti et al., 1988), action performed by others (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996), and the space surrounding the body, where action is most likely to occur (Fogassi et al., 1992; Fogassi et al., 1996; Gentilucci et al., 1988; Graziano & Gross, 1994; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997). Evidence also emerged of neuroanatomical and functional specialisation within the visual system for the online execution of action (Castiello & Jeannerod, 1991; Goodale & Milner, 1992; Jeannerod, 1994; Jeannerod et al., 1995; Jeannerod, Decety, & Michel, 1994; Mishkin & Ungerleider, 1982). Last, neuroimaging studies demonstrated activity in sensorimotor regions during perceptual and cognitive tasks, despite the absence of action execution or intention (Chao & Martin, 2000; Grafton, Fadiga, Arbib, & Rizzolatti, 1997; Grèzes & Decety, 2001). This modality-specific activation was viewed as simulation, suggesting that higher-order cognition can include a sort of neural re-creation of sensorimotor experiences (Barsalou, 1999; Borghi, 2005; Gallese & Lakoff, 2005; Glenberg & Kaschak, 2003; Pulvermuller, 2001).

These theoretical and neuroscientific advancements arguably contributed to the rising interest in *embodied* theories of cognition within contemporary cognitive neuroscience. The term *embodied cognition*, also referred to as *grounded cognition*, is a broad term to encompass theories that include a role of sensorimotor processes in the development and execution of higher-order cognition. Accordingly, under these views action is not simply the product of cognition as cognitivist theories posit, but rather actively contributes to it (Wilson, 2002). The body's sensorimotor capabilities and experience with the external world shapes and constrains cognitive development and functioning. Embodied theories exist to explain cognitive processes such as semantic memory (Allport, 1985; Barsalou, 1999; Gallese & Lakoff, 2005; Glenberg, 1997), language (Pulvermuller, 2001), working memory (Wilson, 2001) and emotion (Niedenthal, 2007).

There are numerous iterations of embodied theories, varying in the degree to which cognition is accounted for by sensorimotor processes and experience. Examples of the strongest forms claim that the internal representation of concepts *necessarily implicates* or *depends on* information in sensory and motor systems (Gallese & Lakoff, 2005; Pulvermuller, 2001). Claims of a *critical* role of sensorimotor neural resources on conceptual understanding have been highly criticised (Mahon & Caramazza, 2005, 2009), primarily because neuropsychological research demonstrates a dissociation between conceptual knowledge and related sensorimotor resources and functioning (see Mahon & Caramazza, 2005 for a review). For example, patients with apraxia, a neurological disorder associated with impaired use of familiar objects and tools, can recognise objects while being unable to use them (Rosci, Chiesa, Laiacona, & Capitani, 2003). Visual agnosia patients can instead show the reverse pattern, manipulating objects appropriately while being unable to recognise them or their function (Goodale & Milner, 1992; Sirigu, Duhamel, & Poncet, 1991). These criticisms are well-founded and undermine embodied theories that make strong claims about the role of sensorimotor neural resources on conceptual knowledge. However, in light of the neuroscientific evidence for visuomotor integration, as well as the shortcomings of cognitivist theories, other forms of embodied cognition theories remain worthy of consideration.

Weaker forms of embodied theories are currently more prevalent and plausible. These are typically characterised by claims that sensorimotor content functionally supports higher-order cognition, that the internal representation of concepts is mediated or 'grounded' by modal processes (Barsalou, Kyle Simmons, Barbey, & Wilson, 2003; Farah & McClelland, 1991; Kiefer & Pulvermüller, 2012; Pulvermüller, 1999; Simmons & Barsalou, 2003; Vigliocco, Vinson, Lewis, & Garrett, 2004). The nature and organisation of conceptual representation, and the manner in which it is supported by modal systems is inconsistent across theories, however, and in some cases, not well defined. Damasio and colleagues (Damasio, 1989; Meyer & Damasio, 2009) have however provided a more detailed framework of a distributed representational network in which neural connectivity with 'convergence zones' activate the relevant modality-specific information. Other theorists have proposed instead that sensorimotor processes contribute to the development of cognition and conceptual representation, but are not necessarily implicated in subsequent functioning (Hommel, 2015; Wilson, 2002), or may contribute to cognitive function but only in a context-dependent fashion (Barsalou et al., 2003; Hommel, 2015; Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012; Wilson, 2002). Other theories specify that internal representations are symbolic as under a cognitivist view, but that these symbols are not amodal or arbitrary (Barsalou, 1999; Hommel, 2015).

Mahon and Caramazza (2008) propose that conceptual representations are both symbolic and amodal, but that these concepts are isolated and therefore, in a sense, incomplete without influence from and context provided by related sensorimotor information.

These weaker forms of embodied theories arguably have the most promise, as there is an ever-growing consensus that cognition is best explained with an approach encompassing aspects of both cognitivist and embodied views (Hommel, 2015; Mahon & Caramazza, 2008; Matheson, White, & McMullen, 2014b; Meteyard et al., 2012; Pulvermüller, 2013; Shapiro, 2012; Willems & Francken, 2012; Zwaan, 2014); however these theories have not escaped criticism. Some are viewed as vague or poorly defined (Hommel, 2015; Mahon & Caramazza, 2009; Wright, 2008), and Mahon and Caramazza (2008) argued convincingly that much supporting evidence is of a correlational nature, proving only a co-activation of sensorimotor content, not the role of this activation. Additionally this field has suffered from inconsistent and contradicting hypotheses and findings, which regardless fall under the same banner of ‘embodied cognition’. It is likely for this reason that these theories have been accused of being unfalsifiable at times (Hommel, 2015; Wright, 2008), although the same criticism has been made of amodal, cognitivist approaches to cognition (Barsalou et al., 2003). Some of these issues will be discussed in greater detailed throughout this thesis.

Concluding remarks

In considering the role of the body, its capabilities and experience on higher-order cognition, strong forms of both cognitivist and embodied approaches are generally considered to be implausible (Matheson, White, et al., 2014b; Meteyard et al., 2012; Willems & Francken, 2012; Zwaan, 2014). The phenomenon of human cognition is likely best explained with an approach that lies somewhere along the spectrum between strongly cognitivist and embodied views (Hommel, 2015; Mahon & Caramazza, 2008; Matheson, White, et al., 2014b; Meteyard et al., 2012; Pulvermüller, 2013; Shapiro, 2012; Willems & Francken, 2012; Zwaan, 2014). Certainly continued research in this area is required to understand the complex relationship between action, perception and cognition. Willems and Francken (2012) suggest that discussion and research should henceforth focus on determining when and how, rather than if, the body's physical experiences and sensorimotor processes influence cognition.

Chapter 2: Perception and action – evidence for visuomotor integration

Successful existence within and interaction with the physical world requires precise, online co-ordination of vision and action. Sensorimotor or embodied theories account for this effortless precision by rejecting the claim that visual perception provides sensory input that is entirely separate from motor output. Some have argued not only that perception serves to guide action, but also that motoric experience contributes to the development of perceptual processes, both within an individual and also across the evolved species (Borghi, 2005; Gibson, 1979; Varela, Rosch, & Thompson, 1991). Indeed, from an adaptive perspective it could be argued that vision's primary purpose is to guide action (Glenberg, 2015).

One of the most influential and currently relevant motor theories of perception is Gibson's (1979) *Ecological Approach to Visual Perception*. Inherent in Gibson's approach was the view that perception exists to guide action, and action is a function of the body's capabilities. Gibson proposed that we directly perceive the possibilities for action and interaction with the physical environment, referring to these action possibilities as *affordances*. This view was a relational perspective, encompassing the relationship between the perceiver and their environment. He argued that affordances are an intrinsic component of physical objects but that their perception was relative to the perceiver's physical capabilities. For example, a chair affords sitting for a human but not an elephant (Glenberg, 2015).

Many behavioural findings in contemporary cognitive psychology are consistent with Gibson's (1979) affordance hypothesis. One area of this research relates to highly manipulable objects like tools or kitchen utensils. These provide a convenient class of stimuli with which to study action-related perception because a) they are physical structures that humans commonly act upon and b) their action-relevant properties are easily classifiable. For example, manipulable objects can be grouped according to prehension-related properties, like the type of grip aperture or wrist orientation required for grasping, or the gestural motor pattern employed during use. In particular, manipulable objects that have a handle, such as a mug or a hammer, are often used in investigating affordances as there is clear distinction between the objects' functional and grasp-relevant components. Affordance research relating to manipulable objects will be discussed in detail in the following chapter.

Witt and collaborators have also provided behavioural research consistent with affordance perception. Studies in this field typically include measuring changes in perception[1] associated with varying motor capabilities and skills of participants (Witt, Linkenauger, Bakdash, & Proffitt, 2008; Witt & Proffitt, 2005; Witt, Proffitt, & Epstein, 2004, 2005; Witt & Sugovic, 2010). For example, targets are perceived as closer when they are reached more easily (Witt et al., 2004, 2005). Better performing golfers report seeing holes as larger than poorly performing golfers (Witt et al.,

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[1] Of note, a debate exists whether these results truly reflect top-down influences on perception as opposed to post-perceptual processes. See publications by Firestone (2013) and Witt (2016) for opposing arguments on this matter.

2008). This research suggests that reported perception reflects the skills and capabilities of the perceiver.

Inherent in Gibson's (1979) theory is the idea that perception and action are fundamentally inseparable processes, a view echoed by others (Fagg & Arbib, 1998; Prinz, 1990). Although from an adaptive or evolutionary perspective it is plausible that perception and action evolved together (Borghi, 2005; Gibson, 1979; Glenberg, 2015; Varela et al., 1991), in a teleological sense, vision does not always serve action (Michaels, 2000; Wilson, 2002). Sometimes perception simply provides a visual experience, for example, watching a sunset (Michaels, 2000; Wilson, 2002). In this case, perception is not for action but simply for understanding. Therefore, it follows that perception and action are unlikely to be fundamentally inseparable processes as Gibson argued (Michaels, 2000; Wilson, 2002). There is, however, neuroscientific evidence suggesting visual processes are in some ways functionally intertwined within the motor system. This body of evidence is summarised below.

Neuroscientific evidence for visuomotor integration

The existence of bimodal pre-motor neurons in the monkey cortex provides strong evidence for visuomotor integration. One class of neurons, known as *canonical neurons,* fire when action is executed and also when an actionable object is observed nearby (Jeannerod et al., 1995; Rizzolatti et al., 1988). In line with Gibson's (1979) integrated view of perception and action, canonical neurons respond selectively to action-relevant object properties that match the motor output associated with that neuron (Jeannerod et al., 1995). In this respect, these neurons literally code objects in motor terms, as an affordance, as a function of the perceiver's motor repertoire.

Research into canonical neurons also led to the discovery of what have been termed *mirror neurons* within the same pre-motor and parietal areas of the monkey cortex (Di Pellegrino et al., 1992; Gallese et al., 1996; Kohler et al., 2002; Rizzolatti et al., 1996). Activity is detected in these neurons not only when the monkey performs an action but also when observing someone else perform a similar action. This bimodal activity has been interpreted in several ways, with some authors suggesting it explains or contributes to our ability to understand the actions and intentions of others (Brincker, 2015; Gallese & Lakoff, 2005; Ocampo & Kritikos, 2011; Rizzolatti & Craighero, 2004). This interpretation has been challenged, however, (Hickok, 2009; Hickok & Hauser, 2010; Mahon & Caramazza, 2005), primarily because action understanding dissociates from action production. Although the specific function of mirror neurons is an ongoing matter of debate, their existence does at least suggest a common coding mechanism between performing and understanding action.

Neuroscientific discoveries have even demonstrated that the space around us is visually coded in motor terms. The space close to the body, and objects within that space, are processed differently compared with areas further from the body. Given that action and interaction with the physical world typically occurs in areas near rather than far from the body (Cléry, Guipponi, Wardak, & Ben Hamed, 2015), this distinction in visual processing is thought to represent a difference between stimuli located within, as compared to beyond, an actionable distance from the body. To illustrate, Rizzolatti, Scandolara, Matelli, and Gentilucci (1981) reported the existence of bimodal neurons in the monkey cortex with both somatosensory and visual properties that were specialised for stimuli appearing close the animal. The discovery of these neurons was particularly significant because their visual receptive fields are anchored not to a position on the retina, but to the area of the body providing somatosensory information. Thus, visual stimuli are coded in terms of their proximity and position relative to the body (Fogassi et al., 1992; Fogassi et al., 1996; Gentilucci et al., 1988; Graziano & Gross, 1994; Rizzolatti et al., 1981) and this neuroscientific discovery inspired the view that the brain codes near-body space in motor terms. The practical, motor based representation of close, actionable space is referred to in the literature as *peripersonal space* (Rizzolatti et al., 1997; Rizzolatti et al., 1981), and is neurologically distinct from far or extrapersonal space, which is less relevant for body-environment interactions (see Cléry et al., 2015 for a review).

The boundary of what the visual system codes as an actionable distance is not simply a function of one's reaching span, though. Research demonstrates that peripersonal space boundaries are dynamic and expand or contract according to motor-related situational factors (Maravita, Spence, & Driver, 2003), providing further evidence of visuomotor integration. For example, Iriki, Tanaka and Iwamura's (1996) neurophysiological study of single cells in the monkey cortex indicated that bimodal neurons responded to stimuli near the animal's hand, but also to stimuli further away when a tool such as a rake was used to reach more distant objects. Thus, peripersonal space seemed to expand as though the tool was a functional extension of the body. Research in various domains of human sensorimotor and attentional processing supports the idea that tool use affects space representation (Berti & Frassinetti, 2000; Davoli, Brockmole, & Witt, 2012; Longo & Lourenco, 2006), and there is also evidence to suggest that social presence and related factors can remap peripersonal space boundaries (Constable, Pratt, Gozli, & Welsh, 2015; Teneggi, Canzoneri, Di Pellegrino, & Serino, 2013). The mapping of peripersonal space may also influence processing of object affordances (Cardellicchio, Sinigaglia, & Costantini, 2011; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010; De Stefani et al., 2014; Kalénine, Wamain, Decroix, & Coello, 2016; but see Tucker & Ellis, 2001), although much work remains to be done in this area.

A motor-based functional and neuroanatomic distinction within the visual system

Motor-based theories of perception are also bolstered by research into the organisation and functions of the visual system, which suggests that there is a motor component in the way visual information is processed. Namely, there is evidence of two functionally and anatomically distinct visual processing systems or streams that interact to enable successful visually guided action. Mishkin and Ungerleider (1982) first distinguished the two streams in the monkey cortex, but neuropsychological research later refined the functions of the two visual systems in humans by observing deficits in patients with lesions in one stream but not the other (Castiello & Jeannerod, 1991; Goodale & Milner, 1992; Jeannerod et al., 1994). Neuroimaging work supports the functional and anatomic distinctions in the human visual system (Grèzes & Decety, 2002).

Broadly, the organisation and motor-related function of the two distinct but highly interactive streams is as follows. The *ventral* stream, often referred to as the 'what' stream, is a cortical pathway extending from the primary visual cortex to the inferior temporal cortex. This stream has also been described as the ‘semantic’ route to action (Jeannerod, 1994; Jeannerod et al., 1995; Jeannerod et al., 1994), owing to its role in object identification based on associations with long-term semantic or conceptual object information. The second stream, the *dorsal* stream, extends dorsally from visual cortex to posterior parietal areas. Its primary function is to identify visual features relevant to acquiring and acting on an object so as to generate appropriate motor commands. Initially dubbed the ‘where’ pathway (Mishkin & Ungerleider, 1982; Mishkin, Ungerleider, & Macko, 1983), Goodale and Milner (1992) later renamed the dorsal visual stream as the ‘how’ pathway, highlighting that properties like object structure, form and orientation, as well as spatial location, are relevant for acquiring an object. The dorsal route has been described as the ‘pragmatic’ route to action (Jeannerod, 1994; Jeannerod et al., 1995; Jeannerod et al., 1994).

Since the seminal work in this area, Rizzolatti and Matelli (2003) have provided evidence of a further anatomical subdivision of the dorsal stream. These dorsal subsystems were conceived based on connections with the inferior and superior parietal lobules, and are referred to as the *ventro-dorsal* and *dorso-dorsal* streams, respectively. The ventro-dorsal route is implicated in skilled object use, related to long-term functional and manipulation knowledge (Vingerhoets, Acke, Vandemaele, & Achten, 2009). It has strong connectivity with the ventral stream, which contributes to object recognition. The dorso-dorsal route is thought to underlie online control of grasping actions based on visuomotor translations of object form and structure. Damage to the dorso-dorsal stream can lead to optic ataxia, which is characterised by impairments in visually guided reaching and grasping while general perceptual abilities and other skilled actions can remain intact (Buxbaum, Sirigu, Schwartz, & Klatzky, 2003).

Evidence of dorsal route functioning is consistent with Gibson's (1979) ecological approach to perception, as it suggests online processing of environmentally-derived action information (Michaels, 2000). It is considered the primary, online, visuomotor processing channel with more or less direct links to the motor system (Hommel, 2015; Wilson, 2002). Neuropsychological research also suggests that the dorso-dorsal stream's role in online motor control does not rely on long-term semantic or conceptual object information (Barde, Buxbaum, & Moll, 2007; Buxbaum et al., 2003; Norman, 2002), which is consistent with Gibson's view that action-related information is perceived directly from the external environment. As such, the term *affordance* has been commandeered by contemporary cognitive science, referring to the visual cues of object form and structure that are relevant for online, visually-guided action (Fagg & Arbib, 1998).

The functioning of the ventral route, however, conflicts with aspects of Gibson's (1979) theory. Although Gibson's view was that action was determined entirely from environmentally derived information, the ventral processing stream, and connectivity to the ventro-dorsal system suggests that long-term, stored knowledge does contribute to how we interact with the physical world. Consistent with this idea, neuropsychological evidence demonstrates that action processes relying on learned, conceptual or functional knowledge dissociate from the online control of grasping actions based on visuomotor translations of object form and structure (Barde et al., 2007; Buxbaum et al., 2003).

Concluding remarks

In summary, the research reviewed above demonstrates a motor component to the development and functioning of the visual system. This compelling evidence provides a strong basis for embodied theories of cognition in that action, a function of the capabilities of the body, can influence perceptual processes. Gibson (1979) has provided a significant theoretical contribution to this work on visuomotor integration, and in light of evidence that action is guided by environmentally derived visual information, his term "affordance" enjoys widespread use within modern cognitive science. As there is little support for Gibson's strong claims that perception and action are fundamentally inseparable, science has moved on from Gibson's original work. Yet, his contribution to our understanding of visuomotor processing is clearly evident in contemporary cognitive neuroscience and embodied theories of cognition.

Chapter 3: Motor-based coding of highly manipulable objects

Embodied theories of cognition attempt to account for our skill in performing action with a role of motor processes in cognition. To summarise the issues discussed so far, evidence for visuomotor integration suggests that the structural properties of the physical world are perceived as affordances, mapped for online control of action. Embodied theories also include a motor component in internally represented, action-related conceptual information. In applying these ideas, contemporary cognitive scientists have investigated how we perceive and represent highly manipulable, human-made objects like tools and kitchen utensils. Research suggesting the human brain codes these types of objects in motor terms is reviewed and evaluated below, as it provides the basis for the experimental work in this thesis.

A function-based representation of manipulable objects

Although our experience with the physical world extends beyond highly manipulable objects, evidence suggests this class of stimuli are represented uniquely in the human brain according to their motoric or functional relevance. To illustrate, early neuropsychological research from Warrington and McCarthy (1983) demonstrated selective loss of semantic information for tools compared with foods, plants and animals in a patient with significant left-hemisphere damage. Warrington and Shallice (1984) later found evidence of the reverse pattern of category-specific information loss/preservation in other patients. The authors suggested that manipulable objects are represented in functional terms, owing to their unique functional relevance to humans. They later proposed sub-categories of object representation based on more specific motor and somatosensory information, after observing disproportionate semantic impairment for objects sharing particular action-relevant features (Warrington & McCarthy, 1987). These proposals were somewhat consistent with earlier theories of representation from Rosch and colleagues (Rosch, 1977; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), who hypothesised multiple levels of conceptual organisation, some of which were based on relative perceptual and functional relevance. Research with young children also demonstrates that the functional similarities between highly manipulable objects are more salient than the visual similarities, but that the reverse is true for other classes of stimuli like animals (Kalénine & Bonthoux, 2008; Kemler Nelson, Frankenfield, Morris, & Blair, 2000). Overall, this research suggests that highly manipulable objects are represented largely in terms of the action they afford us.

Buxbaum and colleagues (Binkofski & Buxbaum, 2013; Buxbaum, 2001; Buxbaum & Kalénine, 2010; also see Borghi & Riggio, 2015) have detailed a theory on how objects are perceived and represented according to both motor-related structural properties and learned, skilled use-related information. Their framework, the *Two Action Systems* theory, is informed by evidence of action-related distinctions within the visual system, as well as clues from neuropsychology demonstrating the neurological dissociation of different types of actions. Specifically, they propose that object-directed actions are controlled by two distinct but highly interactive cognitive and neuroanatomical systems within the brain. One system, referred to here as the *Grasp* system, controls online translation of visual and spatial cues of objects' structural properties into motor commands. This bilateral system has roots in the dorsal processing stream, or more specifically, the dorso-dorsal stream, as reviewed in Chapter 2. The *Use* system instead draws on long-term, stored information of objects' function and manipulation to enable learned, skilled actions. This system has roots in the ventral processing stream, which underlies object recognition, as well as its connectivity with the ventro-dorsal stream, which contributes to performing skilled manipulations. The *Use* system is primarily left-hemisphere lateralised, based in superior temporal and inferior parietal areas. Both *Grasp*- and *Use*-related motor information are activated in response to object stimuli (Bub, Masson, & Cree, 2008; Jax & Buxbaum, 2010; Masson, Bub, & Breuer, 2011), and both types of information contribute to successful object-directed action.

Manipulable objects implicitly activate motor programs

Further evidence that manipulable objects are coded in motor terms is provided by neuroimaging findings of object-related, implicit motor activation. This research demonstrates that imagining or visually processing a manipulable object results in motor neural activity, even when there is no reported intention to perform action (see Grèzes & Decety, 2001 for a systematic review). For example, Kellenbach, Brett, and Patterson (2003) found using positron emission tomography (PET) that action- and function-related judgements of highly graspable objects were associated with ventral pre-motor activation compared with non-manipulable objects. They also found increased pre-motor activity when participants made action rather than function judgements of manipulable objects. Neural activation in motor areas also occurs during tool naming or hearing tool names (Chao & Martin, 2000; Grafton et al., 1997; Martin, Wiggs, Ungerleider, & Haxby, 1996), naming tool-related actions (Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995) and imagined tool use (Decety et al., 1994). In their meta-analysis, Grèzes and Decety (2001) reported that imagined use of viewed objects is typically associated with activation of dorsal areas, most commonly the inferior parietal cortex, prefrontal cortex, the supplementary motor area, and sometimes the motor cortex.

Behavioural paradigms likewise demonstrate that processing highly manipulable objects can activate related motor programs. The bulk of these findings are stimulus-response compatibility effects whereby the object stimulus has a particular action-relevant feature and the physical act of responding comprises an action that is in some way congruent or incongruent with that feature. The typical finding is that a response is performed more quickly when it matches the action afforded by or associated with the object stimulus. For example, responses that require a certain grasp-related configuration of the hand and fingers (Derbyshire, Ellis, & Tucker, 2006; Grèzes, Tucker, Armony, Ellis, & Passingham, 2003; Tucker & Ellis, 2001) or wrist orientation (Bub et al., 2008) are performed faster when they are congruent rather than incongruent with the structural, affordance-related properties of the object stimulus. These paradigms typically involve images of objects, but even object names alone can elicit motor congruency effects relating to an intrinsic, action-relevant object feature (Bub et al., 2008; Tucker & Ellis, 2004). There is also evidence that objects can activate several different kinds of motor plans, for example when an object requires a different action for grasping it than using it, like a calculator or smartphone (Bub et al., 2008; Jax & Buxbaum, 2010).

In investigating implicit motor activation associated with manipulable objects, one technique in behavioural paradigms is to employ unimanual object stimuli with handles oriented towards the left or right. Tucker and Ellis (1998) were the first to vary object handle orientation to investigate how we process the action afforded by highly manipulable objects. They asked participants to judge whether object images were upright or inverted with respect to their normal manner of use. Participants responded to each stimulus with a speeded, bimanual key press. Although object handle orientation was task-irrelevant, participants responded to objects more quickly when handle side (left/right) matched rather than conflicted with response hand (left/right). The authors argued that this lateralised stimulus-response compatibility effect, or *handle effect* as it will be referred to in this thesis, results because the object is coded in motor terms; that is, affording a left- or right-handed grasp. Since Tucker and Ellis' seminal study, lateralised objects have been widely used in studies investigating object-related implicit motor activation (Bub & Masson, 2010a; Bub, Masson, & Lin, 2015; Buccino, Sato, Cattaneo, Roda, & Riggio, 2009; Constable, Kritikos, & Bayliss, 2011; Costantini et al., 2010; Goslin, Dixon, Fischer, Cangelosi, & Ellis, 2012; Iani, Baroni, Pellicano, & Nicoletti, 2011; Matheson, White, & McMullen, 2014c; Myachykov, Ellis, Cangelosi, & Fischer, 2013; Pappas, 2014; Riggio et al., 2008; Symes, Ellis, & Tucker, 2005; Vainio, 2009; Witt, Kemmerer, Linkenauger, & Culham, 2010).

Issues to be addressed

A key issue is that although the above neuroimaging and behavioural research demonstrates that object recognition activates related motor programs, the purpose or role of this motor activity is unknown. On one hand, motor resources may functionally support object knowledge retrieval (Paulus, Lindemann, & Bekkering, 2009; Witt et al., 2010; Yee, Chrysikou, Hoffman, & Thompson-Schill, 2013). Conversely, Mahon and Caramazza (2008) highlighted that the evidence only proves a co-activation or correlation between object recognition and motor activation, rather than demonstrating a causal or functional relationship. They argued that because attending to and recognising objects often co-occurs with acting upon them, it may be that motor activation is simply the result of associative neural connectivity. From this perspective, motor activation may be epiphenomenal and play no functional role in object knowledge at all. Another possibility is that motor neural resources do not aid object recognition per se, but could play a role in providing relational or contextual information based on past experience (Mahon & Caramazza, 2008).

More specifically, the role and nature of *lateralised* object-related motor activation is unclear. Although the handle effect has been interpreted as motor activation owing to visuomotor transformations of object affordances (Tucker & Ellis, 1998), some findings suggest that a certain level of semantic processing is required to elicit the effect (Loach, Frischen, Bruce, & Tsotsos, 2008; Symes et al., 2005; Tipper, Paul, & Hayes, 2006). For example, the handle effect is not often found when participants are asked to judge object colour (Loach et al., 2008; Symes et al., 2005; Tipper et al., 2006); therefore it may be that the effect reflects not only affordance processing but also stored object knowledge. There is, however, evidence that is inconsistent with this view (Cho & Proctor, 2011; Symes, Ellis, & Tucker, 2007; Vainio, Ellis, & Tucker, 2007). Bub and Masson (2010a) found that a colour judgement did in fact elicit a handle effect, but only when the response action comprised a reach-to-grasp, not a simple button press. They argued that when object identity is task-irrelevant, as in colour discrimination, objects' structural affordance of handle only elicits a handle effect when the motor goal of the task (e.g., key press, reach-to-grasp movement) comprises an action schema that overlaps sufficiently with the motor representation automatically evoked by simply viewing the object. Their account, discussed in more detail in the General Discussion of the thesis, could also explain why handle effects are more likely during tasks relying on object knowledge. Perhaps semantic processing activates object-related motor schemas of greater complexity, beyond that evoked from superficial visual processing of object structure. There are also clues that social context can influence the handle effect, adding another layer of complexity to the literature. For example, Constable et al. (2011) demonstrated that the effect was modulated by object ownership. Thus, there is much work to be done to increase our understanding of lateralised, object-related motor activation.

Uncertainty surrounding the handle effect is further complicated by the existence of a plausible, alternative explanation that is unrelated to affordances or object-specific motor coding. The handle effect may simply reflect abstract spatial compatibility between left and right responses and the salient, asymmetrical stimulus feature of handle (Anderson, Yamagishi, & Karavia, 2002; Cho & Proctor, 2010, 2011; Lien, Gray, Jardin, & Proctor, 2014; Lien, Jardin, & Proctor, 2013). To explain, a large body of literature demonstrates there is a general, robust response advantage when there is relative spatial congruency between stimulus and response (Simon, 1969). Given that an object handle can be a visually salient stimulus feature in a relative left or right location (e.g., a mug's handle), it may be that handles draw attention laterally and facilitate a spatially congruent response advantage. In this respect, the handle effect could simply be explained by abstract spatial coding rather than visuomotor transformations of object affordances (Anderson et al., 2002; Cho & Proctor, 2010, 2011; Phillips & Ward, 2002; Vainio, Ellis, et al., 2007).

Aim of the thesis

In summary, the research reviewed above suggests that there is a motor component to the way manipulable objects are coded by the human brain. There is strong evidence that objects are uniquely represented according to their functional relevance, in terms of the action they afford us. A large body of research also demonstrates that visually processing manipulable objects or retrieving relevant semantic, functional and action knowledge implicitly activates related motor programs. In many respects, however, the meaning of this activation is unclear. The primary aim of this thesis is therefore to investigate the nature and role of object affordance-related motor activation. Doing so will increase our understanding of how the brain codes and prepares action towards objects in the physical environment.

Chapter 4: Motor interference on object naming

Introduction

In cognitive science there is much interest in the way the human brain acquires, stores and retrieves knowledge. Contemporary, *embodied* theories of cognition suggest that neural representations of concepts are supported by the sensorimotor processes associated with their experience (Allport, 1985; Barsalou, 1999, 2008; Gallese & Lakoff, 2005; Glenberg, 1997). Consistent with this idea, there is evidence that motor processes are behaviourally and neurologically activated when accessing semantic knowledge of action-related concepts, for example language denoting action (Glenberg & Kaschak, 2002; Hauk, Johnsrude, & Pulvermuller, 2004; Tettamanti et al., 2005; Zwaan & Pecher, 2012; Zwaan & Taylor, 2006) or highly manipulable objects (Bub, Masson, & Lin, 2013; Chao & Martin, 2000; Grafton et al., 1997; Grèzes & Decety, 2002; Grèzes et al., 2003; Martin et al., 1996; Tucker & Ellis, 1998, 2001). The role of this neural motor activation, however, is unclear. Although some authors have argued that this neural activity functionally supports the retrieval of action-related semantic or conceptual knowledge (Paulus et al., 2009; Pulvermuller, Hauk, Nikulin, & Ilmoniemi, 2005; Shebani & Pulvermüller, 2013; Witt et al., 2010; Yee et al., 2013), another possibility is that it is simply a *by-product* of accessing concepts, reflecting long-term associations in neural connectivity (Mahon & Caramazza, 2008). Whether or not motor neural resources play a functional role in the retrieval of action-related concepts has received much attention in the literature, and reflects a greater theoretical question regarding the nature of higher order cognition.

Cognitive researchers have employed dual-task, behavioural paradigms in an attempt to establish a functional role of motor processes on action concept representation. Typically in these paradigms participants perform a primary task that relies on conceptual knowledge, such as knowledge of language describing action (Shebani & Pulvermüller, 2013) or manipulable objects (Paulus et al., 2009; Witt et al., 2010; Yee et al., 2013). There is also a concurrent, secondary task comprising physical activity which relates in some way to the action concept accessed in the primary task. For example, the primary task might involve processing hand-related verbs and the secondary task could be a motor task performed with the hands. If motor activation does in fact functionally support retrieval of action-related concepts, then it has been argued that a related, secondary motor task should disrupt or interfere with accessing this knowledge, owing to competition for neural resources. This interference should in turn result in impaired performance on the primary task. This idea will be henceforth referred to as the *motor interference hypothesis*.

These dual-task paradigms have produced mixed evidence in favour of the motor interference hypothesis. For example, Shebani and Pulvermüller (2013) showed that secondary motor tasks engaging the hands or feet did in fact differentially interfere with working memory of hand- or foot-related action words, respectively. Furthermore, several studies have found that manual motor tasks impair processing of objects that are typically manipulated with the hands, whereas a secondary, concurrent mental rotation task (Paulus et al., 2009) or motor task performed with feet do not (Yee et al., 2013). These findings are consistent with the motor interference hypothesis and have been argued to support a functional role of motor resources on action concepts. Conversely, Pecher (2013) found that a secondary motor task did not uniquely interfere with working memory of manipulable objects compared with a concurrent syllable articulation task. Pecher et al. (2013) also demonstrated that a manual motor task did not differentially impair working memory of manipulable compared with non-manipulable object stimuli. Postle, Ashton, McFarland, and de Zubicaray (2013) likewise found reading hand-related words did not uniquely interfere with a manual motor task compared with words related to other body parts.

Witt et al. (2010) were the first to investigate *lateralised* motor interference as it related to the structural object property of handle orientation. There is evidence that motor codes for the left- or right-hand can be activated when attending to objects with handles oriented to the left or right sides (Goslin et al., 2012; Tucker & Ellis, 1998; Vainio, 2009). This lateralised motor activation is primarily thought to reflect processing of the object's *affordance* (Gibson, 1979), or the action it affords the perceiver. In line with the motor interference hypothesis, Witt et al. suggested that if motor activation functionally supports conceptual knowledge of manipulable objects, then a one-handed motor task should interfere with recognising lateralised objects. In their study, participants named objects aloud while squeezing a foam ball one hand at a time. Consistent with the motor interference hypothesis, Witt et al. found that participants were slower (Experiment 1) and less accurate (Experiment 2) in naming objects with handles facing the squeezing hand. They did not find any effect of motor task on naming images of animals, suggesting a unique effect of motor interference on manipulable objects, and a functional role of affordance-related motor activation.

There are some limitations to Witt et al.'s (2010) design, however. The primary limitation is that participant hand position was uncontrolled. The authors did not give specific instructions regarding hand placement, instead reporting that participants typically rested their arms on the chair arm rests. Controlling hand position is important in light of known attentional biases to near-hand space (Abrams, Davoli, Du, Knapp, & Paull, 2008; Reed, Grubb, & Steele, 2006). Thus, participants' attention may have been drawn to different components of the objects as a function of their varied hand locations. Second, although stimuli appeared facing both left and right within each experimental block, Witt et al. varied individual object orientation across participants only. To illustrate, a particular object would only ever appear facing the left (or right) for a given participant, and it would then be presented facing the right (or left) for another participant. This design feature does not invalidate Witt et al.'s results, but may have influenced the way they presented and analysed their data. They described the results in terms of whether the handle was facing toward the occupied versus unoccupied hand, rather than exploring potential differences across left/right object handle sides and squeezing hands. They may have done so because varying individual object orientation across participants essentially reduces the stimulus set by half in an investigation of these lateral differences. Employing an entirely balanced, within-subjects design with respect to object orientation and squeezing hand may have allowed any potential differences across left/right object handle sides and squeezing hands to be explored more easily.

In addition to these shortcomings, there is also an alternative interpretation of Witt et al.'s (2010) results. Perhaps naming was impaired for objects affording the squeezing hand, not because of competition for neural motor resources, but because this hand was occupied and therefore unavailable to perform a grasping action. Although Witt et al. interpreted their results as impaired naming when handles faced the squeezing hand, alternatively their findings could also be described as *enhanced* performance for objects affording the *unoccupied* hand. From this perspective, proprioceptive feedback about the body's action state, and the match between the object's affordance and available hand could explain their results rather than competition for neural motor resources. Consistent with this idea, other research from Witt and colleagues has shown that the action capabilities of the observer can influence his or her reported experience of manipulable objects (see Witt, Linkenauger, & Wickens, 2015 for a review). Furthermore, studies have shown that body and hand posture, in particular restricting the use or availability of the arm, can influence processing of object stimuli (Colman, Remington, & Kritikos, 2017; Dutriaux & Gyselinck, 2016; Iachini, Ruggiero, Ruotolo, & Vinciguerra, 2014).

In light of the uncertainties regarding Witt et al.'s (2010) methodology and interpretation, as well as the mixed evidence for the motor interference hypothesis more generally, the current study aimed to clarify the mechanism underlying Witt et al.'s results. I employed a variation of their paradigm that comprised a completely balanced, within-subjects design with respect to both object orientation and squeezing hand. Doing so allowed me to investigate any differences across left/right object handle sides and manual activity. Participants' hand position was also controlled.

Of note, since conducting the following experiments, further research has emerged on the current issue, which employed a comparable paradigm (Matheson, White, & McMullen, 2014a). As their findings did not inform the conceptualisation of the current experiments, their findings will not be discussed until this chapter's General Discussion.

Experiment 1

Experiment 1 aimed both to replicate and to clarify the mechanism underlying Witt et al.'s (2010) findings with object stimuli. The animal stimuli were not included because they did not aid in addressing this issue. Participants named lateralised objects aloud while squeezing a foam ball one hand at a time. Object orientation (handle facing left, right) and occupied hand (left, right) were both varied within subjects. To replicate Witt et al.'s original findings, when participants squeezed the ball with their left hand I expected slower verbal response times (RTs) for objects with left- rather than right-facing handles. The reverse pattern was expected when they squeezed the ball in their right hand.

Experiment 1 also extends Witt et al.'s (2010) work by introducing the between subjects factor of handedness. If sensorimotor experience influences higher order cognitive processes, then it follows that handedness could influence performance on a task implicating lateralised motor activity. Few studies have investigated how handedness modulates processing of lateralised, manipulable objects and no study to date has examined it in the context of motor interference or object naming. There is evidence, however, that object lateralisation influences right-handers' but not left-handers' reachability judgements (Linkenauger, Witt, Stefanucci, Bakdash, & Proffitt, 2009) and memory for objects' physical manipulability instructions (Apel, Cangelosi, Ellis, Goslin, & Fischer, 2012). Given that right-handers typically show a stronger tendency to use their dominant hand than left-handers (Main & Carey, 2014; Nicholls, Thomas, Loetscher, & Grimshaw, 2013), these findings are consistent with the idea that motoric experience influences action-related perception. Furthermore, Yee et al. (2013) showed that the degree of motor interference on an object naming task varied with participants' reported experience with the object stimuli. The authors found greater interference of a manual motor task when participants named objects they had more rather than less experience handling. Given that handedness reflects lateralised motor experience, these findings suggest that handedness might moderate effects in the current paradigm.

I predicted the following results with respect to handedness, under the assumptions that Experiment 1 replicated Witt et al.'s (2010) findings and that these findings reflect motor interference rather than an alternative mechanism. Based on results from Yee et al. (2013), greater motor interference was predicted for right-handers when they squeezed the ball with their right than left hand. That is, reduced naming speed was expected for right- than left-handled objects when the right hand was occupied, compared with the interference expected for left-handled objects when the left hand was occupied. For left-handers I predicted the opposite pattern, although based on results from Apel et al. (2012) and Linkenauger et al. (2009) it was considered that left-handers might not show a difference in motor interference across lateralised objects. Furthermore, in line with the idea that motoric experience influences action-related perception, right-handers were expected to show an overall naming speed advantage for right-handled objects over left-handled objects. Once again, it was considered that left-handers might show an equivalent advantage for naming left-handled objects, or that there might not be a difference across object lateralisation.

Method

Participants. Thirty-two Flinders University students participated in the study in exchange for course credit. Sixteen were right-handed (8 female, mean age 20.1 years) and 16 were left-handed (9 female, mean age 21.6 years), as measured by the Flinders Handedness Inventory (Nicholls et al., 2013). Participants were native English-speaking monolinguals who reported normal or corrected-to-normal vision and gave informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus. Stimuli were presented on a Dell Optiplex 745 PC with a 21" monitor (1920 x 1080 pixels) using E-prime 2.0 software (Psychology Software Tools, Inc.; www.pstnet.com/E-prime/e-prime.htm). Participants' verbal RTs were recorded using an Audio-Technica ATR1200 dynamic microphone situated on the desk to the participant's left that connected to an E-prime 200A PST serial response box. A small closed-circuit video camera allowed the experimenter to monitor performance from behind a partition in the testing room. A small, blue, foam ball 63 millimetres (mm) in diameter was used for the motor task.

Stimuli. Stimuli comprised 200 colour photographs of 100 highly graspable, unimanual objects (e.g., mug, whisk, nail clippers, umbrella) isolated on white backgrounds. A single photograph of each object was obtained from Shutterstock's online database (www.shutterstock.com) and a mirror-image copy of each was created so that objects faced both directions during the experiment. Colour photographs were used so that objects looked realistic. Objects were various sizes and appeared in approximate proportion to one another. For example, the umbrella looked considerably larger (145mm x 128mm) than the nail clippers (58mm x 35mm; see Figure 4.1). A full list of items can be found in Appendix A.

Figure 4.1. Example of different sized stimuli with handles facing the left (umbrella) and right (nail clippers).

Procedure. The experiment comprised 12 practice trials followed by 2 experimental blocks. Participants sat centrally approximately 500mm from the screen and squeezed the ball in a different hand in each block. Participants were instructed to keep their hands on the desk placed naturally on either side of their body's midline. They squeezed the ball gently but with constant pressure while relaxing their unoccupied hand, consistent with Witt et al.'s (2010) participants. Hand order was counterbalanced across participants.

Each block contained 200 trials. Each object appeared twice in each block, once with the handle pointing to the left and once to the right. Stimulus presentation order was randomised and participants were offered a short break halfway through each block.

One image was displayed per trial and a white screen appeared in the inter-trial period. Participants named each object aloud as quickly and accurately as possible. Images remained on the screen until participants responded or for a maximum of 2000ms. The experimenter coded response accuracy online and each trial began 1000ms after the experimenter had entered an accuracy decision key press for the previous trial. Accurate trials were those in which the participant's first response was an appropriate descriptor for the object. Errors included incorrect object labels, false starts (voice key triggered by a noise other than a complete object label) and missed trials (no response given). Following missed trials, on-screen text feedback reminded participants to respond within 2000ms. The testing session lasted approximately 45 minutes.

Results

The group error rate was 13.813% (*SD* = 5.357) but analyses of participant error rates are not presented. Preliminary error rate analyses indicated no significant main errors or interactions and importantly, the pattern of error rates were not consistent with a speed-accuracy trade-off. Data from one right-handed participant was excluded from analyses owing to an error rate greater than three standard deviations from the group mean. RTs faster than 200ms were likely to reflect anticipatory responses and were also removed (0.1% of trials).

RTs. Participants' correct mean RTs were analysed with a 2 (object handle; left, right) x 2 (hand occupied; left, right) x 2 (handedness; left-handed, right-handed) mixed ANOVA. There were no main effects of object handle, $F(1, 29) = 0.107$, $p = .746$, $\eta_p^2 = .004$, or hand occupied, $F(1, 29) = 0.016$, $p = .901$, $\eta_p^2 = .001$. There was, however, an interaction between these factors, $F(1, 29) = 7.409$, $p = .011$, $\eta_p^2 = .203$. As is displayed in Figure 4.2, RTs were significantly faster for left-handled objects than right-handled objects when the left hand was occupied, $t(30) = 2.062$, $p = .048$, $d = 0.373$. The reverse was true when the right hand was occupied, $t(30) = 2.045$, $p = .050$, $d = 0.367$. There was no main effect of handedness, $F(1, 29) = 2.546$, $p = .121$, $\eta_p^2 = .081$, and handedness did not interact with any other factor, all Fs < 1.117, ps > .299.

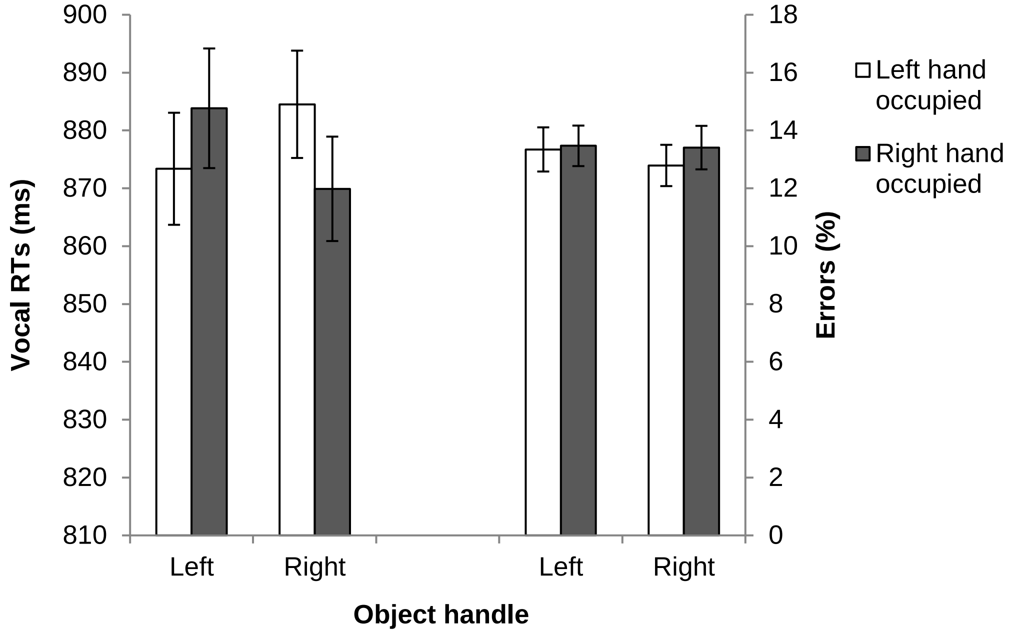

Figure 4.2. Mean correct vocal RTs (ms) and error rates (%) across object handle and hand occupied factors in Experiment 1. Error bars represent a standard error of the mean calculated within-subjects for each condition.

Discussion

Experiment 1 did not replicate Witt et al.'s (2010) findings. Rather than slower naming of objects with handles facing the occupied hand, RTs in Experiment 1 were *faster* for trials in which object handles corresponded with squeezing hand. Furthermore, this pattern was consistent across both left- and right-facing objects and left and right occupied hands. Additionally, in contrast to my hypotheses, object naming did not vary with handedness, nor did handedness interact with any experimental factors. These data are inconsistent with Yee et al.'s (2013) finding that manual experience influences the degree of motor interference on object naming. It is possible that the lack of differences across handedness groups are due to an underpowered sample; however, my sample was larger than in Linkenauger et al.'s (2009) study, in which object lateralisation affected reachability judgements across handedness groups of only 10 participants each. Overall, the findings of Experiment 1 do not support the motor interference hypothesis.

It is unclear why the current paradigm did not replicate Witt et al.'s (2010) results in light of the highly similar paradigms. There were minor methodological differences across the two studies, although these differences are unlikely to explain the contradictory findings. For example, the stimulus sets varied across the two studies but ultimately both comprised colour photographs of lateralised, unimanual objects of varied orientation within blocks. Another difference was that in the current experiment the factor of individual object handle was varied within subjects to enable a design that was entirely balanced within participants, but there is no reason why doing do should lead to opposing results. The other key difference was that hand location was controlled in the current experiment. Participants' hands remained on the desk near the visual display at all times, comfortably either side of the mid-sagittal plane. Holding the ball in one hand may have cued attention to the space near the occupied hand, although this still does not explain my results; attention to the object handles should lead to slower not faster object identification as the handle is not typically the defining feature (Skiba & Snow, 2016). Regardless, if lateralised neural motor activation accounted for Witt et al.'s findings then controlling hand location would not negate this mechanism. One possibility is that in the current study, participants did not squeeze the ball with the same intensity as

Witt et al.'s and therefore, motor neural resources were not activated to the same degree. This explanation is unlikely though because Experiment 1's participants were instructed to squeeze the ball with constant pressure, which is consistent with that described by Witt et al. Regardless, this possibility was explored in Experiment 2.

A key, remaining question is why Experiment 1 not only failed to replicate Witt et al.'s (2010) findings, but in fact produced the *opposite* pattern of results. It is difficult to explain the current findings because any potential explanation will be inconsistent with both Witt et al.'s account as well as the proposed alternative explanation that prompted the current work. For example, one possible interpretation is that the current findings are explained by the match between the action performed in the secondary, motor task and the action afforded by the object stimuli. That is, object handles afforded grasping from one hand and, in squeezing a ball, one hand was performing a grasping action and the other was not. This idea is inconsistent with Witt et al.'s interpretation but is supported by Yee et al. (2013), who argued that motor interference is contingent on the concurrent motor task comprising actions that are incompatible with the stimuli. They proposed that compatible actions should instead facilitate responses to objects. Although their study did not provide evidence of this idea, their suggestion is consistent with single-task, stimulus-response compatibility paradigms with object stimuli (Glenberg & Kaschak, 2002; Grèzes et al., 2003; Tucker & Ellis, 1998, 2001; Zwaan & Taylor, 2006) and an object naming study by Pine, Reeves, Howlett, and Fletcher (2013). Although the grasp compatibility explanation of Experiment 1's findings is not well founded in the context of Witt et al.'s (2010) original paper, it is supported by other literature and as such, this interpretation will be explored later in this chapter (Experiment 4).

In light of these considerations, it is difficult to draw meaning from Experiment 1's results. Experiment 2 explored the possibility that insufficient neural motor activation accounted for the failure to replicate Witt et al.'s (2010) findings in Experiment 1.

Experiment 2

Experiment 2 determined whether the motor task in Experiment 1 failed to sufficiently engage motor neural resources to replicate Witt et al.'s (2010) lateralised motor interference effect. Experiment 2 employed the same paradigm as in Experiment 1 but the intensity of the motor task was increased. Rather than squeezing the ball with gentle, constant pressure as Witt et al. described, in Experiment 2 participants were asked to make repeated actions of tightly squeezing and then relaxing their grip on the ball.

The following results were predicted. Once again, in line with the motor interference hypothesis, if motor activation functionally supports object identification, then Experiment 2 was expected to produce results consistent with Witt et al. (2010). Specifically, slower verbal responses were expected when the left hand squeezed the ball and object handles faced the left rather than the right. The opposite pattern was expected when the right hand squeezed the ball. Handedness was not included as a factor in Experiment 2 because it did not produce any significant effects in Experiment 1.

Method

Participants. Twenty-four right handed (20 female, mean age 24.4 years) Flinders University students participated and received a small reimbursement for their time. Participants were native English-speaking monolinguals who reported normal or corrected-to-normal vision and gave informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus and stimuli. Apparatus and stimuli from Experiment 1 were reused except that participants squeezed a different, softer foam ball. The ball used in Experiment 1 was too firm for participants to squeeze repeatedly into a fist for the length of the testing session. The softer ball used in Experiment 2 was primarily blue in colour and measured 72mm in diameter.

Procedure. Procedure was identical to Experiment 1 except the motor task varied slightly. Instead of holding the foam ball with gentle but constant pressure, participants squeezed the ball tightly so that it compressed as their hand formed a fist and then relaxed their fingers outward so the ball was held only loosely. They repeated these movements continuously throughout the object naming task at a rate of approximately one cycle of squeeze and release movements per second.

Results

The group error rate was 13.552% (*SD* = 7.349). All participant error rates fell within three standard deviations of the group mean and so data from all participants were included in analyses. Preliminary error rate analyses indicated no significant main errors or interactions and the pattern of error rates did not suggest a speed-accuracy trade-off. RTs faster than 200ms were removed (0.2% of trials).

RTs. A 2 (object handle; left, right) x 2 (hand occupied; left, right) repeated measures ANOVA was performed on participant mean RTs from correct trials (see Figure 4.3). There was no main effect of object handle, $F(1,23) = 0.204$, $p = .655$, $\eta_p^2 = .009$ or hand occupied, $F(1,23) = 0.009$, $p = .927$, $\eta_p^2 < .001$, nor an interaction between the two factors, $F(1,23) = 0.040$, $p = .843$, $\eta_p^2 = .002$.

Discussion

In Experiment 2, the one-handed motor task did not differentially influence speed of naming lateralised objects. The motor task arguably employed motor resources to a greater degree than in Experiment 1, yet did not replicate the pattern of findings from Witt et al. (2010). Once again, these findings are inconsistent with the motor interference hypothesis and as such, do not support a functional role of motor activation on object knowledge. Experiment 2 also failed to replicate findings from the current Experiment 1, however. Given that the motor task included the same grip action employed in the task from Experiment 1, these findings also do not support a grasp congruency account of Experiment 1's data. One last attempt to elicit lateralised motor interference was made in Experiment 3.

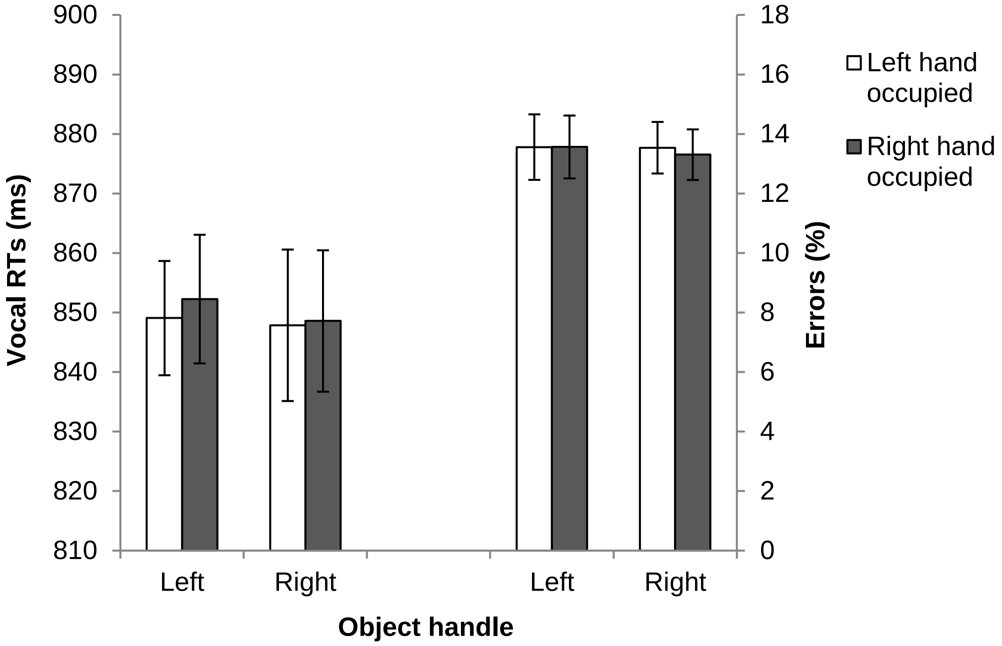

Figure 4.3. Mean correct vocal RTs (ms) and error rates (%) across affordance and hand occupied factors in Experiment 2. Error bars represent a standard error of the mean calculated within-subjects for each condition.

Experiment 3

Experiment 3 aimed once again to elicit interference from a unimanual motor task on naming of lateralised object images. In this experiment, the motor task comprised movements of one hand only, but without the use of a ball. Thus, the motor task involved less of a grasping action, in line with Yee et al.'s (2013) argument that an incompatible action is critical in eliciting motor interference. It was predicted that if motor activation plays a functional role in object identification, participants would be slower in naming objects with handles directed to the right rather than left when the right hand was moving. The reverse pattern was expected when the left hand performed the motor task.

Method

Participants. Twenty-five right-handed (20 female, mean age 25.0 years) Flinders University students participated in the study in exchange for course credit. Participants were native English-speaking monolinguals who reported normal or corrected-to-normal vision and gave informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus and stimuli. The apparatus and stimuli from Experiments 1 and 2 were again used in Experiment 3, except that the foam ball was omitted from the motor task.

Procedure. Procedure was identical to Experiment 1 except the motor task varied once again. Instead of squeezing a foam ball, participants made a tight fist with one hand and, starting with the thumb, extended each finger out one by one until all fingers were outstretched, then returned them to a fist and began again (Pecher, 2013). They were instructed to make these movements continually throughout the object naming task.

Results

The group error rate was 15.700% (*SD* = 5.139). All participant error rates fell within three standard deviations of the group mean and so data from all participants were analysed. Preliminary error rate analyses indicated no significant main errors or interactions and the pattern of error rates did not suggest a speed-accuracy trade-off in responses. RTs faster than 200ms were removed (0.1% of trials).

RTs. A 2 (object handle; left, right) x 2 (moving hand; left, right) repeated measures ANOVA was performed on participant mean RTs from correct trials. There was no main effect of object handle, $F(1,23) = 0.145$, $p = .707$, $\eta_p^2 = .006$ or moving hand, $F(1,23) = 0.097$, $p = .758$, $\eta_p^2 = .004$, nor an interaction between the two factors, $F(1,23) = 0.202$, $p = .658$, $\eta_p^2 = .009$ (displayed in Figure 4.4).

Discussion

The data from Experiment 3 were consistent with Experiment 2. A one-handed, secondary motor task did not differentially affect naming of left- or right-handled objects. There was no significant effect of the motor task on naming speed for any condition. These findings are again inconsistent with Witt et al.'s (2010) results and do not support a functional role of motor activation on lateralised object recognition.

Given that neither Experiment 2 nor 3 suggests a role of concurrent motor activity on object identification, the mechanism underlying Experiment 1's findings remains unclear. This issue was explored further in Experiment 4.

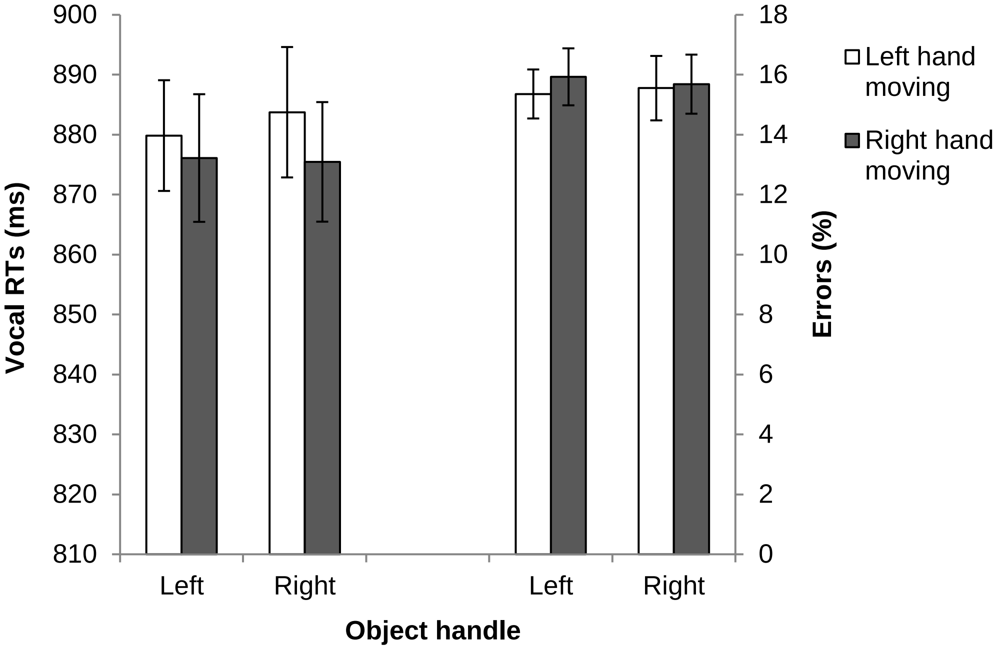

Figure 4.4. Mean correct vocal RTs (ms) and error rates (%) across affordance and hand occupied factors in Experiment 3. Error bars represent a standard error of the mean calculated within-subjects for each condition.

Experiment 4

Experiment 4 aimed to clarify the mechanism underlying Experiment 1's results. In Experiment 1, participants were faster to name objects with handles facing toward rather than away from the hand that squeezed the ball. This finding is in direct contrast to Witt et al.'s (2010) study, in which the reverse pattern was observed. It is difficult to interpret these results given the highly similar methodologies across the two studies. Although the critical interaction in Experiment 1 was a strong effect, it was not replicated in Experiment 2, which employed a near-identical paradigm. This failure to replicate could point to a Type I error in

Experiment 1. Thus, Experiment 4 aimed both to replicate and account for Experiment 1's results.

A possible explanation for the findings of the first experiment is that in maintaining a grasp action with one hand, the motor task comprised an action that was congruent with that afforded by the object stimuli. Of course this interpretation contrasts Witt et al.'s (2010) original account, although any explanation will do so given the contradictory nature of the two datasets. Yee et al. (2013) suggested that a secondary motor task will only produce motor interference if it involves actions that are *incompatible* with the stimuli. Consistent with this idea, single-task, stimulus-response compatibility paradigms do in fact typically show enhanced performance when the action comprising the response is compatible rather than incompatible with the action afforded by object stimuli (Grèzes et al., 2003; Pine et al., 2013; Tucker & Ellis, 1998, 2001), or the action described in verbal stimuli (Glenberg & Kaschak, 2002; Zwaan & Taylor, 2006). In further support of this idea, in paradigms where a prime object or action image precedes the target object, responses to the target are typically faster when the prime stimulus has a congruent rather than incongruent grasp feature (Helbig, Graf, & Kiefer, 2006; McNair & Harris, 2012). Thus, although it contrasts Witt et al.'s original study and the current Experiment 2, it is possible that a grasp compatibility mechanism explains Experiment 1's findings.

In Experiment 4 the degree of grasp-related compatibility between the object stimuli and the motor task was varied systematically. The methodology was similar to Experiment 1 but included two additional within-subject variables relating to grip aperture. The stimulus set was altered so that half of the objects afforded a whole-hand, *power* grip during use (e.g., knife, kettle) and the other half are typically used with a pincer or *precision* grip between thumb and index finger (e.g., needle, toothpick). For simplicity, Experiment 4's object stimuli will be referred to as *large* or *small*, based on their affordance properties of power or precision grip aperture, respectively. The motor task also varied such that it comprised either a power or precision grasping action. In half of the experiment participants performed a power grasp by squeezing and maintaining constant pressure on a foam ball with their whole hand, identical to Experiment 1. In the other half of the experiment, they performed a precision grip by holding a small, glass marble tightly between thumb and forefinger. Accordingly then, trials were either congruent or incongruent with respect to grip aperture of the object stimuli and motor task. Congruent trials were those in which participants either named large objects while squeezing the ball, or named small objects while squeezing the marble. Incongruent trials were those with the reverse combinations.

The following results were predicted. If grasp compatibility accounted for Experiment 1's findings, then Experiment 4 was expected to replicate the pattern of results from Experiment 1 when grip aperture was congruent. That is, faster RTs were expected when large object handles faced toward rather than away from the hand that squeezed the ball, or when small object handles faced the hand squeezing the marble. Based on the current study's lack of evidence for motor interference, I did not expect an effect of handle side on naming when grip aperture was incongruent. Furthermore, if grasp compatibility does influence object naming then, overall, faster RTs were expected when grip aperture was congruent rather than incongruent, regardless of object handle orientation.

Method

Participants. Forty-four right-handed (36 female, mean age 19.36 years) Flinders University students participated in the study in exchange for course credit or a small reimbursement. A larger sample size was recruited in this study due to the more complex factorial design. Participants were native English-speaking monolinguals who reported normal or corrected-to-normal vision and gave informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus. Apparatus from Experiment 1 were used and included the original blue, foam ball. A glass marble 15.91mm in diameter was also used. The marble was a transparent 'cat's eye' with a blue and green core.

Stimuli. Stimuli comprised 120 colour photographs of 60 highly graspable objects isolated on white backgrounds. Half of the objects require a whole-hand, power grasp during use (large objects; e.g., knife, kettle, frypan) and the other half are typically used with a precision grip between the thumb and index finger (small objects; e.g., needle, toothpick, pencil). Images of 30 large and 9 small objects from the first 3 experiments were re-used. Twenty-one additional photographs of small objects were obtained from Shutterstock (www.shutterstock.com) so that there were 30 objects from each size category. Once again mirror image reversals were made so that objects afforded a grasp from the left or right.

Procedure. Unless otherwise specified, the procedure was identical to the first experiment. This experiment consisted of four experimental blocks. Participants were instructed to hold the ball or marble tightly in one hand per block while relaxing their unoccupied hand. The marble was held with a precision grip, between thumb and index finger only whereas the ball was held with the participant's whole hand. The occupied hand alternated after every block and the starting hand was counterbalanced across participants. The ball/marble condition was also counterbalanced but participants swapped from ball to marble or vice versa after two blocks, resulting in four counterbalancing conditions.

Each block comprised 120 trials. Every object appeared twice in each block, once with the handle pointing to the left and once to the right. Participants were offered a short break after every block. The testing session lasted 45-60 minutes.

Results

The group error rate was 11.040% (*SD* = 5.930). All participant error rates fell within three standard deviations and so data from all participants were included in analyses. Preliminary error rate analyses indicated no significant main errors or interactions and the pattern of error rates did not indicate a speed-accuracy trade-off in responses. RTs faster than 200ms were removed (0.1% of trials). To simplify the analyses, data were collapsed across object size and ball/marble factors to create a grip aperture congruency variable. Congruent trials were those in which large objects comprised the stimuli and participants squeezed the foam ball, or when small objects were the stimuli and participants held the marble. Incongruent trials were those with the reverse combinations.

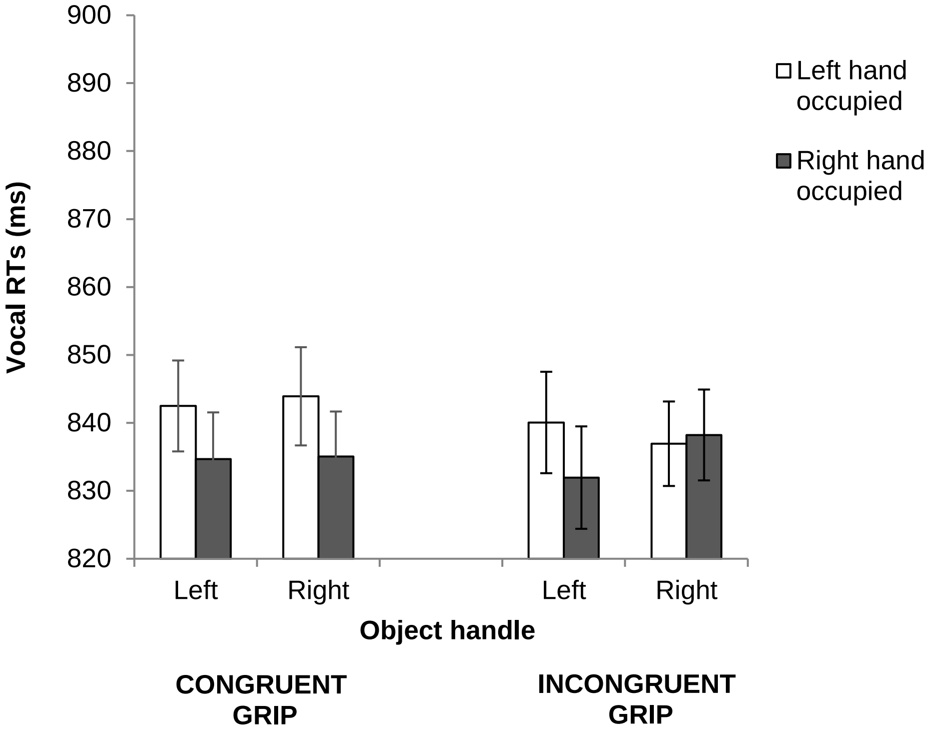

Figure 4.5. Mean correct vocal RTs (ms) across object handle and hand occupied factors when grip aperture was congruent (left panel) and incongruent (right panel) in Experiment 4. Error bars represent a standard error of the mean calculated within-subjects for each condition.

RTs. A 2 (object handle; left, right) x 2 (hand occupied; left, right) x 2 (grip aperture; congruent, incongruent) repeated measures ANOVA was performed on mean RTs from correct trials. There were no main effects of object handle, $F(1, 43) = 0.165$, $p = .686$, $\eta_p^2 = .004$, hand occupied, $F(1, 43) = 0.259$, $p = .614$, $\eta_p^2 = .006$, or grip aperture, $F(1, 43) = 0.261$, $p = .612$, $\eta_p^2 = .006$, displayed in Figure 4.5. None of the interactions were statistically significant, all Fs < 1.416, ps > .241.

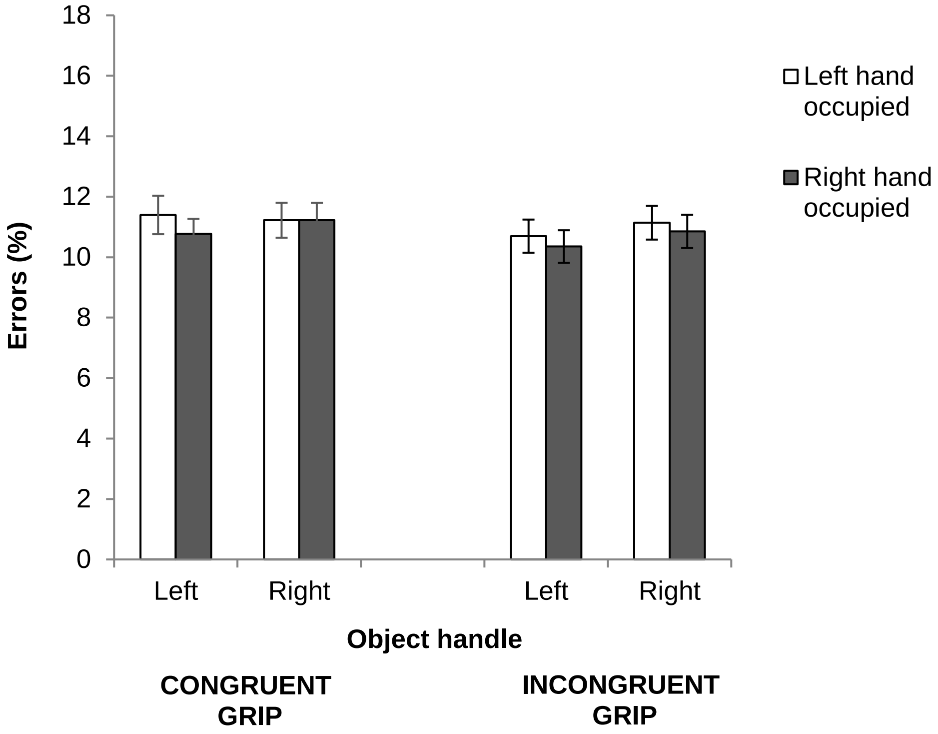

Figure 4.6. Mean correct error rates (%) across object handle and hand occupied factors when grip aperture was congruent (left panel) and incongruent (right panel) in Experiment 4. Error bars represent a standard error of the mean calculated within-subjects for each condition.

Discussion

Experiment 4 failed to replicate the findings from Experiment 1. Object handle direction, hand occupied and grip aperture congruency all had no effect on speed of naming lateralised objects. Trials in which participants squeezed the foam ball were more or less identical to Experiment 1 but did not elicit the same pattern of results. Thus, these data do not support a grasp compatibility account of Experiment 1's findings, nor the suggestion from Yee et al. (2013) that a congruent motor task facilitates naming. The findings are, once again, inconsistent with those from Witt et al. (2010).

General Discussion

Over four experiments, the current study investigated the effect of a secondary, unimanual motor task on naming objects affording a left or right grasp. The original aim was to extend findings of Witt et al. (2010) in order to confirm the underlying mechanism. Witt et al. demonstrated lateralised motor task interference on naming left- and right-handled objects, and consequently argued that neural motor activity functionally supports object identification. Despite employing a highly comparable paradigm, the current Experiment 1 produced a pattern of RTs that directly contrasted Witt et al.'s original findings, with faster rather than slower naming of objects with handles facing the occupied hand. Also contrary to my hypotheses, motor experience in the form of handedness did not have any effect on lateralised object naming, nor did it moderate any effects of the motor task. The motor task was varied in Experiments 2 and 3 in further attempts to replicate Witt et al.'s findings, but neither task differentially influenced naming of left- or right-handled objects. Experiment 4 investigated grip compatibility as an explanation for Experiment 1's findings, but there was no effect of grip aperture congruency on naming, nor were Experiment 1's findings replicated. It is possible that the lack of controlled timing of the motor activity in Experiments 2 and 3 contributed to the null results; however, this issue does not apply to Experiment 1, in which the motor activity was identical to that described by Witt et al., nor does it explain the failure of Experiment 4 to replicate Experiment 1's findings. On balance this study does not provide evidence of motor task interference on object naming.

As noted earlier, since conducting the current study, further research has emerged that employed a comparable paradigm. Matheson et al. (2014a) had participants name lateralised, greyscale objects while squeezing a ball with one hand at the start of each trial. In their study, the squeezing hand was varied between subjects and its location was fixed below the visual display at the horizontal centre. In one experiment, the authors oriented object handles at approximately 45 degrees from horizontal on the picture plane, such that handles pointed to the left and right bottom corners of the screen. When participants squeezed the ball with their left hand, left-handled objects were named more slowly than right-handled objects, and the reverse was true when the right hand squeezed the ball. This pattern is consistent with Witt et al. (2010). In a second experiment, however, they presented objects with handles angled at 0 degrees (i.e., horizontal) and found the *opposite* pattern, consistent with the current study's Experiment 1. Matheson et al. also included animal stimuli as in Witt et al.'s original study, but found that the motor task did not differentially affect naming of objects and animals in either experiment.

It is difficult to reconcile Matheson et al.'s (2014a) results with those from both Witt et al. (2010) and the current study. Matheson et al. explained their divergent findings in terms of an attentional bias to near-hand space (Abrams et al., 2008; Reed et al., 2006). They argued that varying the angle of object handles changed the spatial relationship between the (centred) squeezing hand and object handles across experiments. They argued that for corresponding (e.g., left hand, left facing handle) trials in one experiment, the squeezing hand was closer to the functional, defining ends of objects rather than handles. In this case, attention was drawn first to objects' defining features and those objects were identified more quickly. They argued that for corresponding trials in the other experiment, however, near-hand attention was first drawn to handles, leading to slower RTs for those objects. Although this reasoning might fit with their findings, it is not consistent with the current Experiment 1, in which near-hand biases were controlled because both hands were placed laterally near the display. Attention may have been drawn to the hand that held the ball, but then Experiment 1's data would reflect faster RTs when attention was first drawn to object handles, which contradicts Matheson et al.'s account. Moreover, in Witt et al.'s study, participants' hands were typically not near the visual display but on the chair arm rests. Thus, Matheson et al.'s results add further to the inconsistencies associated with this paradigm, rather than clarifying the existing, conflicting results. It is unknown why this paradigm produces such variable effects but on balance, it seems that there is little evidence to support Witt et al.'s original interpretation of lateralised motor interference on object naming.

The current study's lack of evidence for motor interference is consistent with some previous research (Pecher, 2013; Pecher et al., 2013; Postle et al., 2013), but contrasts other findings demonstrating that a secondary motor task can disrupt access to action-related knowledge (Paulus et al., 2009; Shebani & Pulvermüller, 2013; Yee et al., 2013). It is unclear why these other studies produced motor task interference whereas the current study did not. The present findings are also inconsistent with Yee et al.'s study, which also employed object naming. One consideration here is that Yee et al. only found interference for stimuli with which participants reported a certain degree of manual experience. Although the present study did not account for individuals' experience with the object stimuli, it did include handedness – an indicator of motoric experience – but this factor did not interact with any effects. Another consideration is that the current paradigm differs from others by investigating *lateralised* motor interference, which relates specifically to the situational or variable object property of handle orientation. If neural motor resources do in fact functionally support object knowledge owing to sensorimotor experience, then it follows that intrinsic or stable object properties would be more tightly connected to long-term, semantic knowledge than variable properties. In line with this reasoning, perhaps motor interference is more likely when the motor task relates to a stable rather than variable, action-relevant object property. Data from the current Experiment 4 speak against this idea, however, in that grip aperture had no effect on naming, irrespective of handle orientation. Regarding this issue, of note, the within-object consistency of variable (grasp) and stable (action) affordances was not controlled within the current study's stimulus set. Although my choice of stimuli may have created a degree of noise within the data, the stimulus set was chosen to be comparable to that employed by Witt et al. (2010), and so this issue is unlikely to explain the divergent results across the two studies. On balance, consistent with Pecher and colleagues (Pecher, 2013; Pecher et al., 2013) and Matheson et al.

(2014a), the current findings do not support the view that a secondary motor task disrupts processing of manipulable objects.

A question remains as to the implications of the current findings for the motor interference hypothesis. In line with the hypothesis, the current data do not support a functional role for motor neural resources in object knowledge retrieval. In turn the findings could suggest the motor activation that accompanies object processing is simply a by-product of this process. On reflection, however, although the motor interference hypothesis is plausible and has been endorsed in the literature (Paulus et al., 2009; Witt et al., 2010; Yee et al., 2013), it may not test the role of motor activation as conclusively as it first seemed. If conceptual knowledge is grounded in or supported by modal, sensorimotor processes as per embodied cognition theories, then one could also plausibly argue that a secondary task that engages these sensorimotor processes could *facilitate* rather than impair knowledge retrieval. Indeed, even in the current study I proposed such a mechanism in attempting to explain Experiment 1's findings, which reflected a facilitation mechanism, but contrasted Witt et al., whose findings suggested an impairment of knowledge retrieval. Although this idea was inconsistent with the motor interference hypothesis, it was supported by the literature in some respects.

This contradiction highlights a significant issue in this field in that a single, theoretical perspective can predict opposing patterns of results (Willems & Francken, 2012). To provide another example, when processing action language relating to a specific effector (e.g., hand, foot), responses using the relevant effector have both facilitated (e.g., Scorolli & Borghi, 2007) and impaired (e.g., Buccino et al.,

2005) performance compared with an irrelevant effector. In this respect, then, the current research both suffers from and highlights a significant limitation in this field and the need for falsifiable hypotheses, as suggested by Hommel (2015) and Wright (2008). In light of these considerations, it seems unlikely that the motor interference hypothesis will produce a strong test of the role of motor neural activity. Perhaps future research should explore other methodologies for this purpose, such as transcranial magnetic stimulation (TMS) virtual lesion paradigms, as Masson (2015) suggested.

This study also highlights the inconsistent findings within and across object naming paradigms in general and begs the question of why this is the case. Regardless of the direction of expected effects, the current study's lateralised motor tasks had little influence on object naming at all, which is puzzling in light of the considerable evidence for action-related stimulus-response compatibility effects (Ellis & Tucker, 2000; Glenberg & Kaschak, 2002; Grèzes et al., 2003; Tucker & Ellis, 1998, 2001; Zwaan & Taylor, 2006). It is particularly surprising that grip aperture did not influence naming, given that it a) is a stable object property, and b) has elicited action-compatibility effects reliably in other single-task paradigms (Ellis & Tucker, 2000; Grèzes et al., 2003; Tucker & Ellis, 2001; Vainio, Schulman, Tiippana, & Vainio, 2013; Vainio, Tucker, & Ellis, 2007). There is, however, evidence suggesting that a mechanism other than affordance-related motor codes could explain congruency effects relating to left/right handle orientation (handle effect; Anderson et al., 2002; Cho & Proctor, 2010, 2011; Lien et al., 2013). The uncertainty surrounding the handle effect is interesting to note in light the inconsistencies in lateralised object naming. The mechanism underlying the handle effect will be investigated in Chapter 5 of this thesis.

It is also possible that naming paradigms produce especially inconsistent results owing to the use of verbal responses. In support of this idea, psycholinguistic and articulation research has shown high variability in vocal latencies for responses beginning with different phonemes (Kessler, Treiman, & Mullennix, 2002; Rastle, Croot, Harrington, & Coltheart, 2005; Rastle & Davis, 2002). Verbal responses can be particularly variable when collected via a *simple voice-key*, which combines a low-cost microphone and standard experimental software such as E-prime (as in the current study) or DirectRT (as in Matheson, White, et al., 2014a). Witt et al., (2010) did not describe their method of collecting vocal responses. Even Yee et al. (2013) found motor interference only in terms of naming accuracy, not speed, which is another example of inconsistent results across naming paradigms.

Aside from psycholinguistic and articulation studies, there is surprisingly little methodological research into verbal responses. Critically, in the current study, vocal RTs were compared for the same objects across handle side and motor task lateralisation and accordingly, phonetic differences in responses were balanced across experimental conditions. Because phonetic differences were controlled, this variability in vocal RTs does not represent a confound. This claim assumes, however, that voice-key measured RTs effectively reflect the speed and accuracy of another cognitive process of interest, an issue that has not been extensively investigated. In light of the striking inconsistencies discussed in the present work, such an investigation seems warranted. Accordingly, I have conducted an evaluation of voice-key measured verbal responses as a methodology. This evaluation comprises Experiments 5 and 6 of this thesis, and can be found in Appendix B. Results from this evaluation suggested that voice key measurement problems are unlikely to account for the inconsistent results produced in the current chapter, and lend support to the conclusions I have drawn.

To conclude, this study did not find any evidence that a unimanual motor task differentially impaired naming of lateralised, manipulable objects. In line with the motor interference hypothesis, these findings do not support a functional role of motor activation on object recognition. Although this view contrasts Witt et al.'s (2010) original study, the findings add to a growing literature of inconsistent results with respect to interference of a concurrent motor task on object knowledge retrieval (Matheson, White, et al., 2014a; Pecher, 2013; Pecher et al., 2013). This chapter has highlighted significant issues within the motor interference area generally and studies investigating a functional role of motor neural activity. The published literature is highly inconsistent, not only with respect to empirical findings but also the meaningful interpretation of these findings. As such, I argue that it is impossible to provide a coherent appraisal of the area. It is inherently problematic that a single, theoretical perspective can predict opposing patterns of results (Willems & Francken, 2012), thus precluding the development of falsifiable hypotheses. This perspective has been endorsed by other authors, such as Hommel (2015) and Wright (2008). In light of these considerations, I argue that the motor interference hypothesis is unlikely to provide a strong test of the role of motor neural resources on object knowledge. Other methodologies, such as TMS virtual lesion paradigms (Masson, 2015), may be useful in providing future avenues of research in this area; however, such methodologies were not available for future work within the current research programme. The following experimental work within this thesis, therefore, investigates different issues with respect to implicit, lateralised motor activation evoked by manipulable objects.

Chapter 5: Abstract spatial compatibility and the handle effect

This chapter is published in the *Journal of Experimental Psychology: Human Perception and Performance* (Saccone, Churches, & Nicholls, 2016). Co-authors contributed to the conceptualisation of the research design and the editing of the manuscript.

Publication abstract

In object perception studies, a response advantage arises when the handle of an object is congruent with the responding hand. This *handle effect* is thought to reflect increased motor activation of the hand most suited to grasp the object, consistent with *affordance* theories of object representation. An alternative explanation has been proposed, however, which suggests that the handle effect is related to a simple spatial compatibility effect (Simon effect). In three experiments, we determined whether the handle effect would emerge in the absence of explicit spatial compatibility between handle and response. Stimulus and response location was varied vertically and participants made horizontally orthogonal, bimanual responses to objects' kitchen/garage category, colour (as in a traditional Simon effect) or upright/inverted orientation. Categorisation and inversion tasks, which relied on object knowledge, elicited a handle effect and a vertical Simon effect regarding stimulus and response locations. When participants judged object colour, as per standard Simon effect paradigms, the handle effect disappeared but the Simon effect strengthened. These data demonstrate a dissociation between affordance and spatial compatibility effects and prove that affordance plays an important role in the handle effect. Models that incorporate both affordance and spatial compatibility mechanisms are discussed.

Introduction

Humans have a highly developed ability to interact with tools and other manipulable objects. These interactions, which occur frequently throughout the day, involve both the *perception* of objects and *actions* directed towards those objects. A large body of research has demonstrated the interconnectedness of perception and action processes within the brain. For example, neuroimaging and neurophysiological studies have shown purely perceptual tasks that elicit object knowledge can activate motor areas of the brain as well as areas associated with semantic knowledge (Chao & Martin, 2000; Gerlach, Law, Gade, & Paulson, 2002; Gerlach, Law, & Paulson, 2002; Grèzes & Decety, 2002). Similarly, behavioural research has demonstrated response advantages when the action permitted by object stimuli corresponds with the motor act performed in making a response (Makris, Hadar, & Yarrow, 2013; Tucker & Ellis, 1998, 2001, 2004). In light of this evidence, some authors have suggested that attending to an object activates relevant motor programs (Ellis & Tucker, 2000; Pellicano, Iani, Borghi, Rubichi, & Nicoletti, 2010; Tucker & Ellis, 1998, 2001). Accordingly, drawing from Gibson's (1979) theory of *object affordance*, contemporary views of object representation include a role of objects' action-relevant properties, or affordances (Ellis & Tucker, 2000; Hommel, 2002; Tucker & Ellis, 2004).

Perhaps the most cited, but also most debated, behavioural finding for affordance comes from Tucker and Ellis (1998). In this experiment, participants viewed images of objects that appeared upright or inverted and with handles directed toward the left or right. Participants responded with bimanual, left and right key presses to the upright or inverted appearance of each stimulus and were faster and more accurate when the response hand matched the task-irrelevant left/right orientation of the object's handle. The authors did not find this *handle effect* using relative left/right finger responses from one hand, which indicated a critical role of bimanual responses. Consequently Tucker and Ellis suggested that perceiving an object's left or right grasp affordance activated a motor response for the hand most suited to perform that grasp. By this account, the response advantage resulted from motor codes relating to object affordance.

As an alternative to the *affordance* model, a *spatial compatibility* model has also been suggested to explain Tucker and Ellis' (1998) findings. Some authors have attributed the handle effect to the abstract spatial relationship between handle and response locations (Anderson et al., 2002; Cho & Proctor, 2010, 2011; Lien et al., 2013). In behavioural studies, there is a common and reliable response advantage when the relative spatial locations of stimulus and response match rather than conflict, known as the *Simon effect* (Simon, 1969). Similarly, for some (but not all) objects, such as a mug, the handle is the visually salient feature in a relative left or right location, which could result in a left or right response advantage owing to common abstract spatial codes. By this account, Tucker and Ellis' handle effect could simply reflect a within-stimulus Simon effect, arising from the visual salience of the object's handle and spatial compatibility of handle and response locations.

There is in fact considerable evidence for the spatial compatibility explanation. Some studies have shown faster responses to spatially corresponding, salient stimulus features that were not action-relevant (Anderson et al., 2002; Cho & Proctor, 2010, 2011). For instance, Cho and Proctor (2011) removed the handles from teapot silhouettes and found a response advantage for teapots with spatially corresponding spouts. These findings are inconsistent with Tucker and Ellis' (1998) affordance account of the handle effect and speak strongly to an influence of spatial processes. Additionally, although Tucker and Ellis initially discounted a simple spatial compatibility explanation after showing handle effects were specific to bimanual responses, the effect has since been found using unimanual responses (Cho & Proctor, 2010; Vainio, Ellis, et al., 2007), crossed hand, bimanual responses (Phillips & Ward, 2002) and foot responses (Phillips & Ward, 2002; Symes et al., 2005). These findings are consistent with a typical Simon effect (Hommel, 1996; Rubichi, Nicoletti, Pelosi, & Umilta, 2004; Wallace, 1971).

Some authors have argued against the affordance account by showing a *critical* role of spatial compatibility. If handle effects simply reflect spatial compatibility processes and not affordance, then a spatial association between handle and response locations should be necessary to elicit the effect. In line with this idea, using typical, bimanual responses in left and right locations, Lien et al. (2013) found a handle effect, not with centred objects, but when stimuli appeared off-centre in the direction of the handle. That is, the effect only emerged when left-facing handles appeared obviously leftward and vice versa for right-facing handles, when there was an obvious spatial association between handle and response. These results, however, contrast many other studies that have found handle effects with centred images (Goslin et al., 2012; Myachykov et al., 2013; Pappas, 2014; Tucker & Ellis, 1998). Given these conflicting findings, it remains unknown whether or not spatial compatibility is critical to the effect.

In light of evidence for both affordance and spatial compatibility accounts, the current study determined if spatial compatibility entirely explains the handle effect. This study tested whether a paradigm without an explicit, spatial relationship between left/right object handle and left/right response would elicit a handle effect. Stimuli varied in their location (above and below centre) and horizontal orientation (handles facing left and right) and participants responded bimanually on a central, vertical plane (upper, lower). Thus, in this novel paradigm the lateral, spatial compatibility between handle and response was largely absent because a) response locations were horizontally orthogonal and b) the stimulus-response configuration strongly emphasised a vertical rather than horizontal spatial association. Furthermore, this design allowed me to investigate handle effects that related only to response hand, independent of response location, which is consistent with the affordance account. I hypothesised that if spatial compatibility is critical to the handle effect, then the current paradigm should not produce one. Conversely, if affordance-related processes influence typical handle effects, then the effect was expected to emerge despite diminished spatial compatibility.

Experiment 7

Experiment 7 investigated whether my novel paradigm would produce a handle effect from an object categorisation task. Participants were asked to classify stimuli as either typically kitchen or garage objects. This task relies on object knowledge and has been used in previous studies of handle effects (Goslin et al., 2012; Lien et al., 2013; Myachykov et al., 2013; Symes et al., 2005) and other affordance effects (Tucker & Ellis, 2001). Both Goslin et al. (2012) and Myachykov et al. (2013) reported a handle effect for RTs, but not for errors. In contrast, Symes et al. (2005) reported a handle effect for both dependent variables.

Previous research in this field (Goslin et al., 2012; Myachykov et al., 2013; Symes et al., 2005; Tucker & Ellis, 1998) has placed the hands laterally, so that the left and right hands also fall into the left and right hemispaces. As noted above, this hand placement could promote a spatial compatibility effect. The current, study therefore placed the responding hands above and below one another – making the response position orthogonal to the position of the handle. This study is the first to investigate handle effects using vertically discriminated responses. Bearing this manipulation in mind, the following predictions were made. If spatial compatibility entirely accounts for typical handle effects, then the current paradigm was not expected to produce a response hand advantage with respect to object handle. Conversely, if affordances contribute to the handle effect, then faster mean RTs were predicted for trials in which response hand (left, right) and object handle (left, right) matched rather than conflicted. Regardless of findings related to handle orientation, a second congruency effect between upper and lower stimulus and response locations (vertical Simon effect) was expected in both mean RTs and error rates. Consistent with Symes et al. (2005), no interaction between the two compatibility effects was predicted.

Method

Participants. An a priori power analysis (G*Power; Faul, Erdfelder, Lang, & Buchner, 2007) was conducted to inform the sample size of the current study. Using a similar paradigm, Iani et al. (2011) reported an interaction between handle and Simon effects with $\eta^2_p = .4$. The power analysis revealed that a sample size of 15 would be sufficient to detect such an interaction at an α of .05 and a power $(1 - \beta)$ of .95. Accordingly, to ensure ample power, 24 right-handed (20 female, mean age 21.8 years) Flinders University students participated for course credit or a small reimbursement. Only right-handers were recruited, as any differences across handedness were not related to these hypotheses. Handedness was measured by the Flinders Handedness Inventory (Nicholls et al., 2013). Participants were English speakers who reported normal or corrected-to-normal vision and gave informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus. Stimuli were presented on a Dell Optiplex 745 PC with a Dell LCD 21'' monitor (1920 x 1080 pixels) using E-prime 2.0 software (Psychology Software Tools, Inc.; www.pstnet.com/E-prime/e-prime.htm). Responses were recorded from two button boxes connected to a serial response box that was concealed (see Figure 5.1). The button boxes were arranged vertically, facing the participant, attached to a small, wooden stand with Velcro. The stand's vertical panel that faced the participant measured 50mm wide x 240mm high. The wooden stand was secured to the desk at the participant's mid-sagittal plane at a distance of approximately 210mm. A chin rest maintained participants' head position centrally with their eyes level with central fixation at a distance of 480mm from the screen. The experimenter used a small closed-circuit video camera to monitor the participant from behind a partition in the testing room.

Stimuli. Stimuli comprised 176 colour photographs of 44 highly graspable objects (e.g., kettle, mug, knife, watering can) isolated on white backgrounds (see Appendix A for a list of stimuli used in the current study). There were 22 objects from each semantic category (kitchen, garage). A single, colour photograph of each object was obtained from Shutterstock's online database (www.shutterstock.com) or a Google search of copyright-free images. In the original photographs, all objects afforded a single-handed grasp and handles faced toward the left or right. Each object was presented as four unique stimuli, appearing in two horizontal orientations (handles facing left, right) and two locations (upper, lower), while always central on the horizontal plane. Objects' inner edges were 2.4º above or below centre. Objects ranged in size to appear in approximate proportion to one another, for example, the hand saw (210mm x 72mm) was considerably larger than the vegetable peeler (100mm x 17mm). Each stimulus appeared twice, resulting in 8 appearances of each object and 352 trials in total.

Figure 5.1. Illustration of the experimental set-up. Stimuli appeared in upper or lower locations with left or right handle orientations. Example stimulus is in a lower location with left handle orientation.

Procedure. The experiment began with 12 practice trials followed by 352 experimental trials (44 objects x 2 horizontal orientations x 2 locations x 2 repetitions). Stimulus presentation order was randomised. Participants were asked to categorise objects as being from the kitchen or "shed" (an Australian term for garage) as quickly and accurately as possible. Participants responded to kitchen objects with their left hand and shed images with their right. This response mapping was not varied across participants because potential differences between object categories or between left and right response hands were not of interest. Left and right hand location (upper, lower) was counterbalanced across participants. This procedure was used because counterbalancing response mapping and hand location entirely within subjects was anticipated to be too confusing for participants.

Each trial began with a central fixation cross (18mm x 18mm), shown for 500ms, followed by the stimulus, which remained on screen for 1500ms or until a response was made. If a response was not made (missed trials), on-screen text feedback reminded participants to respond as quickly as possible. This message was displayed for 2000ms. When participants responded in time, the inter-trial interval was 500ms. Participants were offered a short break halfway through the experiment.

Results

For simplicity, and because I was interested in compatibility effects between response hand and both handle orientation and stimulus location, data were collapsed across experimental factors to create two independent variables. For *handle*, stimuli and response were congruent when the response hand (left, right) and the objects' handle direction (left, right) matched and were incongruent when they conflicted. For *location*, stimuli and response were congruent when response hand (upper, lower) and stimulus locations (upper, lower) matched and were incongruent when they differed. The approach to collapse across experimental factors was planned along with the study design in order to address the key aim of dissociating spatial compatibility from affordance influences on the handle effect. Presenting results in terms of congruency variables is line with previous handle effect studies (Iani et al., 2011; Pappas, 2014) and moreover, any asymmetries in the effect across handle sides (left, right) are typically either not found (Iani et al., 2011; Tucker & Ellis, 1998), or not of interest and not discussed (Symes et al., 2005). Most importantly, any differences across left or right handle sides would not speak to the mechanism underlying the handle effect in line with the study's aim and, as such, would not represent an alternative to the study's conclusions.

Analyses also included the between-subjects factor of hand placement mapping. Stimulus-response paradigms can elicit an *orthogonal compatibility effect* where there is a right response advantage for upper compared with lower stimuli and vice versa for left responses (Bauer & Miller, 1982; Nishimura & Yokosawa, 2006; Weeks & Proctor, 1990). If right responses map onto the upper spatial dimension and left onto lower, it was considered that in the current study participants with their right hand in the upper position might demonstrate a performance advantage compared with those with the reverse hand placement. Thus, it was important to establish that any handle effects were independent of orthogonal effects with respect to hand placement mapping.

Trials with RTs greater than three standard deviations from each participant's mean, as well as those faster than 200ms were identified as outliers and discarded from all analyses (1.49% of trials).

RTs. RT data from correct trials were analysed using a 2 (handle; congruent, incongruent) x 2 (location; congruent, incongruent) x 2 (hand placement mapping; right-upper/left-lower, right-lower/left-upper) mixed ANOVA. There were main effects of handle and location factors, displayed in Figure 5.2. Participants were faster to respond with the hand that was congruent with the object's handle rather than incongruent, $F(1, 22) = 4.879$, $p = .038$, $\eta^2_p = .182$. There was also a strong main effect of location in that participants were faster to respond to stimuli in congruent than incongruent locations, $F(1, 22) = 21.272$, $p <.001$, $\eta^2_p = .492$. There was no significant interaction between these two factors, $F(1, 22) = 0.743$, $p = .398$, $\eta^2_p = .033$.

There was no main effect of hand placement mapping, $F(1, 22) = 0.599$, $p = .447$, $\eta^2_p = .027$, with similar RTs across participants who responded with their right hand in the upper position ($M = 579.889$, $SD = 66.729$) than those with their left hand in the upper position ($M = 600.976$, $SD = 66.729$). Hand placement mapping did not interact with handle, $F(1, 22) = 0.006$, $p = .937$, $\eta^2_p = .000$, or location factors, $F(1, 22) = 0.007$, $p = .932$, $\eta^2_p = .000$, and the three-way interaction was not significant, $F(1, 22) = 1.181$, $p = .289$, $\eta^2_p = .051$.

Errors. Overall, the mean error rate was 6.261% ($SD = 3.529$). The same ANOVA model was performed on participant error rates and results are displayed in Figure 5.2. There was no significant main effect of handle, $F(1, 22) = 0.204$, $p = .656$, $\eta^2_p = .009$. There was, however, a strong, significant main effect of location, $F(1, 22) = 13.205$, $p = .001$, $\eta^2_p = .375$, in that participants made more errors when responding to stimuli in incongruent rather than congruent locations. There was no interaction between handle and location factors, *F*(1, 22) = 742, *p* = .398, η^2_p = .033.

There was no main effect of hand placement mapping, *F*(1, 22) = 1.250, *p* = .276, η^2_p = .054, with similar error rates across participants whose right hand was in the upper position (*M* = 7.047, *SD* = 3.509) and those with the reverse hand placement (*M* = 5.446, *SD* = 3.509). Hand placement mapping did not interact with handle, *F*(1, 22) = 0.261, *p* = .614, η^2_p = .012, or location factors, *F*(1, 22) = 0.236, *p* = .632, η^2_p = .011, and the three-way interaction was not significant, *F*(1, 22) = 1.082, *p* = .310, η^2_p = .047.

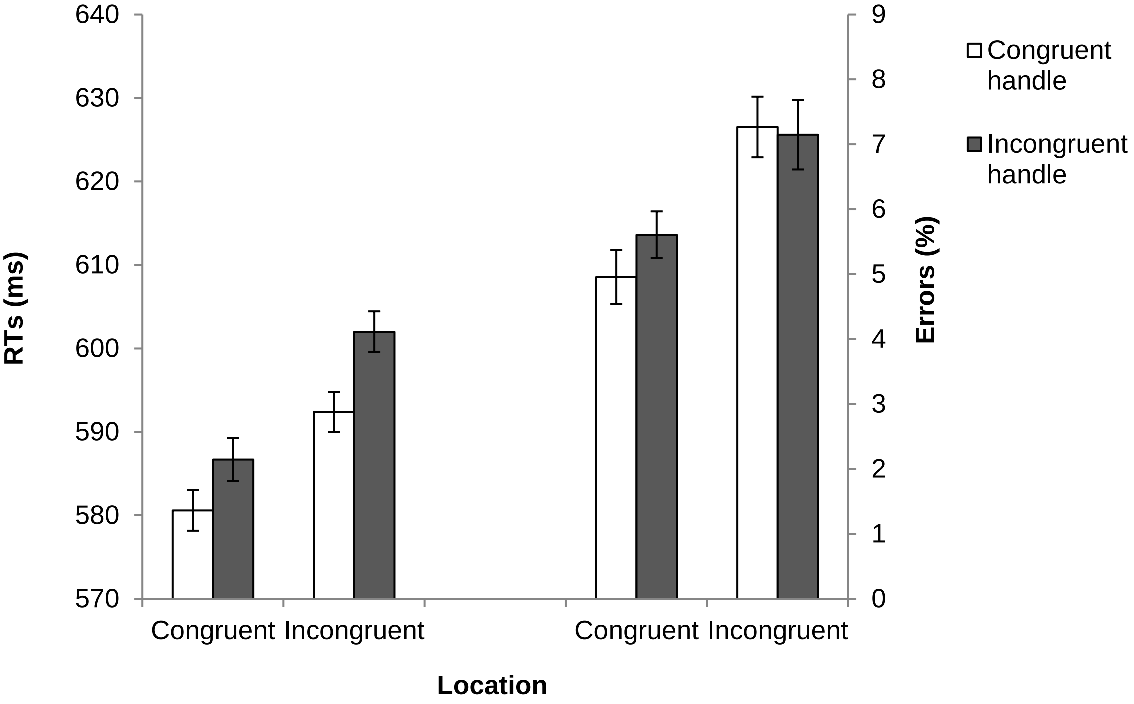

Figure 5.2. Mean correct RTs (ms) and error rates (%) across handle and location congruency factors in Experiment 7. Error bars represent a standard error of the mean calculated within-subjects for each condition.

Inverse efficiency. To complement the results for RTs and errors, analyses were also performed on inverse efficiency scores, which incorporated both response speed and accuracy. Scores were calculated by dividing participant mean RTs by proportion of correct responses for each condition (Townsend & Ashby, 1978). Although inverse efficiency can provide a composite measure of performance, Bruyer and Brysbaert (2011) recommend analyses using these scores complement rather than replace analyses performed on RTs and error rates as distinct dependent variables.

The same ANOVA model performed on inverse efficiency scores revealed a significant main effect of handle, $F(1, 22) = 5.793$, $p = .025$, $\eta^2_p = .208$, with lower, more efficient scores for trials in which response hand was congruent with object handle ($M = 6.260$, $SD = 0.769$) rather than incongruent ($M = 6.370$, $SD = 0.852$). The main effect of location was also significant, $F(1, 22) = 28.028$, $p <.001$, $\eta^2_p = .560$, reflecting an advantage for stimuli in congruent ($M = 6.177$, $SD = 0.843$) over incongruent locations ($M = 6.453$, $SD = 0.784$). There was no interaction between the handle and location factors, $F(1, 22) = 0.022$, $p = .883$, $\eta^2_p = .001$.

There was no main effect of hand placement mapping, $F(1, 22) = 0.152$, $p = .701$, $\eta^2_p = .007$, with similar inverse efficiency scores across the two conditions (right-upper/left-lower $M = 6.251$, $SD = 0.804$; right-lower/left-upper $M = 6.379$, $SD = 0.804$). Hand placement mapping did not interact with handle, $F(1, 22) = 0.308$, $p = .585$, $\eta^2_p = .014$, or location factors, $F(1, 22) = 0.145$, $p = .707$, $\eta^2_p = .007$, and the three-way interaction was not significant, $F(1, 22) = 0.039$, $p = .845$, $\eta^2_p = .002$.

Discussion

The key finding from Experiment 7 was that a handle effect emerged despite diminished spatial compatibility between object handle and the position of the response. Consistent with a number of studies using the categorisation task (Goslin et al., 2012; Myachykov et al., 2013), this congruency effect was reflected in RTs but not errors, perhaps because RT is the more sensitive measure of cognitive processes and therefore more likely to reflect subtle effects. The handle effect was also evident in inverse efficiency scores, which incorporated both response speed and accuracy. As expected, based on a large body of literature (see Lu & Proctor, 1995 for a review), RTs, error rates and inverse efficiency scores showed a strong vertical Simon effect with respect to stimulus and response upper and lower locations. There was no orthogonal compatibility effect regarding hand placement mapping and no interaction with either handle or Simon effects.

Spatial compatibility is unlikely to account for the handle effect in Experiment 7. Lien et al. (2013) employed typical left- and right-located responses and found a handle effect only when stimuli appeared off-centre, when the lateral, spatial association between handle and response was explicit. Centred stimuli did not elicit the effect, despite the lateral response locations, and so the authors proposed that insufficient spatial compatibility led to this null result. The current paradigm reduced spatial compatibility further still than in Lien et al.'s study by employing orthogonal response locations, but the effect was found nonetheless. Spatial compatibility is therefore unlikely to explain the handle effect from Experiment 7. In turn, because the task implicated object representation and the effect related only to response hand, not response location, this finding points to an affordance mechanism.

Despite the evidence against a spatial compatibility account of Experiment 7's handle effect, the finding is in fact consistent with this explanation in one respect. Drawing from Simon effect research, which is relevant to spatial compatibility processes, Proctor, Vu, and Nicoletti (2003) showed that when stimuli vary along horizontal and vertical dimensions simultaneously, a weak, horizontal Simon effect can result from bimanual responses, even when the stimulus-response configuration emphasises a vertical spatial dimension. It seems that the hands as horizontal, left and right effectors can lead to left- and right-coded responses, even when response locations are orthogonal to the horizontal dimension (see Rubichi, Vu, Nicoletti, & Proctor, 2006 for a review). In the current study, therefore, bimanual responses could have produced left and right response codes despite being in upper and lower locations. As such, the handle effect from Experiment 7 may yet reflect a form of spatial compatibility, rather than affordance. Experiment 8 explored this alternative explanation.

Experiment 8

Experiment 8 aimed to determine whether the handle effect from Experiment 7 was driven by spatial compatibility between object handle and left/right response effectors. The paradigm and stimulus set from Experiment 7 were re-used, but objects appeared either red or green and participants responded to object colour instead of semantic category.

Employing this design ensured that the degree of spatial compatibility between handle and response from Experiment 7 remained, while the task-relevance of the object's identity was reduced. Whereas object identification is required to judge semantic category as in Experiment 7, it is not necessary to discriminate object colour. Given that object representation is proposed to include a motor component (Ellis & Tucker, 2000; Hommel, 2002), if object identification is *not* required to discriminate colour then it follows that object-related motor information is unlikely to affect responses to this task (Symes et al., 2005). As such, if object recognition and related motor codes were important in Experiment 7's handle effect, then simple object colour judgement should not produce the effect (Loach et al., 2008; Symes et al., 2005; Tipper et al., 2006). This task can therefore dissociate the spatial compatibility and affordance models (Symes et al., 2005).

In relation to the spatial compatibility model, a colour discrimination task routinely elicits strong spatial compatibility effects in the form of a Simon effect (Ansorge & Wühr, 2004; Hedge & Marsh, 1975; Lu & Proctor, 1995; Proctor et al., 2003). Accordingly, like Experiment 7, a spatial compatibility effect was predicted for the effect of location – where responses to upper and lower images are faster when made with the upper and lower hands (respectively). More importantly, if spatial compatibility accounts for the handle effect from Experiment 7, then a colour judgement task was expected to produce a significant effect of handle as well.

In relation to the affordance model, colour judgement tasks are less likely to elicit handle effects than tasks relying on object knowledge (Loach et al., 2008; Symes et al., 2005; Tipper et al., 2006; but see Cho & Proctor, 2011). These null findings suggest object representation may be important in the effect and in turn support the affordance account. With this in mind, it was predicted that a failure to find a handle effect would support the affordance mechanism proposed in Experiment 7.

Method

Participants. Twenty-five right-handed (18 female, mean age 21.12 years) Flinders University students participated for course credit or a small reimbursement. Handedness was measured by the Flinders Handedness Inventory (Nicholls et al., 2013). Participants were English speakers who reported normal or corrected-to-normal vision and gave informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus and stimuli. All apparatus were identical to Experiment 7. Stimuli were identical except that the objects were coloured red and green. Each object appeared in two horizontal orientations (left, right), two locations (upper, lower), and two colours (red, green), resulting in eight unique stimuli from each object. As in Experiment 7, there were 352 experimental trials in total.

Procedure. The procedure was identical to Experiment 7 except that participants responded to red objects with their left hand and green objects with their right hand.

Results

Data were prepared and analysed in the same manner as in Experiment 7. Outlier RTs were discarded based on the same criteria (1.69% of trials).

RTs. A 2 (handle; congruent, incongruent) x 2 (location; congruent, incongruent) x 2 (hand placement mapping; right-upper/left-lower, right-lower/left-upper) mixed ANOVA was performed on RTs from correct trials. In contrast to Experiment 7, there was no main effect of handle, $F(1, 23) = 2.704$, $p = .114$, $\eta^2_p = .105$. There was a strong, significant main effect of location, $F(1, 23) = 70.596$, $p < .001$, $\eta^2_p = .754$, with faster responses to stimuli in congruent compared with incongruent locations. There was no significant interaction between handle and location factors, $F(1, 23) = 1.149$, $p = .295$, $\eta^2_p = .048$; see Figure 5.3.

There was a significant main effect of hand placement mapping, $F(1, 23) = 5.865$, $p = .024$, $\eta^2_p = .203$. Consistent with an orthogonal compatibility effect, participants with their right hand in the upper position made faster responses ($M = 400.419$, $SD = 48.754$) than participants with their hands in the opposite configuration ($M = 447.684$, $SD = 48.754$). Hand placement mapping did not interact with handle, $F(1, 23) = 0.339$, $p = .566$, $\eta^2_p = .015$, or location factors, $F(1, 23) = 0.041$, $p = .841$, $\eta^2_p = .002$. The three-way interaction was not significant, $F(1, 23) = 0.000$, $p = .992$, $\eta^2_p = .000$.

Errors. The group error rate was 4.058% ($SD = 2.668$). The same ANOVA model performed on error rates showed no main effect of handle, $F(1, 23) = 1.167$, $p = .\ 291$, $\eta^2_p = .048$. Once again there was a strong, significant main effect of location, $F(1, 23) = 33.304$, $p < .001$, $\eta^2_p = .592$, whereby more errors were made for stimuli in an incongruent location. There was no interaction between handle and location, $F(1, 23) = 0.075$, $p = .786$, $\eta^2_p = .003$.

There was a significant main effect of hand placement mapping, *F*(1, 23) = 6.089, $p = .021$, $\eta^2_p = .209$. Participants with their right hand in the upper position (*M* = 2.804%, *SD* = 2.421) were more accurate than those with their right hand in the lower position (*M* = 5.197%, *SD* = 2.423). Hand placement mapping did not interact with handle, *F*(1, 23) = 0.007, $p = .933$, $\eta^2_p = .000$, or location factors, *F*(1, 23) = 1.733, $p = .201$, $\eta^2_p = .070$. The three-way interaction was not significant, *F*(1, 23) = 0.118, $p = .734$, $\eta^2_p = .005$.

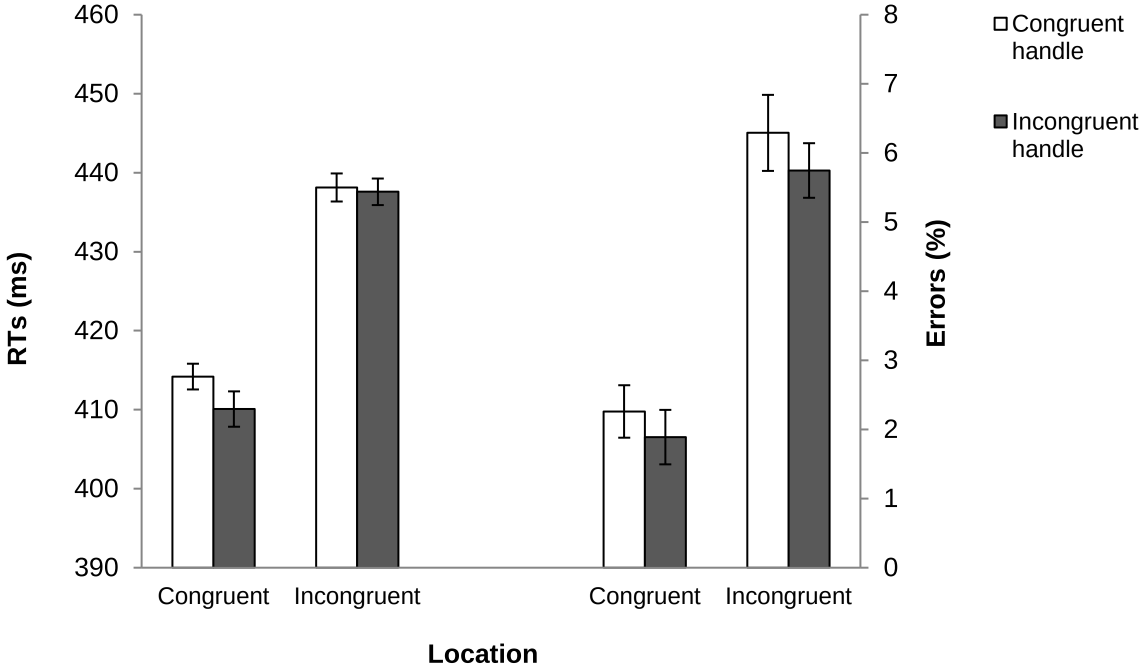

Figure 5.3. Mean correct RTs (ms) and error rates (%) across handle and location congruency factors in Experiment 8. Error bars represent a standard error of the mean calculated within-subjects for each condition.

Inverse efficiency. The same ANOVA model was also performed on inverse efficiency scores. There was no significant main effect of handle, *F*(1, 23) = 2.512, *p* = .127, η^2_p = .098, with similar response efficiency for trials with congruent (*M* = 4.451, *SD* = 0.490) compared with incongruent handles (*M* = 4.405, *SD* = 0.505). The main effect of location was significant, *F*(1, 23) = 59.587, *p* <.001, η^2_p = .722, confirming the response advantage for stimuli in congruent *(M* = 4.200, *SD* = 0.490) over incongruent locations (*M* = 4.656, *SD* = 0.535). There was no interaction between handle and location factors, *F*(1, 23) = 0.257, *p* = .617, η^2_p = .011.

There was a significant main effect of hand placement mapping, *F*(1, 23) = 9.512, *p* = .005, η^2_p = .293, indicating more efficient responses from participants with their right hand in the upper position (*M* = 4.126, *SD* = 0.488) than those with their hands in the opposite configuration (*M* = 4.731, *SD* = 0.490). Hand placement mapping did not interact with handle, *F*(1, 23) = 0.111, *p* = .742, η^2_p = .005, or location factors, *F*(1, 23) = 0.711, *p* = .408, η^2_p = .030, and the three-way interaction was not significant, *F*(1, 23) = 0.031, *p* = .861, η^2_p = .001.

Discussion

The colour discrimination task yielded a strong, vertical Simon effect for RTs, error rates and inverse efficiency scores. This spatial compatibility effect is in line with the reported literature (Ansorge & Wühr, 2004; Hedge & Marsh, 1975; Lu & Proctor, 1995; Proctor et al., 2003) showing that simple discriminations related to colour are sufficient to produce a compatibility effect between hand placement and object location. Despite this strong spatial compatibility effect, there was no sign of a handle effect. Given that affordance may not be evoked by simple colour discrimination judgements (Loach et al., 2008; Symes et al., 2005; Tipper et al., 2006), the results suggest that the handle effect observed in Experiment 7 may be dependent on an affordance mechanism. The conclusion is further strengthened by the fact that the same basic stimuli, with the same asymmetric features were used in both experiments. It seems that the dissociation between the experiments is therefore related to the change in the nature of the discrimination and the degree to which it implicates object knowledge (Loach et al., 2008; Symes et al., 2005; Tipper et al., 2006). In addition to the vertical Simon effect in Experiment 8, there was also an effect of hand placement mapping. RTs, errors and inverse efficiency scores all demonstrated an advantage for right, upper responses and left, lower responses compared with the reverse mapping. Importantly, though, this orthogonal compatibility effect did not interact with handle or Simon effects.

To test whether there was a significant difference between the key results of Experiments 7 and 8, a mixed ANOVA was conducted on mean RTs with experiment entered as a between subjects factor and both handle and location as within subjects factors. This analysis confirmed an interaction between handle and experiment, $F(1,47) = 7.570$, $p = .008$, $\eta^2_p = .139$, demonstrating a significant difference between the handle effect from Experiment 7 and the null effect from Experiment 8. This finding further speaks against a simple spatial compatibility explanation of Experiment 7's handle effect. Moreover, given that object representation was required to perform the task in Experiment 7 but not Experiment 8, these results point to an affordance mechanism in the effect.

There was also a significant difference in the vertical Simon effect across Experiments 7 and 8. The combined analysis described above revealed an interaction between the factors of location and experiment, $F(1, 47) = 8.636$, $p = .005$, $\eta^2_p = .155$. Given that both experiments produced the typical response advantage for stimuli in congruent over incongruent locations, this interaction reflects a significantly stronger Simon effect in Experiment 8. The faster mean RTs in Experiment 8 likely explain this difference, as the Simon effect typically weakens with slower RTs (Hommel, 1994a, 1994b; Kornblum, Stevens, Whipple, & Requin, 1999). Given that the Simon effect reflects spatial compatibility, the stronger effect in Experiment 8 could further suggest that this mechanism does not explain the handle effect from Experiment 7.

In comparing results from Experiments 7 and 8, therefore, there appears to be a dissociation pattern whereby employing a colour discrimination task eliminated the handle effect but strengthened the vertical Simon effect. This dissociation is a novel finding and supports and extends work by Symes et al. (2005). These findings speak against a critical role of spatial compatibility in typical handle effects and point to an affordance mechanism.

One consideration, however, is that Experiment 8's short RTs could explain the absent handle effect if there was simply insufficient time for the effect to manifest in responses. Object handles might not influence responses until *after* attention has first moved to the stimulus if handles are considered object-inherent spatial information (Ansorge, 2003). As stimulus colour is judged quickly and easily, perhaps response codes were activated largely before any specific features of the object had been processed. The stronger vertical Simon effect in this experiment is consistent with the idea that the salient, vertical spatial code affected responses before the relatively more subtle, horizontal spatial code (i.e., handles) became available. In this respect the absent handle effect could be explained by Experiment 8's temporal properties alone, rather than the reduced task-relevance of object representation as I have argued.

Before addressing this alternative explanation for Experiment 8's divergent findings, Experiment 9 was conducted in an attempt to replicate results from Experiment 7 so that data from all three experiments could be considered together. To strengthen the argument for a role of affordance in the handle effect, Experiment 9 employed the current paradigm and a different object knowledge task.

Experiment 9

The current study has demonstrated that a handle effect emerges from a paradigm employing horizontally neutral response locations and a salient vertical, rather than lateral, spatial dimension. The aim of Experiment 9 was to determine if handle effects from this novel paradigm would generalise from object classification (kitchen, garage) to an object inversion task. Accordingly, this experiment employed the task from Tucker and Ellis' (1998) original study, in which participants decide whether an object stimulus is upright or inverted with respect to its normal manner of use. If there is an affordance mechanism in the handle effect, the object inversion task should produce results consistent with Experiment 7, given that both categorisation and inversion tasks rely on object representation, whereas colour discrimination does not.

The object inversion task consistently produces handle effects in mean RTs (Iani et al., 2011; Pappas, 2014; Riggio et al., 2008) and Tucker and Ellis (1998) found the effect in both RTs and error rates. Employing the paradigm from Symes et al. (2005), Iani et al. (2011) used this task to investigate two stimulus-response compatibility effects, one relating to handle orientation and one to left/right stimulus location. They found an interaction between the two effects in one of their experiments, in that a handle effect only emerged when stimulus and response locations were incongruent.

Given that this task implicates object semantic knowledge and typically produces handle effects, results similar to Experiment 7 were predicted. That is, Experiment 9 was expected to produce a handle effect in mean RTs but not error rates. A strong, location-based Simon effect was expected both in RTs and errors. Based on results from Experiment 7, no interaction was predicted between handle and Simon effects.

Method

Participants. Twenty-four right-handed (19 female, mean age 21.54 years) Flinders University students participated for course credit or a small reimbursement. Handedness was measured by the Flinders Handedness Inventory (Nicholls et al., 2013). Participants were English speakers who reported normal or corrected-to-normal vision and gave informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus and stimuli. All apparatus were identical to Experiments 7 and 8. Given that only certain objects have an objectively correct upright orientation during use, the stimulus set was altered in Experiment 9, although the nature of the images was the same as Experiment 7. Stimuli comprised 240 colour photographs of 30 objects, including 16 objects from the first two experiments. Each object was presented as eight unique stimuli, appearing in two horizontal orientations (left, right), two vertical orientations (upright, inverted) and two locations (upper, lower).

Procedure*.* Procedure was identical except that participants were asked to respond to objects' "normal" or "inverted" appearance. The arbitrary term "normal" was used in the instructions rather than "upright" to prevent priming an association with upper locations of stimulus and response owing to lexical similarity. Participants responded to upright objects with their left hand and inverted images with their right.

Results

Data were prepared and analysed in the same manner as in Experiment 7. Outlier RTs were discarded based on the same criteria (1.46% of trials).

RTs. A 2 (handle; congruent, incongruent) x 2 (location; congruent, incongruent) x 2 (hand placement mapping; right-upper/left-lower, right-lower/left-upper) mixed ANOVA was performed on mean RTs from correct trials. Consistent with Experiment 7, there was a main effect of handle, $F(1, 22) = 5.091$, $p = .034$, η^2_p =

.188, with faster responses to stimuli with congruent rather than incongruent handles (see Figure 5.4). As expected, there was a strong main effect of location, $F(1, 22) = 24.200$, $p < .001$, $\eta^2_p = .524$, with a significant speed advantage for stimuli in a congruent location. The interaction between these factors was close to the cut-off for significance, $F(1, 22) = 3.375$, $p = .080$, $\eta^2_p = .133$, and was therefore explored. Paired sampled t-tests revealed that for stimuli in an incongruent location, there was a significant speed advantage for trials in which response hand matched object handle, $t(23) = 3.394$, $p = .002$, *Cohen's* $d = 0.746$. For stimuli in congruent locations, however, there was no response advantage relating to handle orientation, $t(23) = 0.097$, $p = .924$, *Cohen's* $d = 0.020$.

There was no main effect of hand placement mapping, $F(1, 22) = 1.380$, $p = .253$, $\eta^2_p = .059$, with similar RTs across participants who responded with their right hand in the upper position ($M = 627.518$, $SD = 70.089$) than those with the opposite hand placement ($M = 593.905$, $SD = 70.089$). Hand placement mapping did not interact with handle, $F(1, 22) = 0.508$, $p = .483$, $\eta^2_p = .023$, or location factors, $F(1, 22) = 0.166$, $p = .688$, $\eta^2_p = .007$, and the three-way interaction was not significant, $F(1, 22) = 0.144$, $p = .708$, $\eta^2_p = .007$.

Errors. Overall, the mean error rate was 8.491% ($SD = 4.411$). The ANOVA performed on error rates revealed no main effect of handle, $F(1, 22) = 0.189$, $p = .668$, $\eta^2_p = .009$. Consistent with Experiments 7 and 8, there was a main effect of location, $F(1, 22) = 7.968$, $p = .010$, $\eta^2_p = .266$, in that more errors were made for stimuli in incongruent than congruent locations (see Figure 5.4). There was no significant interaction between location and handle factors, $F(1, 22) = 0.342$, $p = .565$, $\eta^2_p = .015$.

There was no main effect of hand placement mapping, $F(1, 22) = 0.381$, $p = .543$, $\eta^2_p = .017$, with similar error rates across participants who responded with their right hand in the upper position ($M = 9.046$, $SD = 4.476$) than those with the opposite hand placement ($M = 7.918$, $SD = 4.476$). Hand placement mapping did not interact with handle, $F(1, 22) = 0.283$, $p = .600$, $\eta^2_p = .013$, or location factors, $F(1, 22) = 0.580$, $p = .454$, $\eta^2_p = .026$, and the three-way interaction was not significant, $F(1, 22) = 1.630$, $p = .215$, $\eta^2_p = .069$.

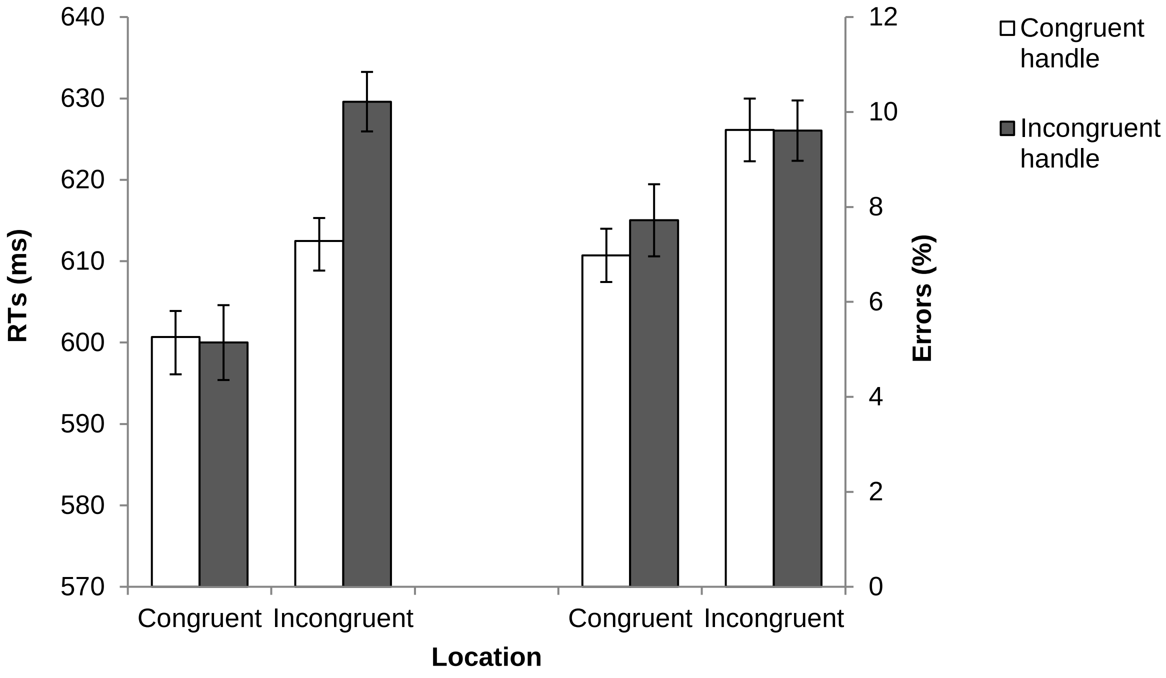

Figure 5.4. Mean correct RTs (ms) and error rates (%) across handle and location congruency factors in Experiment 9. Error bars represent a standard error of the mean calculated within-subjects for each condition.

Inverse efficiency. The same ANOVA model was also performed on scores of inverse efficiency. The main effect of handle was not significant when both response speed and accuracy was taken into account, $F(1, 22) = 2.236$, $p = .149$, $\eta^2_p = .092$, with similar scores for congruent ($M = 6.646$, $SD = 0.872$) and incongruent handles ($M = 6.757$, $SD = 0.848$). The main effect of location was significant, $F(1, 22) = 20.817$, $p < .001$, $\eta^2_p = .486$, confirming the response advantage for stimuli in congruent ($M = 6.505$, $SD = 0.818$) over incongruent locations ($M = 6.897$, $SD = 0.911$). There was no interaction between handle and location factors, $F(1, 22) = 1.487$, $p = .236$, $\eta^2_p = .063$.

There was no main effect of hand placement mapping, $F(1, 22) = 1.909$, $p = .181$, $\eta^2_p = .080$, with similar error rates across participants who responded with their right hand in the upper position ($M = 6.938$, $SD = 0.838$) than those with the opposite hand configuration ($M = 6.464$, $SD = 0.838$). Hand placement mapping did not interact with handle, $F(1, 22) = 0.057$, $p = .814$, $\eta^2_p = .003$, or location factors, $F(1, 22) = 0.733$, $p = .401$, $\eta^2_p = .032$, and the three-way interaction was not significant, $F(1, 22) = 1.716$, $p = .204$, $\eta^2_p = .072$.

Discussion

Findings from Experiment 9 were largely consistent with Experiment 7 despite the change in task and stimuli. A handle effect emerged in RTs, and there was once again a strong, vertical Simon effect in all three dependent variables. There was no evidence of orthogonal compatibility with respect to hand placement mapping, nor did any such effect interact with the handle or Simon effects.

To confirm the consistency in RT results across Experiments 7 and 9, a 2 (experiment; 7, 9) x 2 (handle; congruent, incongruent) x 2 (location; congruent, incongruent) mixed ANOVA was performed on mean RTs. Experiment did not interact with handle, *F*(1, 46) = 0.005, p = .946, η^2_p = .000, or location, *F*(1, 46) = 2.064, p = .158, η^2_p = .043, suggesting handle and location effects were comparable across the two experiments in terms of RT. These results indicate that handle effects from the current paradigm generalise from object categorisation to object inversion. Given that both tasks rely on object semantic knowledge, these findings are consistent with an affordance account of handle effects.

Aside from the similarities between Experiments 7 and 9, a unique finding in Experiment 9 was that for mean RTs, the interaction between the two congruency effects was close to the cut-off for statistical significance. Subsequent analyses showed a handle effect was only present when stimuli and responses were in incongruent locations. Although an interaction of this nature is not typically seen, it is consistent with findings in one of Iani et al.'s (2011) two, very similar experiments also employing an object inversion task. To account for an interaction in one experiment only, the authors noted an overall magnitude difference in mean RTs across the two studies and suggested that different temporal dynamics of the experiments explained the inconsistency. They speculated that the two stimulus components of location and handle might have influenced responses at different stages in response selection and that different temporal dynamics across experiments might have affected these two processes asynchronously. Likewise, in the present study Experiment 7's categorisation task produced slightly faster RTs (*M* = 590.432, *SD* = 66.146) than Experiment 9's inversion task (*M* = 610.712, *SD* = 70.665) and so Iani et al.'s explanation fits with the current findings.

Interpreting these results in the context of Iani et al.'s (2011) findings does not necessarily preclude the current study's conclusions regarding spatial compatibility and affordance influences on the handle effect. Iani et al. investigated how temporal dynamics might influence handle and Simon effects and their interaction, but they did so while interpreting the handle effect in terms of the affordance model. In contrast, the current study aimed to clarify the mechanism underlying the handle effect. It follows that if the stimulus component of handle does in fact influence response codes, it will do so at some point in time, regardless of the mechanism by which this process occurs. Thus, Iani et al.'s findings do not necessarily speak to the current research question of whether spatial compatibility accounts entirely for the handle effect.

In light of the similar findings across Experiments 7 and 9, it is important to consider the alternative explanation for Experiment 8's absent handle effect because it threatens this study's conclusions. RTs were considerably shorter in Experiment 8 than Experiments 7 and 9 and, although it has been argued that the reduced task-relevance of object representation led to the null effect in Experiment 8, conversely it is possible that there was simply insufficient time for the effect to manifest in responses. The stronger vertical Simon effect in this experiment is consistent with the idea that the salient, vertical spatial code affected responses before the relatively more subtle, horizontal spatial code (i.e., handles) became available. In Experiment 9 there was a similar tendency for the handle effect to emerge only in the slower, incongruent location condition, which is consistent with this alternative explanation. In contrast, though, a handle effect was found in Experiment 7 despite *faster* RTs overall than in Experiment 9, which suggests that there was in fact time for the effect to emerge in the congruent location condition of Experiment 9.

In light of the timing differences across experiments, it is nonetheless important to address this alternative explanation for the null handle effect produced by the colour discrimination. As an indication of whether or not Experiment 8's short RTs explain this absence, the temporal development of each experiment's handle effect was investigated (Symes et al., 2005). Participant mean quartile RTs were calculated for congruent- and incongruent-handle trials (Symes et al., 2005) and Figure 5.5 displays the group mean handle effect at quartiles across the three experiments. Experiment 8's null effect contrasts starkly against the significant handle effects from Experiments 7 and 9, which follow a remarkably similar pattern overall despite the different task requirements and stimulus sets employed. Experiment 8's comparatively short RTs are also evident but, importantly, the last two quartiles of Experiment 8 overlap temporally with the first two quartiles of Experiments 7 and 9. During this overlapping period, the handle effect had already begun to manifest in Experiments 7 and 9 but not in Experiment 8. It seems, therefore, that there was sufficient time for handles to influence responses in the latter quartiles but that this did not occur. These observed patterns suggest that the absent handle effect was not simply a function of the time that the handles' horizontal spatial code became available and are inconsistent with a purely temporal account of the null effect. Accordingly it follows that another factor played an important role in preventing the handle effect.

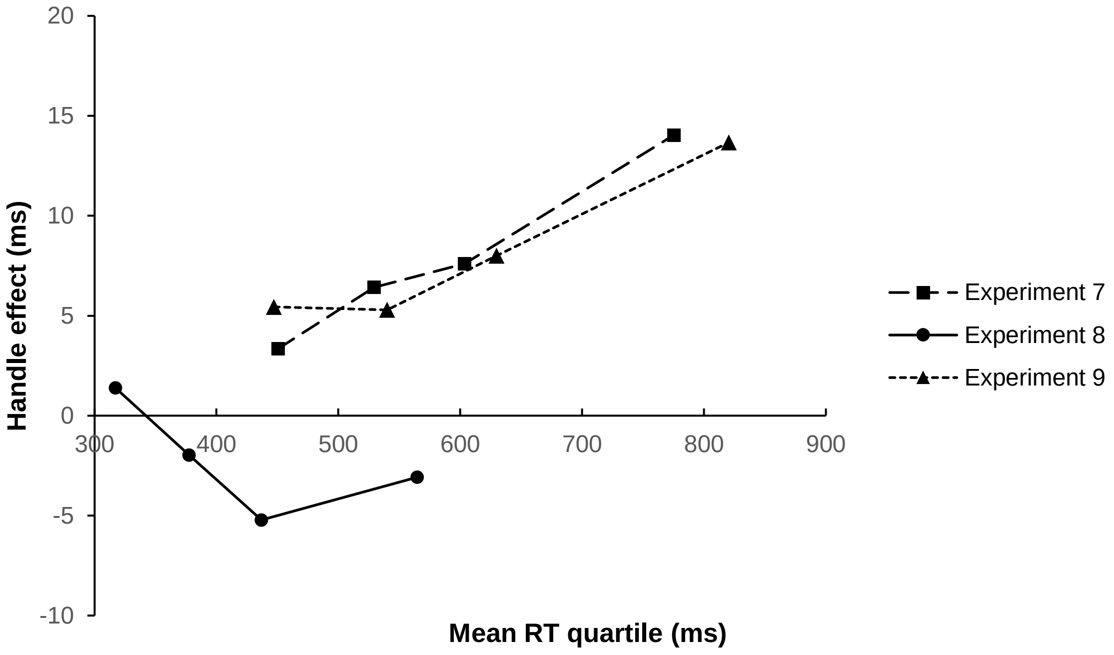

Figure 5.5. Mean quartile RTs (ms) for the handle effect (incongruent – congruent) for Experiments 7, 8 and 9.

Aside from the change in the nature of the discrimination in Experiment 8 and the degree to which it implicated object knowledge, the only other difference in this experiment was the use of coloured stimuli. It is possible this factor contributed to the null effect in that realistic images can be more likely to elicit handle effects (Pappas, 2014), perhaps because realism facilitates object recognition. This idea only supports my interpretation that the reduced task-relevance of object representation led to the absent handle effect, however. Furthermore, it is important to note that the spatial association between handle and response was consistent in strength across all three experiments, so if spatial compatibility accounted for the handle effect in Experiments 7 and 9, then in this respect it should have also produced the effect in

Experiment 8. As such the objects' colouration does not provide an alternative explanation for the null effect.

General Discussion

The current study determined whether spatial compatibility between handle and response is critical to the handle effect. To do so, I used a novel paradigm that controlled response location and strongly emphasised a vertical, rather than lateral, spatial dimension. This is the first handle effect study to employ vertically oriented responses and as such, the findings from all three experiments are novel. Two tasks relying on semantic object knowledge elicited a handle effect in RTs whereas a colour discrimination task did not. All three tasks produced a strong vertical Simon effect with respect to stimulus and response locations, reflected in RTs, error rates and inverse efficiency scores.

The present results suggest that spatial compatibility does not entirely explain the handle effect. In the current study, the spatial association between object handle and response was largely absent but the effect emerged nonetheless. These results contrast with Lien et al.'s (2013) data, which suggested explicit spatial compatibility was critical to the effect. The reason for these inconsistent findings is unclear, although the handle effect in the current study appears robust, as it emerged in two experiments employing different discriminations and stimuli. Moreover, Lien et al.'s conclusions were contingent on a null effect produced by centred images, which contrasts typical findings (Goslin et al., 2012; Myachykov et al., 2013; Pappas, 2014; Tucker & Ellis, 1998).

These results are in turn consistent with an affordance influence on the handle effect. In the current study the effect emerged from two tasks relying on semantic object knowledge, but not from a simple colour discrimination, in which participants were required to attend only to low-level visual features of object stimuli. Examining the handle effect's temporal development across experiments suggested that this absence in Experiment 8 was not simply explained by short RTs. The colour discrimination's failure to elicit a handle effect replicates previous research (Loach et al., 2008; Symes et al., 2005; Tipper et al., 2006) and suggests that object representation and likewise related motor information is important in the effect. Furthermore, consistent with the affordance account, in the current study the handle effect related only to response hand rather response location. Together with other behavioural affordance effects that cannot be explained by spatial compatibility (Makris et al., 2013; Tucker & Ellis, 2001, 2004), as well as neuroimaging and neurophysiological evidence (Chao & Martin, 2000; Gerlach, Law, Gade, et al., 2002; Gerlach, Law, & Paulson, 2002; Grezes & Decety, 2002), these findings support the affordance account of the handle effect.

Despite the current study's support for the affordance account, it remains that there is considerable evidence in the literature in favour of a spatial compatibility mechanism. A number of studies have shown faster responses to spatially corresponding, visually salient stimulus features that were not action-relevant (Anderson et al., 2002; Cho & Proctor, 2010, 2011). Other findings show that handle effects are not limited to bimanual responses (Cho & Proctor, 2010; Phillips & Ward, 2002; Vainio et al., 2007), which is in line with the Simon effect and inconsistent with the affordance account. Moreover, although the current study has demonstrated handle effects can emerge in the absence of explicit spatial compatibility between handle and response, in typical paradigms employing left- and right-located responses there is a strong spatial association between response and lateralised object handles. It follows therefore that spatial compatibility is likely to influence typical handle effects.

To reconcile the strong evidence for both accounts, it may be that both affordance and spatial compatibility mechanisms contribute to the handle effect (Iani et al., 2011; Pappas, 2014; Riggio et al., 2008; Symes et al., 2005). The present research replicates past work showing that two distinct response codes can emerge when processing lateralised object stimuli (Iani et al., 2011; Riggio et al., 2008; Symes et al., 2005), which is consistent with the idea that more than one mechanism could influence the effect. Other researchers have argued that the two accounts are not mutually exclusive and that the effect might result from a complex interplay of both mechanisms (Iani et al., 2011; Pappas, 2014; Riggio et al., 2008; Symes et al., 2005) and the current study's results support this view. Whereas spatial compatibility is likely to influence typical handle effects that feature a strong, lateral spatial dimension, in this study the handle effect persisted even though the lateral spatial association was largely removed. Of note, the current study did not produce any handle effects in error rates, so reduced influence from spatial compatibility processes might explain this absence.

Another possible interpretation is that the handle effect represents a spatial compatibility mechanism that is not identical to a standard Simon effect. Other researchers have proposed that attentional processes are likely implicated in both affordance and spatial compatibility mechanisms (Riggio et al., 2008; Symes et al., 2005) and perhaps object knowledge tasks are more likely to draw attention to object handles through learned, action-related associations. This attentional shift could in turn drive a spatial compatibility mechanism. There is limited eye-tracking research to inform on attentional processes underlying object recognition and they have produced mixed findings. One study showed greater visual attention to object handles (Myachykov et al., 2013) whereas others indicate that functional (i.e., non-graspable) ends of objects receive more attention (Kourtis & Vingerhoets, 2015; van der Linden, Mathôt, & Vitu, 2015). Nonetheless, a purely attentional account of the handle effect does not explain other behavioural findings for affordance that lack spatial compatibility of stimulus and response components, such as grip aperture congruency effects (Makris et al., 2013; Tucker & Ellis, 2001, 2004), including those found with verbal rather than pictorial stimuli (Tucker & Ellis, 2004). Further research using eye-tracking techniques is required to clarify attentional modulation of handle effects.

One final point regards other avenues for future research. The current study did not speak to issues that, although interesting, do not inform the present key research question. For example, it is unknown whether or not handle effects vary across left- and right-handers. Such an analysis was not included in the current study as any effects relating to the dominant hand could be attributed to either motor processes (speaking to the affordance model) or a spatial, attentional bias (relating to the spatial compatibility model; Rubichi & Nicoletti, 2006). In particular it could be interesting to investigate how handedness might moderate handle effects, which rely on online visual processing of handle orientation, as compared with grasp aperture compatibility effects, which reflect more stable object-action associations (Tucker & Ellis, 2004).

On balance, the current study is in agreement with previous calls for a more integrative approach when accounting for handle effects, rather than viewing affordance and spatial compatibility explanations as mutually exclusive. The current study has demonstrated that the effect can emerge in the absence of explicit spatial compatibility, which speaks against a pure spatial compatibility account and points to an affordance influence. It seems likely that spatial processes do influence the effect, however, particularly for typical paradigms where left and right response locations emphasise a lateral spatial association with object handles. Thus, the present research, along with the considerable evidence in the literature for both affordance and spatial compatibility accounts, suggest that the effect reflects a complex interplay of both mechanisms.

Chapter 6: Object affordances in social space

Since submitting this thesis, a version of this chapter has been accepted for publication in *Attention, Perception & Psychophysics (Saccone, Szpak, Churches, & Nicholls, 2017)*. The published version appears in Appendix C. Co-authors contributed to the conceptualisation of the research design and the editing of the manuscript.

Introduction

The physical and social world in which we exist is complex and dynamic, yet we navigate it with remarkable ease. Our rapid, unconscious decision making and motor precision translates to an extraordinary ability to interact with the environment. Without conscious thought, we can effortlessly carry food on a fork to our mouths or transport our bodies through a crowded marketplace, avoiding collisions with the people and objects around us. To account for our remarkable ability to interact with the physical environment, modern cognitive neuroscience research has investigated how the human brain represents objects in the space around our bodies.

Drawing from Gibson's (1979) theory that we directly perceive action afforded by the environment, contemporary object perception research suggests that the brain codes objects as possibilities for action, or *affordances*. For example, a cup affords grasping and a chair affords sitting. In support of contemporary affordance views, there is evidence demonstrating that simply attending to a highly manipulable object can activate related motor programs, even without conscious intention to act on it (Cardellicchio et al., 2011; Chao & Martin, 2000; Gerlach, Law, & Paulson, 2002;

Grèzes & Decety, 2002; Tucker & Ellis, 1998). Findings from Witt and colleagues have further shown that our ability to act on an object influences our reported experience of it (see Philbeck & Witt, 2015; Witt et al., 2015 for reviews). For example, participants who were able to reach an object using a long tool reported the object as closer than participants without a tool (Witt & Proffitt, 2008). These findings highlight the tight link between action processes and object perception, in line with the idea that we perceive action possibilities, or affordances, in the physical environment.

Objects are not the only action-relevant stimuli in the environment, however; humans are highly social and the other people around us affect how we move our bodies and interact with the physical world. Others can afford us possibilities for action that would not otherwise be available. For instance, two people can work together to perform a task that an individual acting alone could not achieve, like carrying a heavy table (Pezzulo, Iodice, Ferraina, & Kessler, 2013; Richardson, Marsh, & Baron, 2007). The others around us also influence our motor planning and behaviour even when we are acting independently. For example, we account for the presence of others when simply walking down a street (Soper & Karasik, 1977) and adjust our gestures during speech (Özyürek, 2002) based on the location of others.

One way the people around us can constrain our actions relates to our perceived ownership of the space immediately surrounding our bodies. We typically view our near-body space as our own private or *personal space* (Hall, 1966). Most of us alter our behaviour to maintain a comfortable distance from others, for example when choosing a seat on public transit, or even opting to stand instead (Evans &

Wener, 2007; Hirsch & Thompson, 2011), as unwelcome personal space invasions are often associated with discomfort and physiological arousal (Evans & Wener, 2007; Perry, Rubinsten, Peled, & Shamay-Tsoory, 2013). Social comfort distances vary depending on many social and cultural factors but are generally between 500mm-800mm (Kennedy, Gläscher, Tyszka, & Adolphs, 2009; Lloyd, 2009; Szpak, Nicholls, Thomas, Laham, & Loetscher, 2016; Tajadura-Jiménez, Pantelidou, Rebacz, Västfjäll, & Tsakiris, 2011). In crowded situations where people are forced into uncomfortable social distances, many people engage in private behaviours, like listening to music or using smartphones (Hirsch & Thompson, 2011). These behaviours are thought to reduce the salience and discomfort of personal space invasions (Lloyd, Coates, Knopp, Oram, & Rowbotham, 2009; Tajadura-Jiménez et al., 2011). Our desire to maintain a certain distance from others, particularly strangers, likely serves an adaptive function in interest of protecting our bodies from unwanted physical contact (de Vignemont & Iannetti, 2015; Graziano & Cooke, 2006). Furthermore, research suggests that we are aware of and represent the near-body space of other people (Brozzoli, Gentile, Bergouignan, & Ehrsson, 2013; Maister, Cardini, Zamariola, Serino, & Tsakiris, 2015), which may also contribute to maintaining comfortable social distances.

Near-body space is not only socially relevant, however; it is also the region in which we are most likely to interact with objects in the physical environment. In fact, cognitive neuroscience has provided evidence that the brain uniquely represents near-body space by its potential for action and interaction with the physical world (e.g., Fogassi et al., 1996; Graziano & Gross, 1994; Rizzolatti et al., 1997). This practical, motor-based representation of close, actionable space, known in the neuroscience literature as *peripersonal space* (Rizzolatti et al., 1997) is neurologically distinct from *extrapersonal*, far space, which is less relevant for body-environment interactions (see Cléry et al., 2015 for a review). Accordingly, research demonstrates that affordances are more likely to activate motor programs for objects located within peripersonal space than extrapersonal space (Cardellicchio et al., 2011; Costantini et al., 2010; De Stefani et al., 2014; Kalénine et al., 2016; but see Tucker & Ellis, 2001). For example, Cardellicchio et al. (2011) provided evidence of greater grasp-related motor activation when participants viewed graspable objects in reachable compared with non-reachable space. Near-body space, therefore, is an important region for action and interaction with both inanimate objects as well as people.

Given that both the objects and people near our bodies drive our motor plans and behaviour, it is surprising that there is so little research into how these two types of action-relevant stimuli interact in their effect on our perception and motor processes. Object affordance research is typically conducted on participants in isolation, in keeping with the tradition of experimental psychology to keep extraneous variables to a minimum. There has, however, been a recent trend to include social variables in research into action processes , but these studies have often investigated how participant pairs coordinate to perform a collaborative, joint task (Ciardo, Lugli, Nicoletti, Rubichi, & Iani, 2016; Sebanz, Bekkering, & Knoblich, 2006). There is certainly research suggesting we recognise and represent the action possibilities of other people (see Creem-Regehr, Gagnon, Geuss, & Stefanucci, 2013 for a relevant review), including with respect to manipulable objects (Constable et al., 2016; Costantini, Committeri, & Sinigaglia, 2011), but once again these studies typically focus on how these processes facilitate joint or coordinated action. An important question remains, however, as to how the presence of other actors around us affects how we process and interact with the physical environment. In our highly social world we frequently act in cooperation with others; however, other times we act in spite of others. Given our strong desire to preserve our near-body space from strangers, and to avoid entering theirs, there is an intriguing question of how this instinctive drive influences how we process and interact with manipulable objects in space that is 'near' more than one person.

The present study investigated object affordances in space shared between two human strangers in close proximity, henceforth referred to as *social space*. Accounting for the people around us is critical to successful and socially appropriate interactions with the environment. Therefore, investigating how close interpersonal proximity affects action planning and related perception is fundamental to understanding how these processes operate in an ecologically valid way. Accordingly, the current study provides an important step in understanding object affordances, and associated motor activation, in a real world, social context.

Although little is known of object affordances in social space, there is research that suggests action-related processes are modulated within near-body space that is shared between two people. Heed, Habets, Sebanz, and Knoblich (2010) showed that two actors integrated visual and tactile stimuli differently when they shared space by holding onto the same experimental apparatus. These results suggest altered multisensory coding of stimuli within social space. Constable et al. (2015) also suggested that the way space is represented as ‘near’ in egocentric terms changes when another actor enters that space, owing to the way the other represents it as their own near, action space. Similarly, neuroscience research into peripersonal space has shown that the boundary of what the brain codes as actionable space is flexible and dynamic (see Maravita et al., 2003 for a review), and findings from Teneggi et al. (2013) suggest the boundary of actionability can be socially modulated. They showed that another person standing nearby caused an inward contraction of peripersonal space boundaries. When the other person demonstrated intent to cooperate, however, peripersonal space boundaries expanded to include the co-actor.

This research suggests that coding of shared, social space involves a complex and interdependent representation of one’s own near-body space and that of other actors. In light of this research, and given our strong desire to maintain comfortable social distances whenever possible, I propose that there is a perceptual division of space between two strangers acting independently in close proximity. This division in turn may modulate the processing of action-relevant stimuli within social space and I reasoned that this modulation would apply to object affordances. If attending to nearby objects activates affordance-related motor programs, and if close space between two strangers is segmented or divided to preserve independent near-body space boundaries, then an object in shared, social space is likely to be processed differently than if it were located near one person only. The present study therefore sought to answer the following question: If an object located in near space is closer to another actor, does it still activate affordance-related motor codes?

Experiment 10

To investigate object affordances in social space, participants in Experiment 10 performed an object recognition task both alone and together with a stranger (confederate) standing in close proximity. Both the participant and the confederate viewed object images from opposite sides of a flat screen, illustrated in Figure 6.1. Objects either appeared nearer the participant or nearer the confederate but, importantly, were always within the participant's close, reachable space.

To test affordance-related motor processing, the study employed Tucker and Ellis' (1998) object inversion task. Participants viewed object images and responded with a bimanual key press to the objects' upright or inverted orientation. Critically, all objects afforded a single-handed grasp and appeared with handles facing the left or right. Although the stimulus feature of handle orientation is task-irrelevant, this task elicits a robust response speed advantage for trials in which object handle (left, right) and response hand (left, right) correspond rather than conflict (Iani et al., 2011; Pappas, 2014; Riggio et al., 2008; Saccone et al., 2016; Tucker & Ellis, 1998). This congruency effect is primarily thought to reflect a match between the action afforded by the object (left- or right-handed grasp) and the action performed in making a response (left- or right-handed key press). This task lends itself to the current paradigm because two people facing one another can perform it concurrently in that an object appearing upright for one person appears inverted to the other.

The following key results were predicted. The typical handle congruency effect was expected to emerge in RTs. That is, faster responses were expected for trials in which object handles (left, right) matched rather than conflicted with response hand (left, right). The critical prediction was that the handle effect would interact with alone/joint condition and object proximity (near participant, far from participant). It was reasoned that if social space is divided or segmented between strangers in order to preserve near-body space boundaries, then in the presence of the confederate, only objects closer to the participant would elicit the handle effect. When participants performed the task alone, however, I expected the effect to emerge for objects in both locations because both objects were in reachable space.

Method

Participants. A priori power analyses were conducted to inform participant recruitment numbers (G*Power; Faul et al., 2007). At an α of .05 and a power ($1 - \beta$) of .95, it was determined that 33-42 participants were required to detect an interaction of moderate effect size ($\eta^2_p = 0.25 - 0.30$). Thus, we aimed to recruit approximately 40 participants, which is highly consistent with previous studies employing joint task paradigms (Constable et al., 2015; Sebanz, Knoblich, & Prinz, 2003). Thirty-nine right-handed (20 female, mean age 24.51 years) Flinders University students participated for a small reimbursement. Handedness was measured by the Flinders Handedness Inventory (Nicholls et al., 2013). Participants were English speakers who reported normal or corrected-to-normal vision and gave written, informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

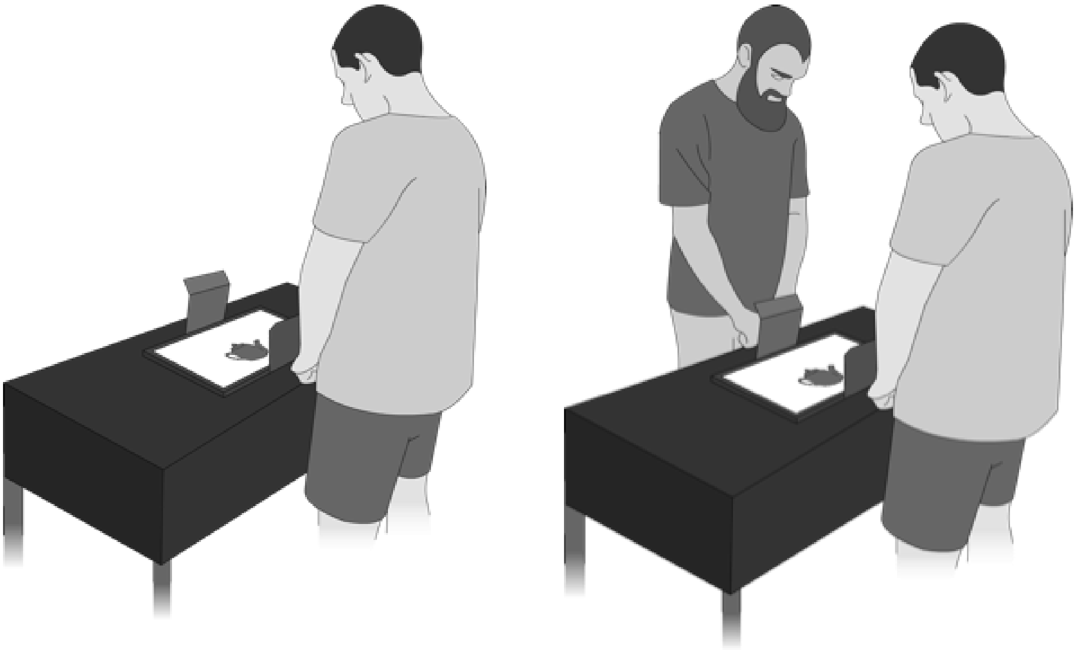

Figure 6.1. Illustration of the experimental set-up when participants performed the task alone (left panel) and with the confederate (right panel).

Apparatus. Stimuli were presented with a Dell Optiplex 745 PC and a LCD 23'' monitor (5182mm x 2921mm) using E-prime 2.0 software (Psychology Software Tools, Inc.; www.pstnet.com/E-prime/e-prime.htm). The monitor was embedded in a table, facing upwards, 790mm from the floor (see Figure 6.1). The table was 1200mm long and 600mm wide. Responses were recorded via a numeric keypad, located at the participant's mid-sagittal plane, in line with the screen's horizontal centre. The confederate responded via an identical keypad but his responses were not recorded. The keypads were placed within black cardboard boxes to obscure responses from the other's view. The experimenter monitored the session using a small closed-circuit video camera.

Stimuli. Stimuli were colour photographs of 30 highly graspable objects (e.g., kettle, mug, watering can) which had an objectively correct upright orientation during use. This stimulus set was identical to that employed in Experiment 9 of the previous chapter. Object location was varied distally with respect to the participant, with objects' inner edges 20mm from centre. Owing to the narrow table, all objects were in the participant's reachable space (within a range of approximately 150mm-450mm) but were relatively near to or far from the participant. Each object appeared eight times, presented in two horizontal orientations (handle facing participant's left, right), two vertical orientations (upright, inverted) and two locations (near participant, far from participant), resulting in 240 unique trials. Objects ranged in size to be in approximate proportion to one another, for example, the hand saw (210mm x 72mm) was considerably larger than the vegetable peeler (100mm x 17mm).

Procedure. Participants entered the laboratory to find the confederate (male, aged 21) already present. The confederate was instructed to maintain a neutral demeanour throughout the session and not to initiate any conversation or engage greatly with the participant. The experimenter explained to the participant and confederate (henceforth referred to as the actors) that the experiment comprised three blocks, one each that they would perform alone and one together, although in reality only the two blocks including the participant were performed. The actors then gave informed consent to participate.

The experiment began with 12 practice trials, which the actors completed together, followed by two experimental blocks, each comprising 240 trials (30 objects x 2 horizontal orientations x 2 vertical orientations x 2 locations). Blocks varied by alone/joint condition (alone, with confederate), the order of which was counterbalanced across participants. The Flinders Handedness Inventory was completed in between blocks, when participants were also offered a short break.

The actors were asked to respond to each object's "normal" or "inverted" appearance as quickly and accurately as possible, regardless of object location. Responses were left and right key presses, with response mapping counterbalanced across participants. Actors were asked to stand with their thighs touching the table so that their viewing position remained constant throughout the experiment. Stimulus presentation order was randomised.

In the joint block, participant and confederate responded to each stimulus concurrently, giving opposing correct responses given their contrasting viewpoints. Only the participant's responses were recorded, however. Owing to the width of the table, when performing the task together the actors stood approximately 600mm apart, with a distance of approximately 450mm between their hands. The confederate was quiet and focused on the task, maintaining a constant gaze on the experimental display in order to encourage the participant to behave likewise.

Each trial began with a central fixation cross (18mm x 18mm), shown for 500ms, followed by the stimulus, which remained on screen for 1500ms or until the participant responded. If no response was made (missed trials), on-screen text feedback reminded the actors to respond as quickly as possible. This message, displayed for 2000ms, appeared in two orientations so it could be read by both participant and confederate. Where participants responded in time, the inter-trial interval was 500ms.

After the two experimental blocks were completed, participants were told that there would not be a third block and that the experiment was finished. Participants were debriefed appropriately and thanked for their time.

Results and discussion

Data analysis. For simplicity, and because I was interested in spatial congruency effects relating to object handle and response, data were collapsed across response (left, right) and object handle side (left, right) to create the factor of handle (congruent, incongruent). Congruent trials were those in which the response and handle side matched and incongruent trials were those in which they conflicted. Although this congruency effect reliably manifests in response speed, error rates often fail to produce an effect (e.g., Constable et al., 2011; Iani et al., 2011; Riggio et al., 2008), including in the previous chapter of this thesis. Furthermore, findings from Chapter 5 of this thesis suggest that affordance processes are not the primary mechanism underlying the effect in errors when it is found. Accordingly, only the RT data were analysed in the current study. Preliminary error analyses suggested that a speed/accuracy trade off did not counteract the key experimental hypothesis. Data from two male participants were excluded from analyses owing to error rates above chance, which were also above three standard deviations from the sample mean

(16.350%, *SD* = 18.534). Once these participants were removed the group error rate was 12.490% (*SD* = 8.025).

Although the factors of participant sex and stimulus upright/inverted orientation did not inform the study's a priori hypothesis, it was considered they could influence responses. Including these additional variables would result in a highly complex factorial design and a 5-factor ANOVA model that would be difficult to interpret. Accordingly, these additional factors are not included in the analysis presented below, but results from the larger, 5-factor ANOVA model is available in Appendix D. Of note, there was no main effect of participant sex and neither sex nor upright/inverted orientation interacted with alone/joint condition and therefore do not counteract the study's key hypothesis. All significant effects detailed below remained significant in the larger, 5-factor ANOVA model.

RTs. A 2 (alone/joint condition; alone, confederate present) x 2 (handle; congruent, incongruent) x 2 (object proximity; near participant, far from participant) repeated measures ANOVA was conducted on mean RTs from correct trials. There were main effects of alone/joint condition and handle, displayed in Figure 6.2. Participants made faster responses in the presence of the confederate (*M* = 563.193, *SD* = 72.335) than when performing the task alone (*M* = 603.196, *SD* = 75.248), *F*(1, 36) = 11.828, *p* = .001, η^2_p = .247. This likely reflects a social facilitation effect (Zajonc, 1965), whereby performance is enhanced in the presence of others. Mean RTs also showed the typical handle effect (Iani et al., 2011; Pappas, 2014; Riggio et al., 2008; Tucker & Ellis, 1998) in that participants were faster to respond with the hand that was congruent with the object's handle (*M* = 576.660, *SD* = 67.669) rather than incongruent (*M* = 598.730, *SD* = 63.265), *F*(1, 36) = 16.647, p <.001, η^2_p = .316. There was no main effect of object proximity, *F*(1, 36) = 0.684, p = .414, η^2_p = .019 and no significant 2-way interactions, all *F*s <0.945, *p*s >.337, but there was a significant 3-way interaction between alone/joint condition, handle and object proximity[2], *F*(1, 36) = 4.451, p = .042, η^2_p = .110.

To explore the significant 3-way interaction, separate 2 (handle) x 2 (object proximity) repeated measures ANOVAs were performed for the alone/joint conditions. There was no significant interaction between handle and object proximity for the alone condition, *F*(1, 36) = 0.649, p = .426, η^2_p = .018, indicating a comparable handle effect for both near (congruent *M* = 597.141, *SD* = 74.244; incongruent *M* = 608.765, *SD* = 76.440) and far objects (congruent *M* = 594.702, *SD* = 83.864; incongruent *M* = 612.177, *SD* = 77.301). There was, however, a significant interaction between handle and object proximity for the confederate condition, *F*(1, 36) = 6.554, p = .015, η^2_p = .154. Paired sample t-tests revealed that, when the confederate was present, the handle effect was elicited by near objects (congruent *M* = 555.806, *SD* = 75.942; incongruent *M* = 574.579, *SD* = 74.105), *t*(36) = 3.731, p = .001, d = 0.614, but not far objects (congruent *M* = 558.989, *SD* = 77.818; incongruent *M* = 563.399, *SD* = 68.257), *t*(36) = 1.095, p = .281.

These findings support the study's central hypothesis. All objects were located within near-body, reachable space of participants but when a stranger was acting in close proximity, only nearer objects elicited the handle effect. When participants

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[2] Of note, this interaction was also significant in the larger, 5-factor ANOVA detailed in Appendix D, *F*(1, 34) = 4.957, p = .033, η^2_p = .127.

were alone, however, the effect was evident for both near and far objects. In line with evidence for modulated processing of action-relevant stimuli in social space (Constable et al., 2015; Heed et al., 2010; Teneggi et al., 2013), and given that humans are instinctively motivated to preserve personal space boundaries (Evans & Wener, 2007; Hirsch & Thompson, 2011; Soper & Karasik, 1977), in Experiment 10 it seems that another actor in close proximity led to a perceptual division of social space, such that far objects no longer produced the same degree of lateralised, affordance-related motor activation.

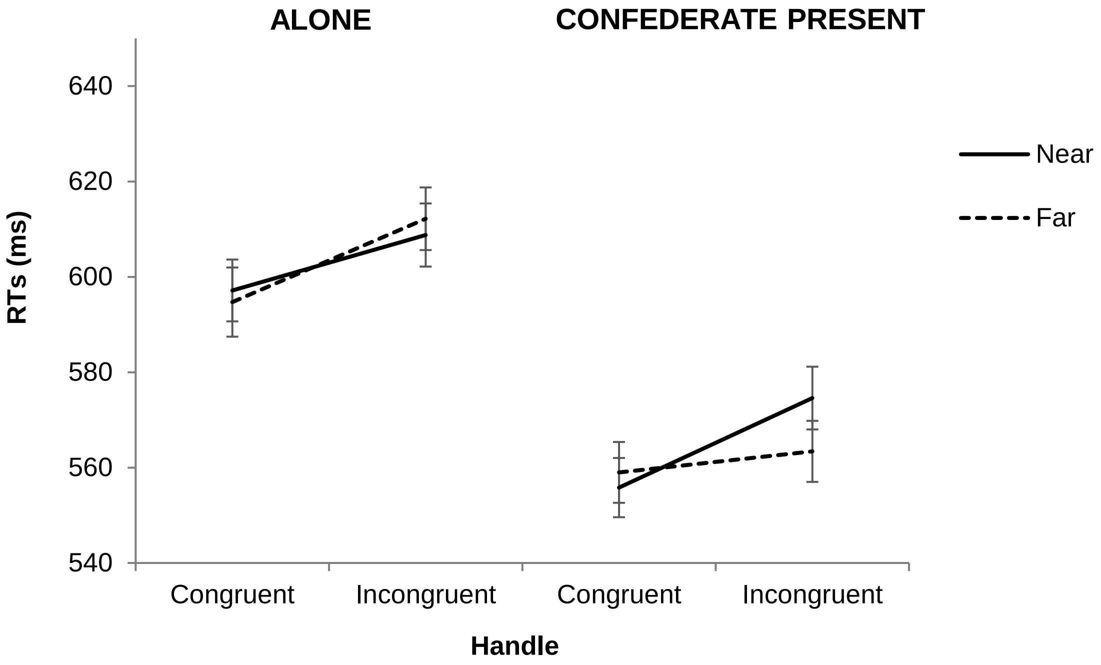

Figure 6.2. Mean correct RTs (ms) across handle and proximity factors for the alone condition (left) and the confederate condition (right) in Experiment 10. Error bars represent a standard error of the mean calculated within-subjects for each condition.

I have interpreted the current findings as a social phenomenon, but alternatively it is possible that a non-social joint condition would produce the same pattern of results. Perhaps the human, biological agency of the confederate was not critical in eliciting these effects. The confederate may simply have served as a distractor that participants attempted to ignore, leading them to neglect near-confederate space and stimuli within it (Tipper, 1985). Certainly it is possible that the close proximity of the confederate caused an inward or proximal withdrawal of the participant's attention (Szpak et al., 2015), although such a process would not necessarily preclude the proposed mechanism of a perceptual division of social space. Critically, in Experiment 10, social presence differentially influenced RTs *only with respect to object affordance*, with no overall reduced RT for far objects. In other words, if a simple distractor mechanism explained the current results, one would expect slower responses overall for far objects in the joint condition, which was not the case. Even if there was an element of attentional withdrawal or an attentional mechanism, therefore, it only affected the visuomotor processing of stimuli (i.e., motor congruency between responses and objects' affordances), not object identification overall. As such, the findings speak against a general attentional or distractor mechanism.

Although the data are not consistent with a simple distractor explanation, it is nonetheless important to provide stronger evidence that these findings represent a social phenomenon. In order to confirm a social mechanism underlying Experiment 10's key interaction, two further experiments were conducted, each employing a non-human distractor object in the joint condition instead of a human confederate. I adapted a methodology from Dolk, Hommel, Prinz, and Liepelt (2013), as described below, whereby the social nature of the distractor objects was reduced in a stepwise manner across the experiments. As I was distinguishing between a social rather than general, attentional mechanism, highly visually and/or aurally salient distractor objects were chosen for the joint conditions in the following two experiments.

Experiment 11

Experiment 11 was conducted to determine whether Experiment 10's key finding was truly a social effect, dependent on the human, biological agency of the confederate. The joint condition in Experiment 11 was adapted from the spatial compatibility literature, in which a similar issue has arisen. To explain, Sebanz et al. (2003) conducted a collaborative task between participant pairs, whereby each member was asked to respond to one of two stimulus colours. They found participants sitting on the left were faster to respond to left- rather than right-located stimuli and vice versa for participants sitting rightward. This stimulus-response spatial compatibility disappeared when participants performed the task alone, even though participants were still sitting in left or right locations. Dolk et al. (2013) subsequently tested whether this joint task effect was truly social in nature with a series of experiments employing visually and/or aurally salient, non-human objects in the joint condition. The authors systematically reduced the “socialness” of distractor objects across each of their experiments. The first, most social of these non-human objects was a gold, Japanese waving cat statue.

Thus, Experiment 11 employed the method from Experiment 10 but in the joint condition participants performed the task in the presence of a small, gold, waving cat statue rather than a human stranger. In line with Dolk et al.'s (2013) reasoning, the statue was a sufficiently visually and aurally salient non-human object due to its moving arm.

The following predictions were made. If the finding from Experiment 10 was driven by a general attentional, distractor mechanism, then similar results were expected in Experiment 11. Specifically, the critical 3-way interaction from Experiment 10 would be replicated, whereby the joint (cat) condition elicited a handle effect for near but not far objects, whereas the alone condition produced the effect for objects in both locations. If the key finding from Experiment 10 did in fact represent a social phenomenon, reflecting visuomotor modulation within social space, then Experiment 11 was not expected to produce a 3-way interaction between alone/joint condition, handle and object proximity. In this case it was expected that objects in both locations would elicit handle effects, regardless of alone/joint condition.

Method

Participants. Forty-one right-handed (20 female, mean age 21.98 years) Flinders University students participated for a small reimbursement. Handedness was measured by the Flinders Handedness Inventory (Nicholls et al., 2013). Participants were English speakers who reported normal or corrected-to-normal vision and gave written, informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus and stimuli. All apparatus and stimuli were identical to Experiment 10 with the addition of the cat statue. The cat measured 205mm high, 120mm wide and 110mm deep, and its left arm waved at a frequency of 0.55 Hz, accompanied by a soft, rhythmic noise.

Procedure. Procedures were the same as Experiment 10 except with respect to the confederate. Rather than performing the task with another person, participants were asked to complete two experimental blocks, one in the presence of the cat statue. During the joint condition, the cat was positioned on the table in place of the confederate's key pad, to ensure it was sufficiently visually salient.

Results and discussion

Data analysis. Data from two male participants were excluded from analyses owing to error rates greater than three standard deviations from the group mean (10.520%, *SD* = 7.896). After removing these two participants, the group error rate was 9.220% (*SD* = 5.492).

RTs. A 2 (alone/joint condition; alone, cat present) x 2 (handle; congruent, incongruent) x 2 (object proximity; near participant, far from participant) repeated measures ANOVA was conducted on mean RTs from correct trials (see Figure 6.3). Unlike Experiment 10, there was no main effect of alone/joint condition (alone *M* = 609.806, *SD* = 62.927; joint *M* = 605.635, *SD* = 79.310), *F*(1, 38) = 0.106, *p* = .747, η^2_p = .003, suggesting the effect from Experiment 10 was in fact social facilitation. There was a significant main effect of handle, *F*(1, 38) = 11.225, *p* = .002, η^2_p = .228, reflecting the typical response speed advantage for congruent (*M* = 601.798, *SD* = 62.995) over incongruent handles (*M* = 613.642, *SD* = 57.643) as seen in Figure 6.3. The main effect of object proximity was not significant, *F*(1, 38) = 1.037, *p* = .315, η^2_p = .027, and there were no significant 2-way interactions, all *F*s <0.019, *p*s >.890.

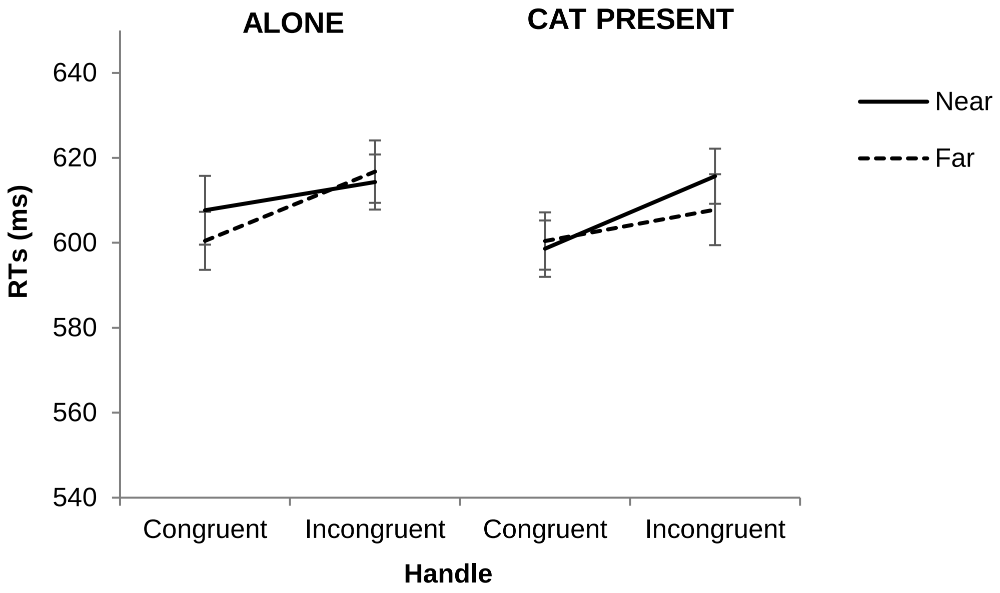

Figure 6.3. Mean correct RTs (ms) across handle and proximity factors for the alone condition (left) and the cat condition (right) in Experiment 11. Error bars represent a standard error of the mean calculated within-subjects for each condition.

The critical 3-way interaction between alone/joint condition, handle and object proximity was not significant, *F*(1, 38) = 3.613, *p* = .065, η^2_p = .087, but it was close to the conventional cut-off for statistical significance. As seen in Figure 6.3, there appears to be a trend for a weaker handle effect for far compared with near objects in the cat present condition, which is consistent with Experiment 10. In light of this pattern, and given its theoretical importance to the study, this non-significant 3-way interaction was investigated further. Separate 2 (handle) x 2 (object proximity) repeated measures ANOVAs were performed for the alone/joint conditions. The interaction between handle and object proximity was neither significant in the alone, $F(1, 38) = 1.981$, $p = .167$, $\eta^2_p = .050$, nor cat present conditions, $F(1, 38) = 2.059$, $p = .159$, $\eta^2_p = .051$.

Last, it was considered the visual asymmetry of the cat's waving left arm might represent a confound and influence responses in the cat present condition. Accordingly, the ANOVA model described above was performed again but with the factor of handle (congruent, incongruent) replaced with response hand (left, right) and object orientation (handle facing left, right). Results from this larger, 4-factor model are available in Appendix E. Importantly, the critical 4-way interaction between alone/joint condition, object proximity, response hand and object orientation remained nonsignificant, $F(1, 38) = 3.495$, $p = .069$, $\eta^2_p = .084$, and alone/joint condition did not interact with any other factors, *F*s <1.891, *p*s >.177.

These findings support a social interpretation of Experiment 10's data. Experiment 11 did not replicate the key finding from Experiment 10, suggesting the presence of a human is necessary to elicit the results. The data are, however, not as convincing as expected. The cat present condition produced a similar pattern of data to that elicited by the human confederate in Experiment 10, although this effect was not statistically significant. Given that human-like features can lead to anthropomorphising of mechanical devices (Prakash & Rogers, 2015), I suggest that the anthropomorphic features of the cat statue (i.e., face, waving arm) may have introduced a social context to Experiment 11 to a degree, but not strongly enough to produce a statistically significant effect. This suggestion is in line with Dolk et al.'s (2013) reasoning. Moreover, as in Experiment 10, on-screen instructions appeared in two orientations, facing both toward and away from the participant. Having instructions directed to the cat statue may have encouraged its anthropomorphisation.

On balance, Experiment 11 provides preliminary support for a social account of the data from Experiment 10. More convincing evidence is required, however, to draw stronger conclusions about the mechanism underlying the study's key finding. Accordingly, Experiment 12 included a joint condition employing a distractor object with no human-like features at all.

Experiment 12

Experiment 12 determined whether a salient but inanimate object with equivocally no social features would produce results similar to Experiment 10. Once again, based on methodology from Dolk et al. (2013), a digital metronome was chosen for the joint condition in Experiment 12. A metronome is completely devoid of human-like features, does not move but is a highly salient object due to its auditory output.

In terms of predicted results, if Experiment 10's key finding is explained by a general attentional, distractor mechanism, then Experiment 12 was expected to reproduce the critical 3-way interaction from Experiment 10. Specifically, in the joint (metronome) condition, near but not far objects would elicit the handle effect whereas objects in both locations would produce the effect in the alone condition. If Experiment 10's key finding is truly a social phenomenon, then Experiment 12 was expected to elicit a comparable handle effect regardless of alone/joint conditions and object proximity, with no significant a 3-way interaction.

Method

Participants. Thirty-six right-handed (32 females, mean age 21.69 years) Flinders University students participated for a small reimbursement. Handedness was measured by the Flinders Handedness Inventory (Nicholls et al., 2013). Participants were English speakers who reported normal or corrected-to-normal vision and gave written, informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus, stimuli and procedure. All apparatus, stimuli and procedures were identical to Experiment 11 except for the inclusion of a small, black, digital BOSS DB-30 metronome in place of the cat statue. Lying flat, the metronome measured 15mm high, 60mm wide and 88mm long. The metronome was placed face-down on the table such that its visual display was hidden and it served primarily as an auditory distractor. It beeped audibly at a rate of 80 beats per minute (Dolk et al., 2013).

Results and discussion

Data analysis. Error rates from all 36 participants fell within three standard deviations from the group mean (12.008%, *SD* = 5.423) and so all data were analysed.

RTs. A 2 (alone/joint condition; alone, metronome present) x 2 (handle; congruent, incongruent) x 2 (object proximity; near participant, far from participant) repeated measures ANOVA was conducted on mean RTs from correct trials. There was a significant main effect of alone/joint condition, $F(1, 35) = 6.497$, $p = .015$, $\eta^2_p = .157$, reflecting faster responses when the metronome was present ($M = 593.676$, $SD = 81.078$) than absent ($M = 623.253$, $SD = 94.151$; see Figure 6.4). The reason for this finding is unclear, as it contrasts both Dolk et al. (2013), who found *slower* responses in their metronome condition, and also the current Experiment 11, in which there was no difference in RTs across alone and cat present conditions. It is possible that the rhythmic metronome sounds had an especially altering or arousing effect, which can lead to faster RTs, particularly in the case of loud auditory stimuli (Ulrich, 1996). There was also a significant main effect of handle, $F(1, 35) = 11.457$, $p = .002$, $\eta^2_p = .247$, with the typical response speed advantage for congruent ($M = 600.676$, $SD = 80.319$) over incongruent handles ($M = 616.092$, $SD = 83.238$). This finding is consistent with both Experiments 10 and 11. The main effect of proximity was not significant, $F(1, 35) = 0.181$, $p = .673$, $\eta^2_p = .005$, and there were no significant 2-way interactions, all Fs <1.879, ps $>.179$. Most importantly, the 3-way interaction between alone/joint condition, handle and object proximity was not significant, $F(1, 35) = 0.115$, $p = .737$, $\eta^2_p = .003$.

Overall Experiment 12's results support a social interpretation of Experiment 10's key finding. The findings suggest that an entirely non-social, aurally salient distractor object does not differentially affect affordance-related visuomotor processing of near and far objects. These findings also indicate that the somewhat ambiguous results from Experiment 11 are most likely attributed to the anthropomorphic features of the cat statue. Although the cat also differed from the metronome in that it was visually as well as aurally salient, the main effect of alone/joint condition in Experiment 12 demonstrates that the metronome was a highly salient distractor object, which captured participants' attention but had no impact on the handle effect.

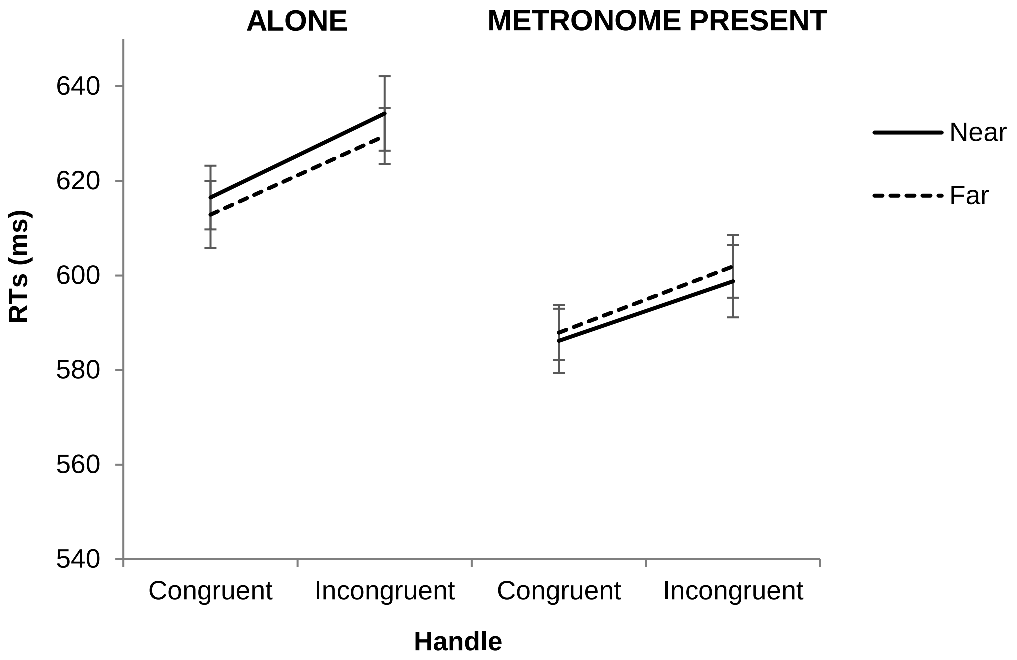

Figure 6.4. Mean correct RTs (ms) across handle and proximity factors for the alone condition (left panel) and the metronome condition (right panel) in Experiment 12. Error bars represent a standard error of the mean calculated within-subjects for each condition.

General Discussion

The present research determined how close interpersonal proximity influences visuomotor processing of manipulable objects in social space between two strangers. As the first study to conduct an object recognition task with two human actors, these findings are an important extension of previous research employing single participant designs. For most humans, social encounters occur frequently throughout each day and as such, investigating how social presence modulates the perception of action possibilities is critical to understanding these processes in a real-world context. This set of experiments has demonstrated that although nearby objects typically elicit visuomotor congruency effects, objects that are within reach but are closer to a stranger do not activate affordance-related motor codes to the same degree. These results suggest that space shared between two human strangers can be divided to preserve one another's near-body space, and in turn this process influences motor coding for stimuli within that social space.

Converging evidence from the three current experiments rules out an alternative, general attentional account of Experiment 10's key finding. When participants were alone, all objects within near space evoked the handle effect, whereas in the presence of the confederate, only objects nearer the participant produced affordance-related motor activation strongly enough to elicit the effect. It was considered that the confederate may have simply served as a distractor that participants attempted to ignore, leading to reduced attentional processing of stimuli in his proximity. If this were the case, I would have expected inhibited responses overall for far stimuli in the joint condition, but instead the confederate differentially affected responses with respect to affordances only for far objects. Moreover, the decreasingly social, non-human, visually and aurally salient joint conditions of Experiments 11 and 12 did not replicate the critical interaction from Experiment 10. These data point to a truly social rather than general attentional explanation.

In demonstrating that affordance-related processing can be socially modulated, these findings invite numerous interesting questions regarding the nature of social space, and how other social and action variables might affect visuomotor processes in this context. First, how might the current findings be modulated by other factors relating to interpersonal distance? There are individual differences in preferred social distance, which could affect coding of near-body space and action processes within it (de Vignemont & Iannetti, 2015). To illustrate, Iachini, Ruggiero, Ruotolo, di Cola, and Senese (2015) showed that trait measures of anxiety and extraversion correlated with preferred social distance, as well as reachability estimates. Social comfort distances may also vary across cultures, related to crowding norms and attitudes (Evans et al., 2000), or with the nature of the actors' social relationship, in that friends typically engage at closer distances than strangers (Hall, 1966).

The research reviewed here could point to a powerful role of discomfort in social space coding. Indeed, de Vignemont and Iannetti (2015) argued that anxiety induced by social proximity can motivate strong desire to protect one's body, which can induce a contraction of peripersonal, action space. This proposal is in line with findings indicating an association between trait anxiety and near-body space coding (Iachini et al., 2015; Sambo & Iannetti, 2013). Szpak et al. (2015) similarly demonstrated that for two strangers in close proximity, attentional withdrawal was most pronounced for those displaying the most physiological arousal. Therefore, discomfort may have played a role in Experiment 10’s findings, given that the confederate was instructed to maintain a neutral, rather than friendly, demeanour and not to engage greatly with the participant.

In considering social discomfort, then, it is likely that other social, contextual variables would also affect visuomotor processing in shared space. As mentioned, friends are typically comfortable at closer social distances (Hall, 1966), and therefore, actors who are friends might not demonstrate the same perceptual division of social space evident in the current study. Aside from considering any pre-established relationship between the actors, the particular characteristics of the co-acting stranger (e.g., sex, age, appearance, apparent disposition) could also impact the nature of the social interaction and therefore, the mapping of social space. The nature of the task and the degree of collaboration required might also be relevant, in that strangers who collaborate on a task might likewise feel more comfortable with one another than in the current paradigm. As de Vignemont and Iannetti (2015) point out, coordinating action with another person requires a degree of trust. Space between two people who are perform an action together (e.g., one passing a cup of coffee to the other) could be coded very differently than for two strangers acting independently, for example. In this vein, Pezzulo et al. (2013) argued for a merging (rather than dividing) of actors’ near-body spaces when they collaborate to achieve a common goal, and findings from Teneggi et al.’s (2013) peripersonal space study supports this idea. Future research could therefore investigate how a friendly, collaborative context influences affordance-related motor coding in social space.

Aside from social, contextual variables, action-related variables are also likely to influence affordance processing in shared, social space. For instance, varying the motor capabilities or goals of the actors might influence visuomotor processes in shared space (Pezzulo et al., 2013). Witt, Sugovic, and Taylor (2012) showed that our reported experience of an object is not only affected by our ability to act on it, but also by the ability of others to act on it. Furthermore, as mentioned in the introduction, findings from Constable et al. (2015) were contingent on the co-actor performing an active role in the experiment, rather than passively observing the participant. Accordingly it is interesting to consider whether the current paradigm would produce the same results if the stranger's motor goals or capabilities were varied or somehow restricted. Overall the present study provides considerable scope for future research into how contextual social and action variables might modulate visuomotor processing of object affordances in space between two human actors.

It is not yet clear how visuomotor modulation in shared space interacts further with other mechanisms that can operate within social action contexts. Findings from some joint tasks indicate, for example, that participants not only understand the spatial perspective of a co-actor but that this perspective can manifest behaviourally. That is, participants' responses to the experimental stimuli can in fact sometimes reflect another's allocentric viewpoint, rather than their own, egocentric perspective (Böckler, Knoblich, & Sebanz, 2011; Tversky & Hard, 2009). This phenomenon may be particularly likely in paradigms where participant pairs stand opposite one another (Frischen, Loach, & Tipper, 2009) and view images in more than one orientation (Surtees, Apperly, & Samson, 2016). Interestingly, though, Experiment 10 comprised of such a paradigm but participants' responses evidently did not reflect the confederate's spatial perspective, given that stimulus upright/inverted orientation did not interact with alone/joint condition (see Appendix B). Further research is therefore needed to determine which conditions are necessary to elicit a perspective taking mechanism, and how this process interacts with social space coding.

In a similar vein, although not evident in the current study, other social action paradigms suggest that participants' responses can sometimes directly reflect the action possibilities of other actors. Costantini et al. (2011) provides an example of this action co-representation mechanism in their virtual reality paradigm. They presented participants with virtual scenes and found affordance-related congruency effects for a mug stimulus appearing far from the participant, but only when the mug was within reach of an avatar within the scene. This finding and the mechanism underlying it contrasts the current study, further highlighting the complexity of social action paradigms. I have suggested that perhaps social discomfort or anxiety contributed to the current findings, whereas participants may not have experienced this same discomfort in Costantini et al.'s virtual paradigm. Constable et al. (2015) likewise suggested that the way actions are co-represented between people is likely to be flexible and task-dependent. Brincker (2015) also argued that we only partially represent others' action possibilities, as they relate contextually to shared space and shared affordances, rather than a full-blown simulation of the other's experience.

Action planning and selection within social contexts - including the mapping of social space and affordances within it - likely reflects a complex and dynamic interplay of many social and action-related variables (Brincker, 2015; Pezzulo et al., 2013). Further research is required to increase our understanding of this complex interaction.

One last point relates to the distinction between *social*- and *action*-related representations of near-body space. I have discussed personal, social space separately from peripersonal, action space because historically they are informed by discrete bodies of literature. Furthermore, it was important to highlight the relevance of both social and action processes to near-body space. In reality, however, it is unknown whether a functional distinction between social and action space representations exists. In terms of conceptual overlap, both representations refer to the space surrounding the body and serve to protect the body from and facilitate interaction with (animate or inanimate) stimuli in the environment and recent papers suggest the two representations may in fact be functionally distinct (de Vignemont & Iannetti, 2015; Patané, Iachini, Farnè, & Frassinetti, 2016). This issue is highly complex, though, and its resolution awaits considerable further, exciting research.

The present study provides an important step forward in understanding the ease with which we can navigate our complex, dynamic environment. Perceiving and interacting with stimuli in the physical world is an essential skill for any biological agent and for most humans, the people around us represent dynamic stimuli that we encounter and share space with every day. Accounting for other people in our motor planning is critical – not only for keeping our bodies safe but also for engaging in successful and socially appropriate interactions. Accordingly, there must be a complex interplay between social and visuomotor processes that translates to our seemingly effortless co-existence with the physical world and the other people in it. The present research represents an important step toward understanding this phenomenon.

Chapter 7: General discussion

Introduction

Evidence reviewed at the beginning of this thesis suggests there is a motor component to the way manipulable objects are coded by the human brain. In line with issues raised in the introductory chapters, the aim of this thesis was to investigate the nature and role of lateralised, affordance-related motor activation. The experimental work in this thesis can divided into the following two sections.

The first section, Chapters 4 and Appendix B, examined whether a lateralised, manual motor task interfered with object naming as a function of handle orientation. Results were inconclusive and add to the already inconsistent findings using this methodology (Matheson, White, et al., 2014a; Witt et al., 2010). Verbal responses were then evaluated to inform the conclusions drawn from the object naming data. This evaluation suggested measurement problems are unlikely to account for the inconsistent object naming results. The findings of Appendix B therefore strengthened my conclusion that a unimanual motor task does not differentially impair naming of lateralised objects. On balance, this research did not produce any evidence to support Witt et al.'s (2010) proposal that lateralised motor activation aids object identification.

Chapters 5 and 6 comprise the second line of research in this thesis. Experiments within these chapters employed novel paradigms to explore the circumstances under which object handles elicit a lateralised stimulus-response compatibility effect (handle effect). Experiments 7, 8 and 9 established that abstract spatial compatibility between handle and response components does not explain the handle effect. Furthermore, these experiments demonstrated that when spatial compatibility influences were largely removed, only tasks implicating a certain degree of object-related semantic knowledge elicited the effect. In Chapter 6, the handle effect was modulated within social space shared between two human strangers. Two experiments addressed a non-social, general, attentional explanation for these results.

The current chapter elucidates how findings from this thesis inform our understanding of the ways in which manipulable objects are perceived and represented in motor terms, the nature and role of object-related implicit motor activation, and what this reveals about how action is planned towards these objects. A new conceptualisation of the handle effect is proposed, as are suggestions for future research.

The nature and role of lateralised object-related motor activity

First, in investigating the alternative account of the handle effect, this thesis has provided important evidence regarding the nature of lateralised, affordance-related motor activation. Findings from Chapter 5 demonstrated that the handle effect is not simply explained by spatial compatibility. This chapter has been published (Saccone et al., 2016) and represents an important contribution to the literature by adding weight to the claims of affordance researchers who have studied lateralised object stimuli. Findings from Chapter 6 further support conclusions that abstract spatial compatibility alone cannot account for the handle effect. The effect was modulated within shared, social space, even though the spatial compatibility between handle and response components remained constant. Thus it can be concluded that a motor-based coding of manipulable objects must contribute significantly to object handle-related motor activation.

The current findings are also informative with respect to the role of this lateralised motor activity in recognising objects. Chapter 4 did not provide any evidence to support Witt et al.'s (2010) conclusions that lateralised, affordance-related motor activity aids object identification. Additionally, upon further consideration of the relevant broader literature, I proposed that support for the motor interference hypothesis is mixed at best and, furthermore, that this hypothesis may not in fact provide a strong test of the role of motor resources after all. Results from Chapter 6 were also inconsistent with the idea that handle-related motor activation functionally supports object identification. These experiments demonstrated that the handle effect varied within shared, social space, suggesting a top-down, social influence. Taken together, the current findings are not consistent with a functional role of lateralised affordance-related motor activity on object identification. Therefore, it is unlikely that this motor activity simply reflects concept retrieval processes.

This is not to say that the current research precludes a role of motor resources more generally in object knowledge or representation. A complex and distributed system is likely to underlie object conceptual representation, but this representation must incorporate motoric information in some respect, for example information regarding learned, skilled manipulation processes or function (Buxbaum

& Kalénine, 2010; Martin, 2007). Consistent with this idea, there is evidence that manipulable object names as well as visual stimuli activate related motor processes (Martin et al., 1995; Masson, Bub, & Newton-Taylor, 2008; Tucker & Ellis, 2004). This finding suggests that concept retrieval itself, rather than simply visuomotor translation of affordances, produces neural motor activity. Whether this motor information is linked intrinsically or peripherally to the object concept itself remains a matter of debate, as outlined in the opening chapters. Regardless, motor processes may yet support representation, particularly with respect to intrinsic object properties.

Although this research has addressed the spatial compatibility account of the handle effect, and points against a role of handle-related activation in object identification, questions remain as to the specific processes underlying the implicit motor activity. If handle-related activation simply reflects affordance processing in a Gibsonian sense (Gibson, 1979), relating to visuomotor transformations of structural object properties through the dorsal stream, then how reasonable is it to expect that it would in fact support object identification? The current work demonstrated that the handle effect varies significantly across task and social context, which supports views that visuomotor processing of object structure is not the only source of the motor activity that accounts for the handle effect (Bub & Masson, 2010a). Findings from Chapter 5 indicate that a certain level of semantic processing is required to elicit the effect, consistent with previous suggestions (Loach et al., 2008; Symes et al., 2005; Tipper et al., 2006). However, the effect cannot simply be explained by an above-threshold contribution of stored, semantic information, because the effect was socially modulated in Chapter 6, in spite of task-elicited semantic content. Therefore in light of the current evidence, although the handle effect relates to a structural object property, it seems unlikely that it is simply an ‘affordance effect’, as it is sometimes referred to in the literature (Iani et al., 2011; Riggio et al., 2008).

The handle effect in the context of the Two Action Systems

In light of the current findings, I offer the following account of the handle effect. I argue that the lateralised motor activity underlying the effect results from an interaction between motor codes relating to both object affordances and stored object knowledge. The idea that both of these processes contribute to object-directed action is not new (Binkofski & Buxbaum, 2013; Borghi, 2005; Borghi & Riggio, 2015; Bub et al., 2008; Buxbaum & Kalénine, 2010; Creem & Proffitt, 2001; Glover, 2004; Hommel, 2015; Johnson-Frey, 2004; Rothi, Ochipa, & Heilman, 1991; Vingerhoets et al., 2009). Likewise, authors have suggested previously that semantic processes contribute to affordance-related motor activation and planning (Bub et al., 2008; Jax & Buxbaum, 2010; Symes et al., 2005); however, this is the first time that a framework of the brain’s different action systems has been applied in detail to the handle effect. In particular, I propose that different types of implicitly activated, object-related motor information interact to produce the handle effect and, consistent with previous suggestions (Bub & Masson, 2010a; Bub et al., 2008; Jeannerod, 1997; Masson et al., 2011; Thill, Caligiore, Borghi, Ziemke, & Baldassarre, 2013), this interaction is modulated by top-down processes. In considering how both affordance-related and learned, internally represented motor information might contribute to and interact within the handle effect, I will review Buxbaum and colleagues' *Two Action Systems* theory (Binkofski & Buxbaum, 2013; Buxbaum, 2001; Buxbaum & Kalénine, 2010), which provides an appropriate framework for considering both types of motor information.

Buxbaum and colleagues (Binkofski & Buxbaum, 2013; Buxbaum, 2001; Buxbaum & Kalénine, 2010) have proposed that object-directed actions are controlled by two distinct but highly interactive cognitive and neuroanatomical systems within the brain; the *Two Action Systems.* The bilateral *Grasp* system, with roots in the dorso-dorsal stream, controls online translation of visual and spatial cues of objects' structural properties into motor commands. The *Use* system draws on long-term, stored information of objects' function and manipulation to enable learned, skilled actions. This primarily left-lateralised system has roots in the ventral processing stream, which underlies object recognition, as well as its connectivity with the ventro-dorsal stream, which contributes to performing skilled manipulations. Both *Grasp*- and *Use*-related motor information are activated in response to object stimuli (Bub et al., 2008; Jax & Buxbaum, 2010; Masson et al., 2011), and both types of information contribute to successful object-directed action.

Jax and Buxbaum (2010) have demonstrated how the *Use* and *Grasp* systems interact in neurologically healthy individuals. The authors identified two sets of objects based on grasping motor patterns. One group of objects requires a consistent grasping action regardless of whether simply moving or actually using the object for its conventional function. The other group of objects are typically grasped in a different manner for transport compared to use (e.g., a smartphone). They referred to objects requiring different move- and use-related grasps as *conflict objects*. In a cleverly designed study, Jax and Buxbaum had participants perform grasp-to-move- or grasp-to-use actions on real objects, and examined the difference in movement initiation speed between conflict and non-conflict objects. They found that for conflict objects, reach-to-grasp movements were initiated more quickly than reach-to-use, but both types of movements were initiated quickly for non-conflict objects. That is, reach-to-use movements were slowed for conflict objects but not for non-conflict objects. These results demonstrate that motor information from the *Grasp* system a) is activated more quickly than the *Use* system and b) can interfere with the *Use* system. They also found evidence of block-wise interference of the *Use* system. That is, grasp-to-move actions were initiated more slowly when participants had already performed grasp-to-use actions in the first half of the experiment. These findings suggest that activation associated with the *Use* system is slower to develop but also persists to a degree, consistent with semantic memory activation more generally (Binkofski & Buxbaum, 2013).

The interactivity between the *Use* and *Grasp* systems is thought to be influenced by the goals of the actor, factors relating to situation and context, as well as each system's capacity (Binkofski & Buxbaum, 2013; Borghi, 2005; Bub et al., 2008; Buxbaum & Kalénine, 2010; Garbarini & Adenzato, 2004; Masson et al., 2011). To illustrate, Osiurak, Roche, Ramone, and Chainay (2013) replicated Jax and Buxbaum's (2010) finding that grasp-to-move actions were initiated more quickly than grasp-to-use; however, Osiurak et al. found that this pattern reversed when participants were asked to hand objects to another person. The nature of the object stimuli also influence the contribution of each system. For instance, object names, which lack visual cues of object structural properties (e.g., handle orientation), are typically are more likely to elicit *Use* than *Grasp* actions (Masson et al., 2008), but Bub and Masson (2010b) found that object words also elicited *Grasp*-related information when object words appeared in sentences describing the object being picked up or used.

Affordances that are derived from object structure[3], then, are primarily processed by the *Grasp* system (Binkofski & Buxbaum, 2013). There may be instances in which there is little input from the *Use* system but in general, both *Grasp* and *Use* motor information must be integrated to enable appropriate object-directed actions (Binkofski & Buxbaum, 2013; Buxbaum, 2001; Hommel, 2015). Consider an object's weight. Sometimes weight information cannot be derived from visual cues but is only known owing to previous physical experience with that object or the material from which it is constructed. This stored information must be converted into motor commands regarding the degree of force or muscle engagement required to lift the object. This internally represented motor information is combined with visuomotor transformation of object structure that produces the appropriate configuration of the hand, wrist and fingers for grasping the object.

There is experimental evidence that *Use* information contributes to action performed on affordances (Bub et al., 2008; Masson et al., 2011). For example, participants in Creem and Proffitt's (2001) study were less likely to grasp real objects in a use-appropriate manner when they concurrently performed a related,

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[3] Affordances related more closely to object function rather than structure (e.g., Adamo & Ferber, 2009; McNair & Harris, 2014; Roberts & Humphreys, 2011) are unlikely to be processed in the same manner.

semantic task compared with an unrelated, spatial task or no dual task. This finding demonstrates that the *Use* system influences the *Grasp* system and, furthermore, indicates how the *Grasp* system can operate when the *Use* system has limited capacity. Neuropsychological research from Castiello and Jeannerod (1991) also demonstrates how the *Use* system can overcome deficits in the *Grasp* system to a degree. The authors described a patient with damage to dorsal areas with general grasp-related impairments; however, these deficits were less severe for familiar objects, particularly objects for which size and shape are intrinsic properties (e.g., lipstick).

In considering the research reviewed above, as well as the work produced in this thesis, I therefore interpret the handle effect as an interaction between *Grasp*- and *Use*-related motor information. More specifically, I propose that the handle effect reflects a particular contribution of *Use* information as it relates to the structural, affordance property of object handle. Both *Grasp* and *Use* information for unimanual, handled objects must be largely lateralised, and therefore, for these types of objects, increased *Use* information would be reflected as increased lateralised activity. I argue that a certain degree of *Use* information must be activated to produce a measureable and general difference in lateralised motor activation as in the handle effect. Although the effect cannot distinguish *Grasp* and *Use* contributions in terms of specific grasp- and manipulation-related motor programs, my interpretation that *Use*-related information is particularly important in the handle effect accounts for Chapter 5’s findings that a degree of semantic processing was required to elicit the effect when spatial compatibility influences were largely removed. Furthermore, time course descriptions of the handle effect demonstrate that it typically builds over time (see Figure 5.5 in Chapter 5; Phillips & Ward, 2002; Symes et al., 2005), which is consistent with the slower and more persistent activation pattern associated with *Use* information (Jax & Buxbaum, 2010) and semantic information more generally (Binkofski & Buxbaum, 2013).

The proposal that the handle effect reflects both *Grasp* and *Use* information can also account for its social modulation in the previous chapter. As mentioned, the interaction between the *Grasp* and *Use* systems is thought to be influenced by contextual information (Borghi, 2005; Buxbaum & Kalénine, 2010; Garbarini & Adenzato, 2004), including the other people's actions and intentions (Buxbaum, 2001). As described earlier, Osiurak et al. (2013) demonstrated that the speed of initiating a grasp-to-move action varied significantly depending on whether or not the participant was handing an object to another person.

More specifically with respect to the findings from my social space paradigm, it may be that object-related *Use* information was inhibited generally for stimuli closer to the human confederate. This suggestion is certainly speculative, given that the precise mechanisms underlying social space coding and how they influence action processes are yet to be confirmed. Notably, however, Buxbaum (2001) has highlighted an overlap in left-hemisphere regions for both the *Use* system and action-related processing within peripersonal space. Furthermore, van Polanen and Davare (2015) speculated that for familiar actions and situations, the ventral-dorsal interaction might be highly practised and therefore efficient. Perhaps sharing social space with strangers is an example of a highly familiar situation, in which we are typically accustomed to constraining our movements according to the location of others nearby (Özyürek, 2002; Soper & Karasik, 1977).

The interaction of *Use/Grasp* information may vary considerably across different social contexts. To illustrate, the processes underlying the perceptual division of shared space in the previous chapter are likely to differ from situations in which two people coordinate action to achieve a common behavioural goal. To provide another example, Constable et al. (2011) demonstrated that the handle effect was modulated by the social construct of ownership. The effect was elicited from a participant-owned mug stimulus, and from unowned mugs, but not from a mug that participants knew belonged to the experimenter. Presumably, then, each stimulus had to be processed and recognised, perhaps by the *Use* system, before the motor information evoked by the experimenter's mug was suppressed. Constable et al. did in fact account for their results with an inhibitory mechanism, as the absent handle effect appeared to result from slower congruent responses, rather than faster incongruent responses to the experimenter-owned mug. In contrast, in the context of shared social space, objects do not need to be identified in order for their proximity to each actor to be coded. As suggested in the previous chapter, it is likely that an interplay of various mechanisms underlies findings from social action paradigms, an interplay that is not yet well understood.

One last consideration with respect to my interpretation of the handle effect is how it fits with an existing account from Bub and Masson's (2010a). They proposed that the effect represents a processing cost/benefit arising from the overlap of motor codes related to a) visually-derived object affordance information and b) performing the response action. Bub and Masson argued that the preparation of the response action exerts a top-down influence on visuomotor translations of object structure. Their findings suggested that when object identity was task-irrelevant, the motor schema involved in preparing a simple key press did not overlap sufficiently with visually-derived, structural object information to elicit a handle effect, whereas a reach-to-grasp movement did. Critically, Bub and Masson's view only accounts for the degree to which objects automatically elicit motor activation upon their perception, rather than deeper semantic processing. In this respect they account for the contribution of *Grasp* information, and have investigated the conditions under which this information will successfully elicit a measurable difference in lateralised motor activity. My account is arguably consistent with theirs, in that I have proposed the handle effect found with key-press responses reflects an important contribution of *Use* information as it interacts with *Grasp* information. Of note, Bub and Masson reported a stronger handle effect when there was a delay between the onset of the object stimulus and the colour cue. Perhaps this delay induced a stronger effect because participants had time to process the object more deeply, thus activating more *Use* information, before the task-relevant colour cue appeared. In this respect, my account can be viewed not only as consistent with their findings and framework, but also an extension of it.

My interpretation of the handle effect is consistent with Bub and Masson's (2010a) theory; however, my account also provides an important contribution above and beyond theirs. Their framework does allow for social, contextual modulation of the handle effect. They argued that their findings reflected a processing cost/benefit as a function of the overlap between motor codes automatically evoked by perceiving object structure and those relating to the motor goal of the response. My findings demonstrated that the handle effect was socially modulated, even though the degree of overlap between object- and response-related motor activation remained constant. Although I have only speculated about the potential mechanism underlying the social, contextual modulation of the effect, my interpretation still provides greater scope to account for such findings. Thus, my interpretation of the handle effect makes an important, novel contribution above existing theoretical accounts.

The nature of conceptual representation

In summary, the findings of this thesis suggest that implicit, object handle-related motor activity reflects motor resources related to both stored object knowledge and visuomotor processing of affordances. This information is activated flexibly in a top-down, task- and context-dependent fashion to facilitate our seemingly effortless object-directed actions. These conclusions beg the question of how the current evidence informs on the nature of object conceptual representation, and the role and meaning of implicit object-related motor activation.

On balance, these findings point against a role for lateralised motor activity in object identification. In particular, the social modulation of the handle effect, which occurred in spite of task-required semantic content, suggests that this motor activity may represent more of a motor preparedness function, rather than concept retrieval. It is particularly informative that the handle effect was modulated in social space without any evidence of hindered or slowed object processing overall. Rather than supporting object recognition, therefore, it may be that the motor resources provide relevant, supplementary information to inform motor planning and behaviour based on past experience. In this respect the current findings may indicate against an intrinsic motor component of object conceptual representation. Instead, the nature of this motor information may be peripheral or auxiliary, and is activated in a context-dependent fashion. This interpretation is consistent with representational accounts from Damasio (1989; Meyer & Damasio, 2009) and Mahon and Caramazza (2008). These claims are of course tempered with the acknowledgement that the current evidence only relates to the handle effect, which is informative insofar as indicating a measureable and general difference in lateralised motor activation, and one that occurs during a particular temporal window as determined by task parameters. I do not suggest that the findings of this thesis resolve these complex issues, but rather, they contribute to the relevant, ongoing debates.

Future directions

With regards to future research, the findings from my social paradigm in particular provide considerable scope for further study. I have identified many factors that might be relevant to object visuomotor coding in social space, such as interpersonal distance, the social dynamic and relationship between the actors, and co-actors' motor capabilities and goals. It is also interesting to consider whether anxiety or discomfort does in fact drive social space-related modulation of motor processing. As such, it could be useful to determine how social space coding is affected by individual differences in social comfort distances and related factors. Investigating how these social distance and situational factors modulate object-related visuomotor processing will increase our understanding of motor planning in a real-world context. Additionally, continued work in this area will inform the debate over the nature of near-body space coding, and the degree to which there are social- and motor-based functional distinctions in the way body-centred space is represented.

Findings from this thesis also highlight the need more generally to disentangle the mechanisms and processes that contribute to social action. Many mechanisms have been proposed to underlie social action paradigms and findings, such as action and space co-representation (Ciardo et al., 2016; Costantini et al., 2011), including spatial perspective taking (Böckler et al., 2011; Tversky & Hard, 2009). Attention-moderating factors like gaze cues and emotional expression are also likely to contribute to action processes in a social context (Ricciardelli, Lugli, Pellicano, Iani, & Nicoletti, 2016). The current research has highlighted how much remains to be understood about the interaction between these processes in accounting for social action and, furthermore, how social space coding might further affect this interaction. If physiological arousal impacts social space coding in an innate or at least adaptive, self-protective manner (de Vignemont & Iannetti, 2015; Graziano & Cooke, 2006), then perhaps this mechanism can in a sense 'override' some other social action processes that have more of a facilitatory function. It is clear that much further work is required to understand processes underlying social action, social space, and the interplay between them. This area of research represents an exciting and burgeoning field within cognitive science, one that will almost certainly generate much interesting work in the coming years.

There is also scope for future work to address the role of attention in the handle effect. Certainly, there is neurophysiological evidence of early visual processing of object handles during lateralised object tasks (Goslin et al., 2012; Lien et al., 2013; Matheson, Newman, Satel, & McMullen, 2014). In general, however, there is only mixed evidence that handles inherently draw attention due to visual salience (Kourtis & Vingerhoets, 2015; Myachykov et al., 2013; Skiba & Snow, 2016; Vainio, Ellis, et al., 2007; van der Linden et al., 2015). Vainio, Ellis, et al. (2007) even provided evidence to suggest that stimulus-specific visual features do not modulate attention to handles during object perception tasks. Their results indicated handle-oriented attention did not differ across objects for which handles are a particular protruding and therefore visually salient feature (e.g. mug, saucepan), compared with objects with handles that continue along the same axis as their functional component (e.g., knife, hammer). Thus, degree of visual salience did not appear to vary attention to the handle. Regardless, strong evidence exists that the handle effect can be influenced by spatial compatibility between handle and response components.

Perhaps the most pertinent factor with regards to this issue is the known influence that action preparation exerts on visual attention. Preparing an action biases attention to visual cues that are congruent with or, of course, the recipient of that action (Craighero, Fadiga, Rizzolatti, & Umilta, 1999; Craighero, Fadiga, Umiltà, & Rizzolatti, 1996). Attention to handles may therefore be highly task-dependent. Bub and Masson (2010a) proposed that such an attentional mechanism explained their finding that participants' action goal modulated the handle effect. In their study, an object colour judgement elicited the handle effect when the response action comprised a reach-to-grasp movement, but not when it involved a simple key press. In light of the current interpretation of the handle effect, perhaps task requirements modulate the *Grasp/Use* interaction, which in turn influences motor-driven attentional biases. Further research using eye-tracking methodologies may shed more light on the attentional underpinnings of the handle effect, including the task-, goal- and contextual-modulation of this mechanism.

Concluding remarks

To conclude, this thesis has made several contributions to our understanding of manipulable object coding and related visuomotor processes. First, findings have highlighted the limitations in using a dual-task, behavioural methodology to test the role of motor neural resources on object identification, particularly in the context of the greater embodied cognition literature. Second, research within the thesis addressed the alternative explanation for the handle effect, which has made an obvious, important contribution to the relevant published literature. Third, results from my novel, social paradigm demonstrated that object-related visuomotor processing can be modulated within shared, social space. Based on these findings, I have proposed a new conceptualisation of lateralised affordance-related motor activity in which different types of motor information are activated in a top-down, task- and context-dependent fashion.

Overall, these findings suggest that implicit motor activation evoked in response to viewing or considering manipulable objects represents an interplay between visuomotor processing of affordances, as well as internally stored motor information, acquired as function of our bodies' capabilities and experience. This motor information is activated flexibly in line with behavioural goals and responds quickly to environmental factors including social cues and context. This rapid exchange and integration of information undoubtedly accounts for our remarkable skill in interacting with the physical world.


TURN
HANDLE

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Appendix A: List of object stimuli

Experiments 1, 2, 3

Army knife
Axe
Beer mug
Bottle
Bottle opener
Bouquet of flowers
Bulldog clip
Butter knife
Cake scraper
Cake server
Chopsticks
Cleaver
Colander
Comb
Computer mouse
Dart
Door handle
Drill
Dust buster
Duster
Dustpan brush
Fan
Fork
Frypan
Garlic press
Gavel
Hair brush
Hair dryer
Hair straightener
Hammer
Highlighter
Horn
Ice cream cone
Ice cream scoop
Iron
Jug
Kettle
Key
Kitchen beaters
Knife
Ladle
Lighter
Lollipop
Magnifying glass
Mallet
Mascara
Microphone
Mug
Nail clippers
Nail file
Net
Nutcracker
Paint brush
Paint roller
Paint scraper
Peeler
Peg
Pen
Pencil
Phone
Pizza slicer
Pliers
Plunger
Potato masher
Rattle
Razor
Roast fork
Saucepan
Saw
Scalpel
Scissors
Screwdriver
Scrubbing brush
Secateurs
Shaver
Sifter
Spatula
Spoon
Spray bottle
Squeegee
Stanley knife
Staple gun
Syringe
Table tennis bat
Tea strainer
Teacup
Teapot
Tenderizer
Tennis racquet
Tongs
Toothbrush
Torch
Trowel
Tweezers
Umbrella
USB
Watering can
Whisk
Wooden spoon
Wrench

Experiment 4

Large/power grip	Small/precision grip
Axe	Bell
Beer mug	Bulldog clip
Bottle	Cake fork
Bottle opener	Clip
Colander	Dart
Comb	Earphone
Dust buster	Flower
Frypan	Guitar pick
Gavel	Key
Hair straightener	Lollipop
Kettle	Mascara
Knife	Match
Magnifying glass	Nail clippers
Mallet	Nail file
Net	Nail
Peeler	Nail polish brush
Phone	Needle
Pizza slicer	Paint brush
Plunger	Peg
Potato masher	Pen
Scrubbing brush	Pencil
Shaver	Pin
Spatula	Screw
Squeegee	Tea spoon
Table tennis bat	Tea strainer
Tea pot	Tee
Torch	Thumb tack
Watering can	Toothpick
Wooden spoon	Tweezers
Wrench	USB

Experiments 7, 8

Kitchen

Cake scraper
Cleaver
Cup
Fork
Frypan
Garlic press
Grater
Jug (ceramic)
Jug (plastic)
Kettle
Kitchen beaters
Knife
Peeler
Pot
Pizza slicer
Potato masher
Spatula
Strainer
Teapot
Tongs
Whisk
Wooden spoon

Shed

Axe
Chisel
Drill
Hammer
Jerry can
Mallet
Paint brush large
Pain brush small
Paint roller
Paint scraper
Pliers
Saw
Saw 2
Screw
Screwdriver
Secateurs
Spade
Stanley knife
Torch
Watering can
Weeder
Wrench

Experiment 9, 10, 11, 12

Cleaver
Cup
Drill
Frypan
Iron
Jug (ceramic)
Jug (plastic)
Kettle large
Kettle small
Kitchen beaters
Knife
Lighter
Lighter 2
Mug
Mug 2
Pan
Peeler
Peeler 2
Pot
Pot 2
Saw
Saw 2
Steak knife
Strainer
Tea pot
Tea pot 2
Tea strainer
Tongs
Watering can
Watering can 2

Appendix B: Convergent validity of vocal response times

Introduction

This study is a methodological adjunct to Chapter 4. The following experiments investigated the effectiveness of vocal latencies in providing a measure of RT. Verbal RTs were employed as the dependent variable in experiments described in Chapter 4 but produced inconsistent data, both across experiments and also with respect to existing literature (Witt et al., 2010; Yee et al., 2013). Thus, it was deemed important to assess verbal responses as an index of RT in order to rule out measurement problems as an explanation for these inconsistencies and in turn, to lend support to the conclusions drawn from Experiments 1-4.

Verbal responses are often used in experimental paradigms to provide a measure of RT when manual responses are impractical or problematic. For example, as in Chapter 4, vocal responses lend themselves to tests of embodied theories of cognition because the arms and body are free to perform a motor dual-task. A vocalisation is also useful in eliminating confounds arising from unwanted stimulus-response spatial compatibility because it is spatially neutral (e.g., Poliakoff, Spence, O'Boyle, McGlone, & Cody, 2002). Cognitive scientists have used verbal responses in a wide range of paradigms, such as perspective taking (e.g., Kessler & Rutherford, 2010), arithmetic (e.g., Klein, Moeller, Willmes, Nuerk, & Domahs, 2011; Wiemers, Bekkering, & Lindemann, 2014), mental time line (e.g., Eikmeier, Hoppe, & Ulrich, 2014) and mental number line tasks (e.g., Kramer, Stoianov, Umiltà, & Zorzi, 2011). Thus, there is a considerable precedence for using vocal RTs in cognitive research.

With respect to apparatus, experimental researchers commonly employ the traditional, electronic voice key to collect verbal RTs and likewise this device was used in Chapter 4. This voice key comprises a microphone connected to a response box which records vocal onset when the sound pressure exceeds a certain threshold (Psychology Software Tools Inc., 2012). The low cost and convenience of such a device would appeal to most experimental psychology researchers looking to measure vocal RT, many of whom would have the necessary components on hand in the laboratory. Several studies, however, have identified sources of inconsistency in voice key data.

Evidence for inconsistency in voice-key measured latencies primarily comes from reading or articulation studies focusing on the effect of phonetic differences in speech (Kessler et al., 2002; Rastle et al., 2005; Rastle & Davis, 2002). Within this context, there is a known delay between the verbal response and its measured latency, which varies according to the first and even second spoken phoneme. To illustrate this point, Kessler et al. (2002) had participants read monosyllabic words aloud and showed that, after controlling linguistic covariates, vocal onset of words beginning with /s/ were measured on average 38.5ms slower than other phonemes. Kessler et al. highlighted two main reasons for these variable latencies. First, some sounds are produced more quickly than others owing to the mechanical processes involved in articulation. For example, plosive consonants (e.g., /t/ in tin) begin with momentary silence while air coming from the lungs is stopped (Kessler et al., 2002) and therefore have a relatively delayed measured vocal onset. The second reason is that different sounds exert varying levels of sound pressure (Fry, 1979), which exceed the voice key’s threshold at variable rates. Research in this area has obvious implications for studies investigating systematic differences in vocal latencies and highlights the importance of controlling for phonetic variables when using verbal RTs.

The degree to which these known inconsistencies influenced Chapter 4’s results is unknown. In Experiments 1-4, vocal RTs were compared for the same objects across handle side and motor task lateralisation and accordingly, phonetic variables were balanced across experimental conditions. It follows then that if phonetic differences are controlled, these known inconsistencies should not represent a confound or threaten the validity of vocal latencies as a measure of RT. This claim assumes that voice-key measured RTs effectively reflect systematic, task-related changes in cognitive processing speed, commensurate with manual or button-press RTs.

Despite the widespread use of voice key-measured RTs, the convergent validity of verbal and manual RTs is largely unknown. On one hand, paradigms including both verbal and manual responses suggest a degree of correspondence between the two RT indices (e.g., Ansorge, Klotz, & Neumann, 1998). On the other hand, the psycholinguistic evidence for inconsistencies in voice key data (Kessler et al., 2002; Rastle & Davis, 2002) threatens the credibility of verbal RTs in this context. The degree to which these measurement inconsistencies influence the convergent validity of vocal and manual RTs, surprisingly, has not been extensively tested. Therefore, the present set of experiments aimed to clarify this issue to inform the interpretation of the Chapter 4’s findings.

Experiment 5

The current study investigated the convergent validity of verbal responses by comparing vocal and manual RTs obtained during an exogenous cueing paradigm, or *Posner* task (Posner, 1980). Given the known phonetic inconsistencies in voice key data (Kessler et al., 2002; Rastle et al., 2005; Rastle & Davis, 2002), a basic, single-response paradigm was employed as an important first step in evaluating verbal RTs. Participants performed a go/no-go version of the Posner task in which they responded to a target stimulus following an exogenous, attentional cue in the same (valid) or different (invalid) spatial location (see Figure B.1). Participants responded with a manual key press for half of the trials and a vocalisation for the other half. Phonetic biases were controlled by having the same verbal response for every target-present trial.

As evidenced by an extensive body of literature, exogenous cues exert a robust and reliable effect on responses to targets during a Posner task. Responses to validly cued targets are reliably faster than invalidly cued targets when there is a short temporal interval between appearance of the cue and the target (Posner, 1980; Samuel & Kat, 2003). This facilitation of RTs occurs for valid targets because attention is drawn to the cue and then the target appears in the attended location. As the current study employed a short interval between cue offset and target onset, faster RTs following valid cues than invalid cues were predicted. If vocal responses provide a measure of RT comparable to a key-press, a similar effect of cue validity should be evident for both response modes.

Besides investigating whether manual and vocal responses yield a comparable cueing effect, I was also interested in the speed of the response itself. Ansorge, Klotz and Neumann (1998) used both verbal and manual responses in their masked priming study and found a speed advantage for manual RTs. Although not a particular focus of their paper, Ansorge et al. speculated that this effect was an artefact of either delays due to mechanical properties of the voice key or the neural processing of a vocal response. In line with these findings, faster mean RTs were expected for manual compared with vocal responses. Critical to my objective, however, was to establish how well RTs obtained with one response modality predicted RTs using the other, regardless of any overall magnitude difference. To explore the extent to which the two RT indices were related, a correlation was performed between mean vocal and manual RTs. If the two response types measure the same construct, then a participant who provides relatively slow manual RTs should also have relatively slow vocal RTs (and vice versa for fast responders).

This study also investigated potential differences in within-individual variability in RTs across the response modalities. To display optimal convergent validity with manual RTs, verbal and manual RTs should have comparable variability. Given that verbal responses are affected by annunciation and volume (Kessler et al., 2002), it may be that they are more variable than a simple button-press. Variability in RT may also be a stable trait within individuals and this should be evident across the manual and verbal response modes. Accordingly, a correlational analysis was conducted to explore whether the degree of variability within an individual corresponded across modalities.

Method

Participants. Twenty-four right-handed (17 female, mean age 25.87 years) Flinders University students participated for a small reimbursement. One participant was excluded from analysis because he did not follow instructions with respect to the vocal response. Handedness was measured by the Flinders Handedness Inventory (Nicholls et al., 2013) and participants were English speakers who reported normal or corrected-to-normal vision. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus. Stimuli were presented on a Dell Optiplex 3020 PC with a Dell LCD 22” monitor (1680 x 1050 pixels) using E-prime 2.0 software (Psychology Software Tools, Inc.; www.pstnet.com/E-prime/e-prime.htm). RTs were recorded via an E-prime 200A PST serial response box located at the participants’ mid-sagittal plane. Vocal RTs were recorded with the voice key, a built-in feature of the serial response box and E-prime software package, via an Audio-Technica ATR1200 dynamic microphone connected to the response box. Following pilot testing, the voice key trip level was set to 0 for all participants. A chin rest maintained participants’ head position with their eyes level with central fixation approximately 500mm from the screen and their mouths approximately 70mm from the microphone.

Stimuli. The visual display is illustrated in Figure B.1. All stimuli appeared on a black background. The fixation display consisted of a central white fixation cross (width: 9mm/1.03º; height: 9mm/1.03º) and two blue square boxes (width: 65mm/7.41º, line thickness: 1.5mm). The boxes’ inner edges were 85mm (9.65º) left and right of centre. The cue comprised one box changing colour from blue to white. The target object was a white square (width: 7mm/0.8º) which appeared inside one of the boxes.

Procedure. After giving informed consent and completing the handedness questionnaire, participants performed the task comprising two experimental blocks. Response modality was varied within subjects in a counterbalanced order. In one block participants were asked to respond to the target square by pressing the centre button on the response box with their right index finger. In the other block they responded by saying the word “target” clearly into the microphone. The same word was used for all participants/trials to control for phonetic biases. The word “target” was chosen because it was plausible within the context of the experiment, which was advertised as a simple attention study. Moreover, the /t/ in “target”, a voiceless alveolar plosive consonant, is articulated with a short burst of sound as trapped air is released (Fry, 1979). If intense enough, this burst of sound should reliably trigger the voice key. Participants were coached to speak at a sufficient volume, emphasising the initial phoneme to ensure the sound pressure exceeded the voice key’s critical threshold. This coaching, admittedly, represents a minor difference in the way participants performed the task in the vocal compared with manual condition.

Each block began with 10 practice trials, followed by 170 experimental trials, resulting in 340 experimental trials per participant. One fifth (20%) of trials were target-absent catch trials, requiring the response to be withheld. In target-present trials the cue was valid and invalid in equal proportions, in line with typical exogenous cueing paradigms (Berger, Henik, & Rafal, 2005). Trial order was randomised within each block.

Each trial began with a fixation display (see Figure B.1). After 500ms the cue appeared for 50ms. Two hundred ms after cue offset the target appeared for 100ms. The fixation display remained on screen for 1500ms or until participants responded. This response interval was shorter than in Experiments 1-4, primarily because I expected that the simple nature of the task and the single response option would result in faster RTs overall than in Chapter 4. Where participants responded appropriately, the inter-trial interval consisted of a blank, black screen for 500ms. If participants did not respond to the target, responded too softly into the voice key, or made an anticipatory response before the target had disappeared, a feedback screen told participants that their response was not recorded. This message remained for 1500ms. The experimental session lasted approximately 25 minutes.

Results

Including responses to catch trials and missed responses to target-present trials, the group error rate was 0.729% (*SD* = 0.651). Missed responses comprised missed targets, anticipatory (RT < 100ms) or slow responses (RTs > 1500ms) or uncaptured vocal responses. Missed response rates were 0.703% (*SD* = 1.119) for the manual block and 0.671% (*SD* = 1.347) for the vocal block. Error rates from all participants fell within three standard deviations from the mean and so all data were included in analyses.

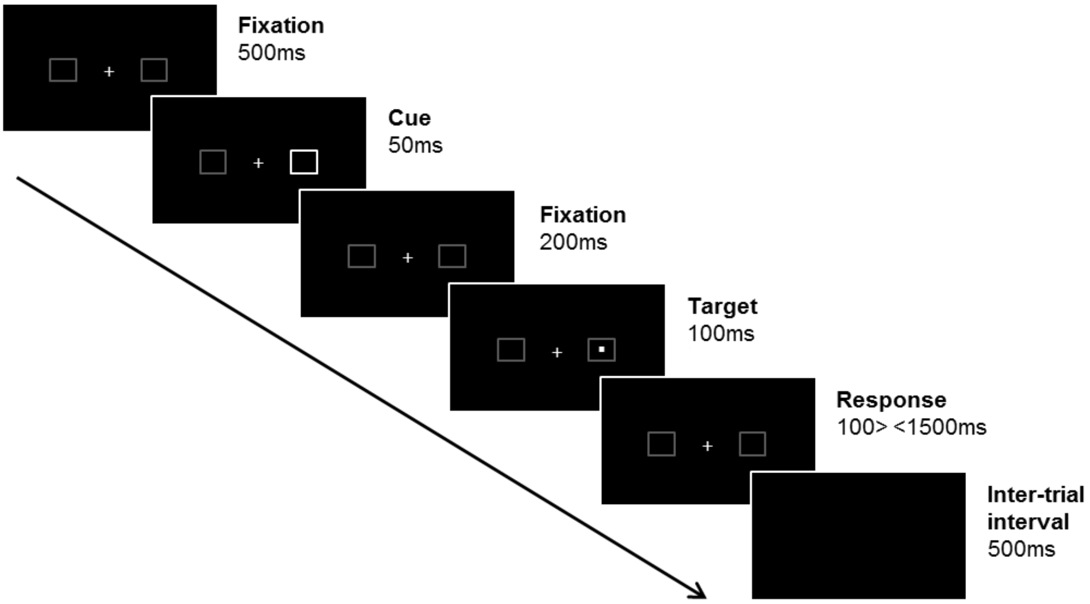

Figure B.1. Illustration of the visual display and trial sequence for a validly cued, target-present trial in Experiment 5. The cue, target stimulus and fixation cross were all white. Other stimuli were dark blue.

RTs. After excluding catch trials and errors, a 2 (cue validity; valid, invalid) x 2 (response modality; manual, vocal) repeated measures ANOVA was performed on mean RTs. Unexpectedly, there was no significant main effect of cue validity, $F(1, 22) = 0.023$, $p =.882$, $\eta^2_p = .001$. There was a strong, main effect of response modality, $F(1, 22) = 94.302$, $p <001$, $\eta^2_p = .811$. Displayed in Figure B.2, manual RTs were significantly faster than vocal RTs. There was no significant interaction between response modality and cue validity, $F(1, 22) = 1.319$, $p = .263$, $\eta^2_p = .057$.

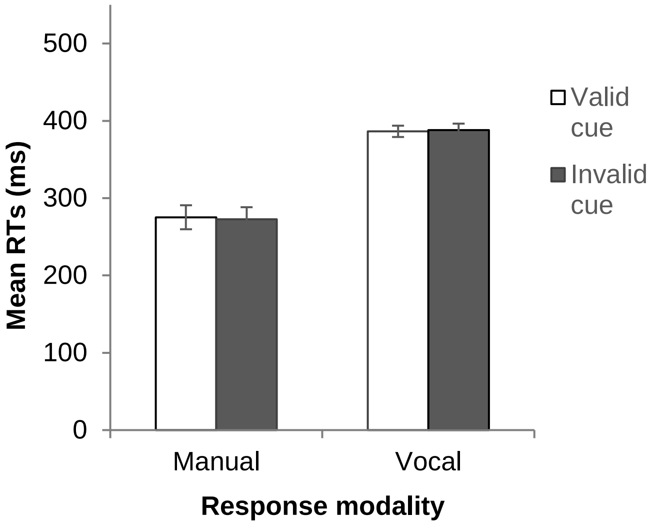

Figure B.2. Mean RTs (ms) for valid and invalid trials across the two response modalities in Experiment 5. Error bars show standard errors of the means.

Variability in RTs. Analyses also investigated differences in within-individual variability in RTs across the two response modes. The standard error of each participant's mean (SEM) manual and vocal responses was calculated based on RTs from all trials. A 2 (cue validity; valid, invalid) x 2 (response modality; manual, vocal) repeated measures ANOVA was performed on RT SEMs and revealed no significant main effect of cue validity, $F(1, 22) = 0.483$, $p = .495$, $\eta^2_p = .021$, or response modality, $F(1, 22) = 3.274$, $p = .084$, $\eta^2_p = .130$, and no significant interaction, $F(1, 22) = 0.575$, $p = .456$, $\eta^2_p = .025$ (see Figure B.3).

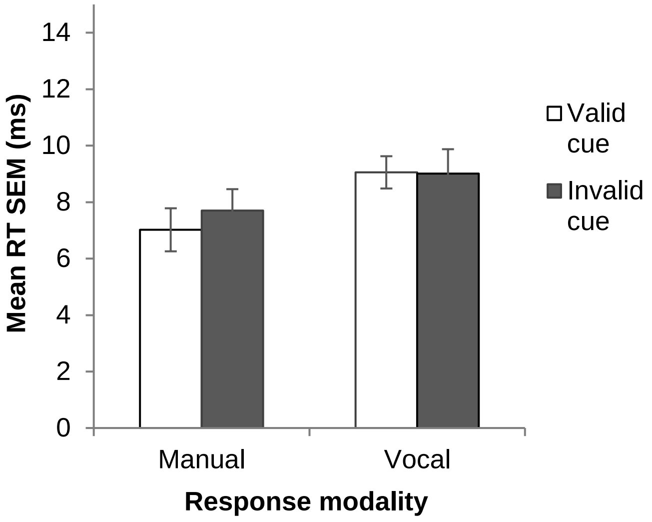

Figure B.3. Mean RT SEMs (ms) for valid and invalid trials across the two response modalities in Experiment 5. Error bars show standard errors of the means.

Correlations.

Mean RTs. The relationship between participants' mean manual and vocal RTs was investigated using a Pearson correlation. This analysis revealed a strong, positive relationship between the two indices of RT, *r*(21) = .683, *p* <.001 (see Figure B.4), demonstrating that an individual's mean manual RT was strongly associated with their mean vocal RT. Mean vocal RTs accounted for 46.645% of the variance in the mean manual RTs.

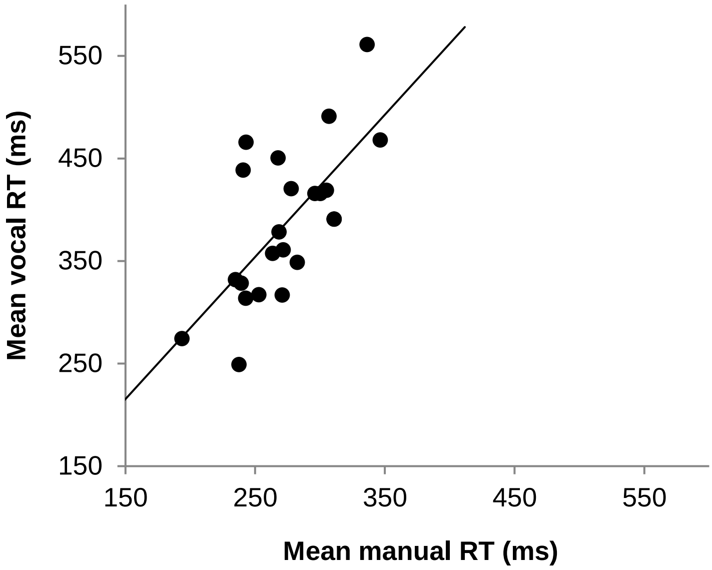

Figure B.4. Scatterplot showing the relationship between vocal and manual RTs (ms) in Experiment 5. The linear line of least squares is shown.

Variability in RTs. The correlation between SEMs of vocal and manual RTs was also explored using a Pearson correlation. There was no significant relationship between participants' SEMs for the two response modalities, *r*(21) = .067, *p* = .762 (see Figure B.5).

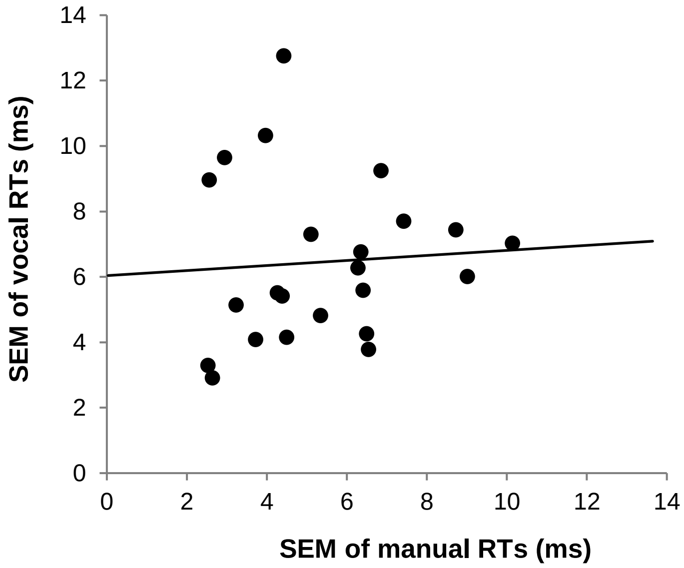

Figure B.5. Scatterplot showing the (nonsignificant) relationship between within-participant standard error of mean vocal and manual RTs (ms) in Experiment 5. The linear line of least squares is shown.

Discussion

Experiment 5 provides preliminary evidence of correspondence between verbal and manual RTs in a simple, go/no-go target detection task. Overall vocal responses were slower than manual responses, which is consistent with previous research (Ansorge et al., 1998) and likely reflects, at least in part, the delay between initiation of the verbal response and its detection by the voice key (Duyck et al., 2008; Jansen & Watter, 2008; Kessler et al., 2002). Despite the overall speed advantage for manual RTs, however, there was a strong correlation between the two indices of RT, indicating that they reflect the same construct. Moreover, although articulation differences were expected to produce greater variability in vocal responses, mean verbal RTs were as consistent as mean manual RTs. There was no correlation between the two indices of variability, though, which suggests either that RT variability is not stable within individuals or that it manifests differently across the response modalities. On balance, these findings suggest a degree of correspondence between verbal and manual RTs; however, unexpectedly, cue validity did not influence mean RTs of either modality. The failure to produce such a reliable effect is puzzling, particularly regarding conventional, manual responses, and limits the strength of conclusions that can be drawn from these data.

The lack of cueing effect may be due to the interval between cue offset and target onset, commonly known as *stimulus onset asynchrony* (SOA). According to Samuel and Kat's (2003) meta-analysis, validly cued targets reliably elicit RT facilitation compared with invalidly cued targets for SOAs of 200ms or less. SOAs greater than approximately 300ms, however, typically produce *longer* RTs for validly cued targets. This RT inhibition for valid cues following long SOAs is thought to arise because during this temporal window, attention has been drawn to the cue, but then has shifted away by the time the target appears in the cued location (inhibition of return; Posner, Rafal, Choate, & Vaughan, 1985). For short SOAs, the target appears while attention is still near the cue, resulting in RT facilitation for valid targets. It seems, though, that there is a temporal crossover point for SOAs between approximately 200-300ms in which there is reliably neither RT facilitation nor inhibition (Samuel & Kat, 2003). Furthermore, on deeper inspection of the literature, it seems that task complexity can shift this crossover interval (Lupiáñez, Milliken, Solano, Weaver, & Tipper, 2001). The temporal window can occur earlier for easier tasks, suggesting even a 200ms SOA is too long to elicit facilitation when task difficulty is low. The current task was likely very easy for participants, in light of the strikingly low error rates, and therefore it is likely that the 200ms SOA employed in Experiment 5 was too long to elicit a facilitation effect, but too short to elicit inhibition.

In summary, although the present experiment suggested a degree of correspondence between manual and vocal RTs, there was no cueing effect evident for either response type. The study's failure to produce the intended effect, particularly in conventional manual responses, limits the conclusions that can be drawn regarding convergent validity of verbal responses. Furthermore, the task was evidently very easy for participants and, together with the chosen SOA, likely prevented a cueing effect. These shortcomings were addressed in Experiment 6.

Experiment 6

As in Experiment 5, Experiment 6 investigated the convergent validity of verbal and manual RTs using a basic Posner task. The design from Experiment 5 was adapted with a view to increasing both task difficulty and the likelihood of eliciting a cueing effect. Rather than simple target detection, in Experiment 6, participants were asked to discriminate between the target stimulus (a white square), which required a response, and a white triangle in catch trials. A mask stimulus was also presented following both target and catch stimuli to further increase task difficulty (Enns & Di Lollo, 2000). To encourage RT facilitation for validly cued targets compared with invalid, the SOA was shortened from 200ms to 100ms. The fixation cross was changed from white to blue to increase the relative visual salience of the cue. Finally, although exogenous cues are thought to influence target detection through automatic attentional capture (Mulckhuyse & Theeuwes, 2010), predictive cueing was employed in Experiment 6. That is, rather than the target appearing in cued locations as often as uncued locations as in Experiment 5, in Experiment 6 the cue predicted target location in 75% of target-present trials. This technique is used to increase motivation to attend to the cue (Mulckhuyse & Theeuwes, 2010).

Experiment 6 once again aimed to test whether manual and vocal responses would yield a comparable cueing effect. Mean RTs from both modalities were again compared and correlated, as were RT SEMs to provide a measure of within-individual variability.

Method

Participants. Twenty-four right-handed Flinders University students (17 female, mean age 21.54 years) participated for a small reimbursement. Handedness was measured by the Flinders Handedness Inventory (Nicholls et al., 2013) and participants were English speakers who reported normal or corrected-to-normal vision. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus and stimuli. All apparatus were identical to Experiment 5. Stimuli were the same with the following exceptions. The fixation cross was blue instead of white. During catch (no-go) trials, a white isosceles triangle (width: 7mm/0.8º; height: 7mm/0.8º) appeared in one of the blue boxes. Both target and catch stimuli were followed by a mask stimulus in both squares, consisting of 3 rows of 4 white Xs (array width: 20mm/2.29º; height: 21mm/2.41º). The visual display is illustrated in Figure B.6.

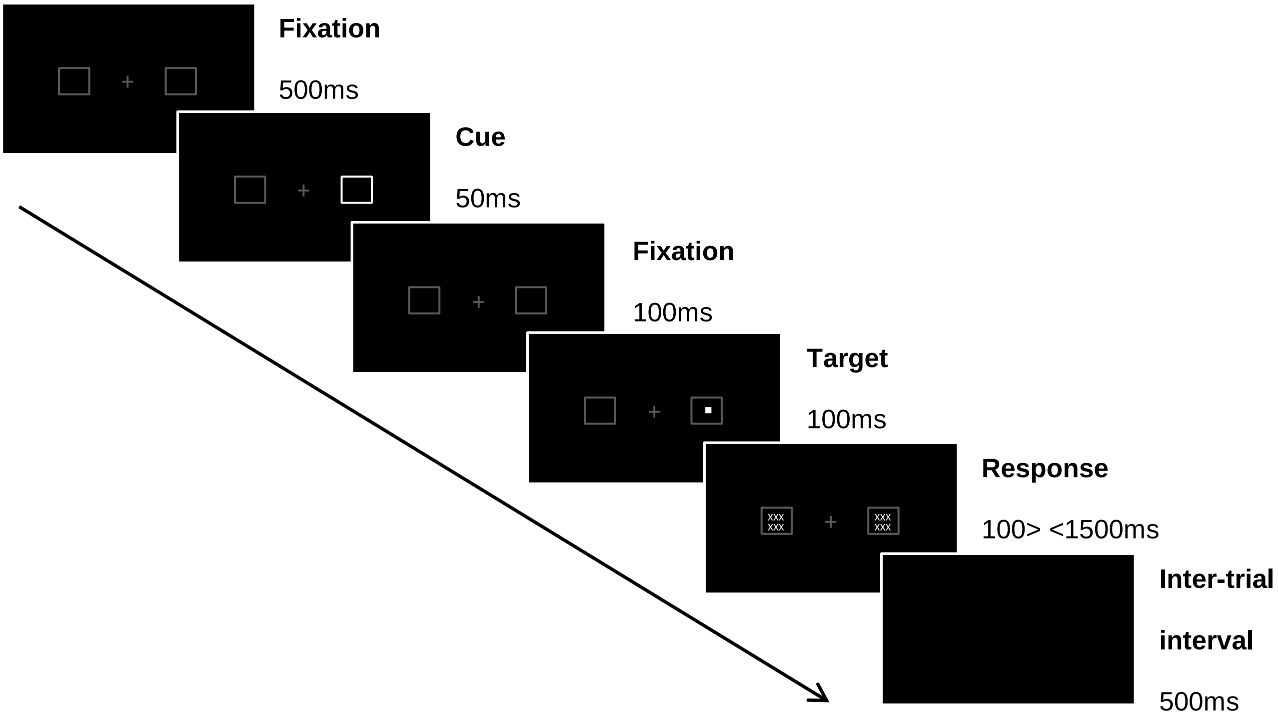

Figure B.6. Illustration of the visual display and trial sequence for a validly cued, target-present trial in Experiment 6. The cue, target/catch stimuli and mask objects were white. All other stimuli were dark blue.

Procedure. Procedure was the same as Experiment 5 with the following exceptions. Cues validly predicted target location in 75% of target-present trials. The target square or catch triangle appeared 100ms after cue offset. Target/catch stimulus offset was immediately followed by the mask stimulus, which appeared for 1500ms or until participants responded. The feedback message for erroneous or missed responses remained until the experimenter dismissed it.

Results

The group error rate, including responses to catch trials and missed responses to target-present trials, was 6.850% (*SD* = 5.180%). Error rates from all participants fell within three standard deviations from the group mean and so all data were included in analyses.

RTs. A 2 (cue validity; valid, invalid) x 2 (response modality; manual, vocal) repeated measures ANOVA was performed on mean RTs from correct trials. There was a strong main effect of cue validity, $F(1, 23) = 43.497$, $p < .001$, $\eta^2_p = .654$, with faster RTs following valid compared with invalid cues. There was also a strong, significant main effect of response modality, $F(1, 23) = 52.487$, $p < .001$, $\eta^2_p = .695$, where manual RTs were significantly faster on average than vocal RTs (see Figure B.7). There was no significant interaction between the two factors, $F(1, 23) = 1.491$, $p = .234$, $\eta^2_p = .061$.

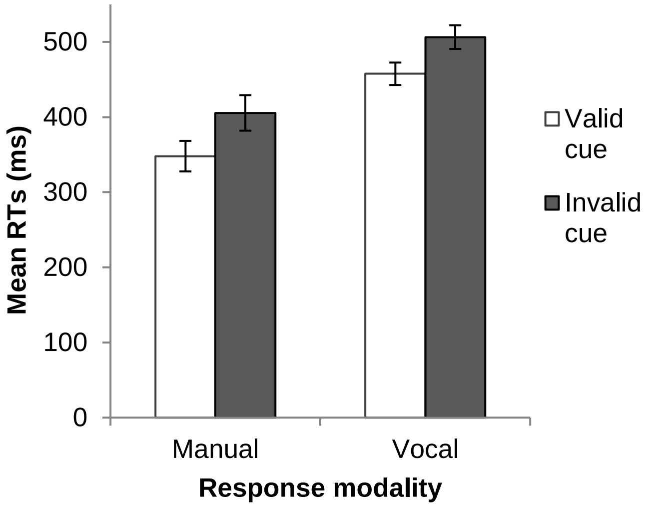

Figure B.7 Mean RTs (ms) for valid and invalid trials across the two response modalities in Experiment 6. Error bars show standard errors of the means.

Variability in RTs. A 2 (cue validity; valid, invalid) x 2 (response modality; manual, vocal) repeated measures ANOVA performed on mean RT SEMs revealed a strong effect of cue validity, $F(1, 23) = 102.304$, $p <.001$, $\eta^2_p = .816$) indicating greater variability in RTs following invalid than valid cues (see Figure B.8). There was no main effect of response modality, $F(1, 23) = 1.176$, $p = .289$, $\eta^2_p = .049$, and no significant interaction between cue validity and response modality, $F(1, 23) = 2.552$, $p = .124$, $\eta^2_p = .100$.

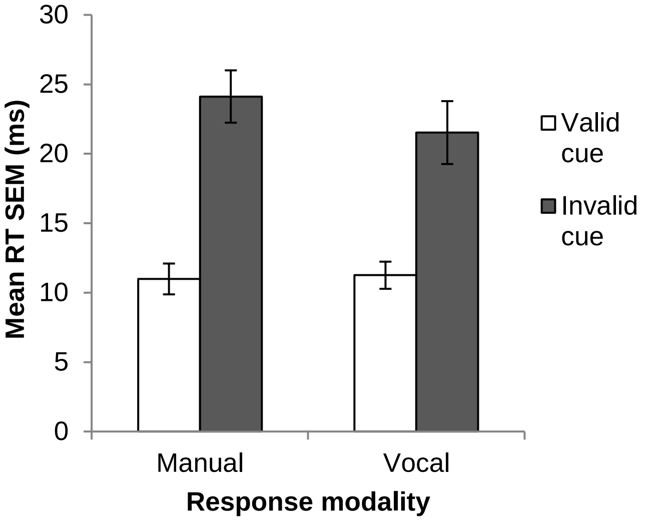

Figure B.8. Mean RT SEMs (ms) for valid and invalid trials across the two response modalities in Experiment 6. Error bars show standard errors of the means.

Correlations.

Mean RTs. The relationship between participants' mean manual and vocal RTs was investigated using a Pearson correlation. This analysis revealed a strong, positive relationship between the two indices of RT, $r(22) = .729$, $p <.001$, (see Figure

B.9), demonstrating that a participant's mean manual RT was strongly associated their mean vocal RT. Mean vocal RTs accounted for 53.144% of the variance in the mean manual RTs.

Variability in RTs. The correlation between SEMs of vocal and manual RTs was also explored using a Pearson correlation. There was a strong, positive relationship between participants' SEMs for the two response modalities, *r*(22) = .764, *p* <.001, whereby the SEM for vocal RTs accounted for 58.370% of the variance in the SEM for manual RTs. This correlation is displayed in Figure B.10.

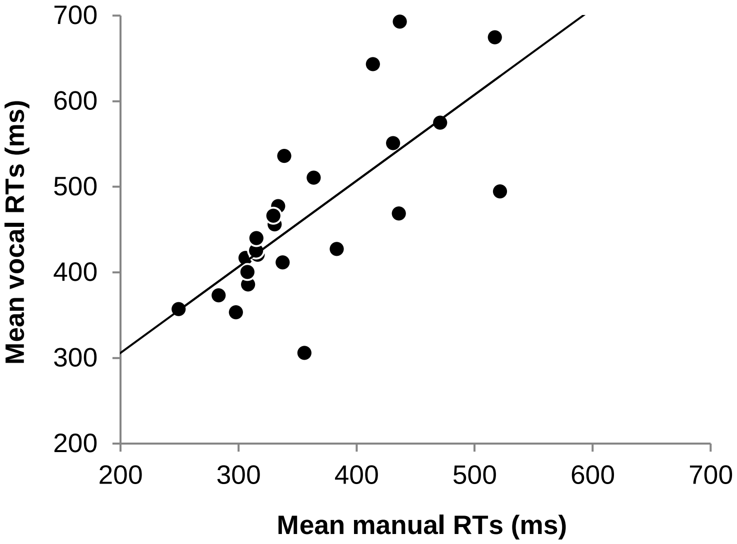

Figure B.9. Scatterplot showing the relationship between mean vocal and manual RTs (ms) in Experiment 6. The linear line of least squares is shown.

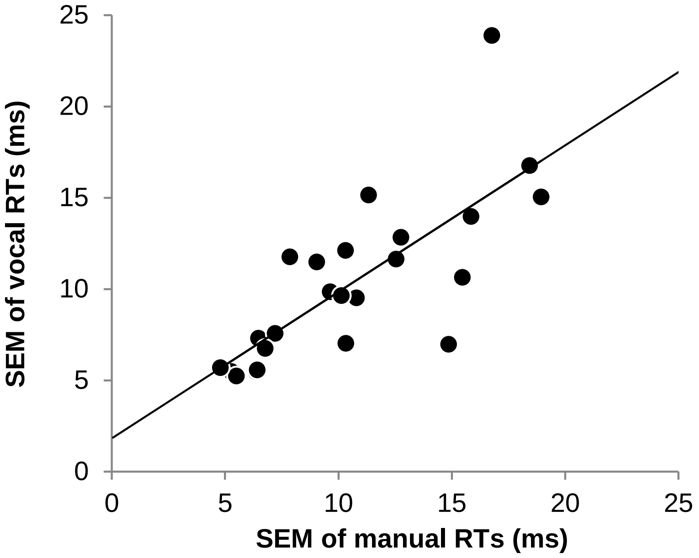

Figure B.10. Scatterplot showing the relationship between within-participant standard error of mean vocal and manual RTs (ms) in Experiment 6. The linear line of least squares is shown.

Discussion

Overall, Experiment 6 demonstrated close correspondence between mean manual and vocal RTs. The experiment successfully elicited a cueing facilitation effect in mean RTs for validly cued targets. Importantly, this cueing effect was comparable across the two modalities. Consistent with Experiment 5, there was an overall speed advantage for mean manual RTs but the two measures of RT correlated strongly. Manual and verbal responses also produced comparable variability in RT, as in Experiment 5, although in Experiment 6 there appears to be greater variability overall and in this case RT SEMs correlated strongly across the modalities. This correlation might indicate that when task difficulty is higher, RT variability is somewhat stable within individuals and manifests similarly across the two response modes. There was also an interesting finding of greater variability for invalid than valid cues, similar to that observed by Bartolomeo, Siéroff, Chokron and Decaix (2001) for a group of control subjects using exogenous cues with a 150ms SOA. The greater deviation likely reflects the greater noise associated with moving attention from the cued, incorrect location to the true location of the target. Importantly, though, the higher variability for invalidly cued targets was consistent across response types. Overall, these findings demonstrate strong convergent validity between vocal and manual RTs during simple go/go-no, target discrimination task.

General Discussion

This research examined the convergent validity of vocal RTs with conventional, manual RTs using basic, exogenous cueing Posner paradigms. Although the target detection task in Experiment 5 failed to produce a cueing effect, Experiment 6's target discrimination task did elicit RT facilitation effect for validly cued targets, and this effect manifested similarly across the response modes. Both tasks showed an overall speed advantage for mean manual RTs over vocal RTs, likely an artefact of the voice key's mechanism. This magnitude difference was a constant, however, and does not diminish the significance of the strong, positive correlations between the two measures of RT found in both experiments. Findings regarding variability in RT also suggested correspondence between the two modalities, and Experiment 6 produced a strong correlation between the two indices of variability. On balance, findings from two experiments support the use of verbal responses in measuring RT.

Overall the present findings show strong convergent validity between manual and voice key-measured RTs in a single response go/no-go Posner task – but further research is needed to determine how these results generalise to other RT paradigms. Although go/no-go paradigms are common in experimental research (Caharel, Ramon, & Rossion, 2014; Müller-Plath & Klöckner, 2014) it is important for the present findings to be replicated using paradigms with multiple response options. In this study vocal RTs were as consistent as manual RTs, but participants decided whether or not to respond, rather than choosing between response options. The resulting within-modality repetition could have contributed to the consistency in RTs. Whether the two modalities would show comparable variability in a forced-choice task with multiple response options (e.g., left/right) is currently unknown, but replicating these results in such a paradigm would provide stronger support for the use of verbal responses as an index of RT.

In employing a single phoneme response, the current study did not speak to the issue of phonetic biases. It is clear from psycholinguistic research that controlling phonetic variables is critical for any paradigm employing voice key-measured verbal RTs (Kessler et al., 2002; Rastle et al., 2005; Rastle & Davis, 2002). Importantly though, the purpose of this study was not to assess the voice key's ability to detect a single response in general, but rather to determine if this response varied systematically with task demands and within individuals, commensurate with a conventional manual response. The present data support the use of verbal RTs as an alternative to manual RTs, assuming that phonetic variables are controlled. Fortunately, in some RT studies it can be easy to control phonetic biases across conditions when the response is limited to one or two spoken words. For example, Ansorge et al. (1998) used the verbal responses “left” and “right”, but the factor of interest was congruency. Thus, phonetic differences in the two responses were balanced across conditions.

In the context of this thesis, the aim of this study was to inform on the inconsistent findings of Chapter 4. The current data demonstrate that in a basic, single response paradigm, voice-key measured latencies can reflect systematic, task-related changes in cognitive processing speed in line with manual RTs. Accordingly, these results lend support to the conclusions drawn in Chapter 4 regarding the role of motor processes in object naming. Although findings from my naming paradigm contrasted the original data and interpretation from Witt et al. (2010), it seems that voice key measurement problems are unlikely to account for the inconsistent results produced in Chapter 4. Therefore, the findings of the current study strengthen my assertion that there is little evidence to support Witt et al.’s proposal of lateralised motor interference on object naming.

The present research was, however, only intended as a first step in evaluating the ability of voice key-measured latencies to provide an index of cognitive processing. Further research is required to reconcile the current findings, which inform on verbal responses as an RT measure, with the psycholinguistic research apprising the voice key’s ability to detect verbal material generally. As discussed, in Chapter 4 phonetic variables were balanced across critical conditions and so do not represent a confound. It is unknown, however, how phonetic variables influence the degree to which verbal responses provide an index of task-related cognitive processing speed. It is important to establish that known phonetic variables do not compromise the correspondence between verbal and manual RTs and, as such, the next step in demonstrating convergent validity of vocal RTs is to replicate the current findings with responses beginning with different phonemes.

On balance the current study supports the use of voice key-measured verbal responses as an index of RT and accordingly the study has important and wide-ranging implications. Verbal responses can be a useful, alternative option for experimental paradigms in which conventional manual responses are problematic. As such the current findings are relevant broadly across the cognitive sciences, from highly conscious, higher-order mental tasks like perspective taking (e.g., Kessler & Rutherford, 2010) to studies of basic cognitive processes like unconscious perceptual asymmetries (e.g., Loftus, Vijayakumar, & Nicholls, 2009). Moreover, the demand for verbal responses may be relatively high at this time due to the popularity of embodied theories of cognition, studies of which can include motor dual-tasks as in Chapter 4 (e.g., Ionta, Perruchoud, Draganski, & Blanke, 2012; Wiemers et al., 2014). There is therefore considerable need for verbal responses across a broad range of cognitive tasks and, notwithstanding the importance of controlling phonetic variables, in light of the current findings, researchers can now enlist this methodology with increased confidence.

Appendix C: Published version of Chapter 6

Saccone, E. J., Szpak, A., Churches, O., & Nicholls, M. E. (2017). Close interpersonal proximity modulates visuomotor processing of object affordances in shared, social space. *Attention, Perception, & Psychophysics*, 1-15. doi:10.3758/s13414-017-1413-7

Publication abstract

Research suggests the human brain codes manipulable objects as possibilities for action, or affordances, particularly objects close to the body. Near-body space is not only a zone for body-environment interaction but is also socially relevant, as we are driven to preserve our near-body, personal space from others. The current, novel study investigated how close proximity of a stranger modulates visuomotor processing of object affordances in shared, social space. Participants performed a behavioural object recognition task both alone and with a human confederate. All object images were in participants' reachable space but appeared relatively closer to the participant or the confederate. Results revealed when participants were alone, objects in both locations produced an affordance congruency effect but when the confederate was present, only objects nearer the participant elicited the effect. Findings suggest space is divided between strangers to preserve independent near-body space boundaries, and in turn this process influences motor coding for stimuli within that social space. To demonstrate that this visuomotor modulation represents a social phenomenon, rather than a general, attentional effect, two subsequent experiments employed non-human joint conditions. Neither a small, Japanese, waving cat statue (Experiment 2) nor a metronome (Experiment 3) modulated the affordance effect as in Experiment 1. These findings suggest a truly social explanation

of the key interaction from Experiment 1. This study represents an important step toward understanding object affordance processing in real-world, social contexts and has implications broadly across fields of social action and cognition, and body space representation.

Introduction

The physical and social world in which we exist is complex and dynamic, yet we navigate it with remarkable ease. Our rapid, unconscious decision making and motor precision translates to an extraordinary ability to interact with the environment. Without conscious thought, we can effortlessly carry food on a fork to our mouths or transport our bodies through a crowded marketplace, avoiding collisions with the people and objects around us. To account for our remarkable ability to interact with the physical environment, modern cognitive neuroscience research has investigated how the human brain represents objects in the space around our bodies.

Drawing from Gibson's (1979) theory that we directly perceive action afforded by the environment, object perception research suggests that the brain codes objects as possibilities for action, or *affordances*. For example, a cup affords grasping and a chair affords sitting. In support of affordance views, there is evidence demonstrating that simply attending to a highly manipulable object can activate related motor programs, even without conscious intention to act on it (Cardellicchio et al., 2011; Chao & Martin, 2000; Gerlach, Law, & Paulson, 2002; Grèzes & Decety, 2002; Tucker & Ellis, 1998). Findings from Witt and colleagues have further shown that our ability to act on an object influences our reported experience of it (see

Philbeck & Witt, 2015; Witt et al., 2015 for reviews). These findings highlight the tight link between action processes and object perception, in line with the idea that we perceive action possibilities, or affordances, in the physical environment.

Objects are not the only action-relevant stimuli in the environment, however; humans are highly social and the other people around us affect how we move our bodies and interact with the physical world. Others can afford us possibilities for action that would not otherwise be available. For instance, two people can work together to perform a task that an individual acting alone could not achieve, like carrying a heavy table (Pezzulo et al., 2013; Richardson et al., 2007). The others around us also influence our motor planning and behaviour even when we are acting independently. For example, we account for the presence of others when simply walking down a street (Soper & Karasik, 1977) and adjust our gestures during speech (Özyürek, 2002) based on the location of others.

Given that both the objects and people around us drive our motor plans and behaviour, there is surprisingly little research into how these two types of action-relevant stimuli interact in their effect on our related perceptual and motor processes. Object affordance research is typically conducted on participants in isolation, in keeping with the tradition of experimental psychology to keep extraneous variables to a minimum. There has, however, been a recent trend to include social variables in research into action processes, but these studies have often investigated how participant pairs coordinate to perform a collaborative, joint task (Ciardo et al., 2016; Sebanz et al., 2006). There is certainly research suggesting we recognise and represent the action possibilities of other people (see Creem-

Regehr et al., 2013 for a relevant review), but once again these studies typically focus on how these processes facilitate coordinated action. Indeed, in our highly social world we frequently act in cooperation with other people; however, other times we act in spite of others. Therefore, an important question remains as to how the presence of other actors around us affects how we process affordances in the physical environment.

Although the impact of social proximity on affordance perception is largely unknown, there is evidence that other people influence our motor behaviour in general owing to the ownership we claim over our near-body space. We typically view the space immediately surrounding our bodies as our own private or *personal space* (Hall, 1966), and often alter our behaviour to maintain a comfortable distance from other people, for example when choosing a seat on public transit, or perhaps opting to stand instead (Evans & Wener, 2007; Hirsch & Thompson, 2011). Unwelcome personal space invasions are often associated with discomfort and physiological arousal (Evans & Wener, 2007; Perry et al., 2013) and our desire to maintain a certain distance from other people, particularly strangers, likely serves an adaptive function in interest of protecting our bodies from unwanted physical contact (de Vignemont & Iannetti, 2015; Graziano & Cooke, 2006). Research also suggests that we are aware of and represent the near-body space of other people (Brozzoli et al., 2013; Maister et al., 2015), which may also contribute to maintaining comfortable social distances.

Near-body space is not only socially relevant, however; it is also the region in which we are most likely to interact with objects in the physical environment. In fact, cognitive neuroscience has provided evidence that the brain uniquely represents this space by its potential for action and interaction with the physical world (e.g., Fogassi et al., 1996; Graziano & Gross, 1994; Rizzolatti et al., 1997). This practical, motor-based representation of close, actionable space, known in the neuroscience literature as *peripersonal space* (Rizzolatti et al., 1997) is neurologically distinct from extrapersonal, far space, which is less relevant for body-environment interactions (see Cléry et al., 2015 for a review). Accordingly, research demonstrates that affordances are more likely to activate motor programs for objects located within peripersonal space than extrapersonal space (Cardellicchio et al., 2011; Costantini et al., 2010; De Stefani et al., 2014; Kalénine et al., 2016; but see Tucker & Ellis, 2001). For example, Cardellicchio et al. (2011) provided evidence of greater grasp-related motor activation when participants viewed graspable objects in reachable compared with non-reachable space.

Near-body space, therefore, is an important region for action and interaction with inanimate objects as well as people. Given our strong desire to preserve our near-body space from strangers, and to avoid entering theirs, there is an intriguing question of how this instinctive drive influences how we process ~~and interact with manipulable objects~~ action possibilities, or affordances, in space that is 'near' more than one person. Accounting for the people around us is critical to successful and socially appropriate interactions with the environment and as such, investigating how close interpersonal proximity affects action planning and related perception is fundamental to understanding how these processes operate in an ecologically valid way. Accordingly, the aim of the current study was to investigate how manipulable objects are processed within space that is shared between two human strangers, henceforth referred to as social space.

Although little is known of object affordances in social space, there is research that suggests other action-related processes are modulated within space shared between people. Findings from Constable et al. (2015) also indicated that areas of a participant's near space were coded as less action-relevant when a co-actor's hands entered into it. Interestingly, in this case only an *active* co-actor encroaching on the participant's space modulated stimulus processing; the same results did not emerge when the experimenter merely sat across from the participant, passively observing. The authors suggested that the way space is represented as 'near' in egocentric terms changes when another actor enters that space, owing to the way the other represents it as their own near, action space. Similarly, neuroscience research into peripersonal space has shown that the boundary of what the brain codes as actionable space is flexible and dynamic (see Maravita et al., 2003 for a review), and findings from Teneggi et al. (2013) suggest the boundary of actionability can be socially modulated. They showed that another person standing nearby caused an inward contraction of peripersonal space boundaries. When the other person demonstrated intent to cooperate, however, peripersonal space boundaries expanded to include the co-actor. This research suggests that coding of shared, social space involves a complex and interdependent representation of one's own near-body space and that of other actors.

In light of the research reviewed above, and given our strong desire to maintain comfortable social distances whenever possible, we propose that there is a perceptual division of space between two strangers acting independently in close proximity. This division in turn may modulate the processing of action-relevant stimuli within social space and we reasoned that this modulation would apply to object affordances. If attending to nearby objects activates affordance-related motor programs (e.g., Cardellicchio et al., 2011; Costantini et al., 2010; De Stefani et al., 2014; Kalénine et al., 2016), and if close space between two strangers is segmented or divided to preserve independent near-body space boundaries, then an object in shared, social space is likely to be processed differently than if it were located near one person only. The present study therefore sought to answer the following question: If an object located in near space is closer to another actor, does it still activate affordance-related motor codes?

Experiment 1

To investigate object affordances in social space, participants in Experiment 1 performed an object recognition task both alone and together with a stranger (confederate) standing in close proximity. Both the participant and the confederate viewed object images from opposite sides of a flat screen, illustrated in Figure 1. Objects either appeared nearer the participant or nearer the confederate but, importantly, were always within the participant's close, reachable space.

To test affordance-related motor processing, the study employed Tucker and Ellis' (1998) object inversion task. Participants viewed object images and responded with a bimanual key press to the objects' upright or inverted orientation. The object inversion task lends itself well to the current paradigm, which required two actors to view the images from opposite sides (see Figure 1). That is, two people facing one another can perform the task concurrently, despite their contrasting viewpoints, because an object appearing upright for one person appeared inverted to the other. Critically, in this task all objects afforded a single-handed grasp and appeared with handles facing the left or right. Although the stimulus feature of handle orientation is task-irrelevant, this task elicits a robust response speed advantage for trials in which object handle (left, right) and response hand (left, right) correspond rather than conflict (Iani et al., 2011; Pappas, 2014; Riggio et al., 2008; Saccone et al., 2016; Tucker & Ellis, 1998). This congruency effect is primarily thought to reflect a match between the action afforded by the object (left- or right-handed grasp) and the action performed in making a response (left- or right-handed key press)[4].

The following results were predicted. The typical handle congruency effect was expected to emerge in response times (RTs). That is, faster responses were expected for trials in which object handles (left, right) matched rather than conflicted with response hand (left, right). The critical prediction was that the handle effect would interact with alone/joint condition and object proximity (near participant, far from participant). It was reasoned that if social space is divided or segmented between strangers in order to preserve near-body space boundaries, then in the presence of the confederate, only objects closer to the participant would elicit the handle effect. When participants performed the task alone, however, we expected the

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[4] There is evidence that a spatial compatibility mechanism also underlies this handle congruency effect (Cho & Proctor, 2010, 2011; Lien et al., 2014); however, it is likely that this mechanism contributes to the effect, rather than explaining it entirely (Pappas, 2014; Saccone et al., 2016; Symes et al., 2005).

effect to emerge for objects in both locations because both objects were in reachable space.

Method

Participants. We conducted a priori power analyses to inform participant recruitment numbers (G*Power; Faul et al., 2007). At an α of .05 and a power (1 – β) of .95, it was determined that 33-42 participants were required to detect an interaction of moderate effect size (η^2_p = 0.25 – 0.30). Thus, we aimed to recruit approximately 40 participants, which is highly consistent with previous studies employing joint task paradigms (Constable et al., 2015; Sebanz et al., 2003). Thirty-nine right-handed (f = 20, m = 19; mean age 24.51 years) Flinders University students participated for a small reimbursement. Handedness was measured by the Flinders Handedness Inventory (Nicholls et al., 2013). Participants were English speakers who reported normal or corrected-to-normal vision and gave written, informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

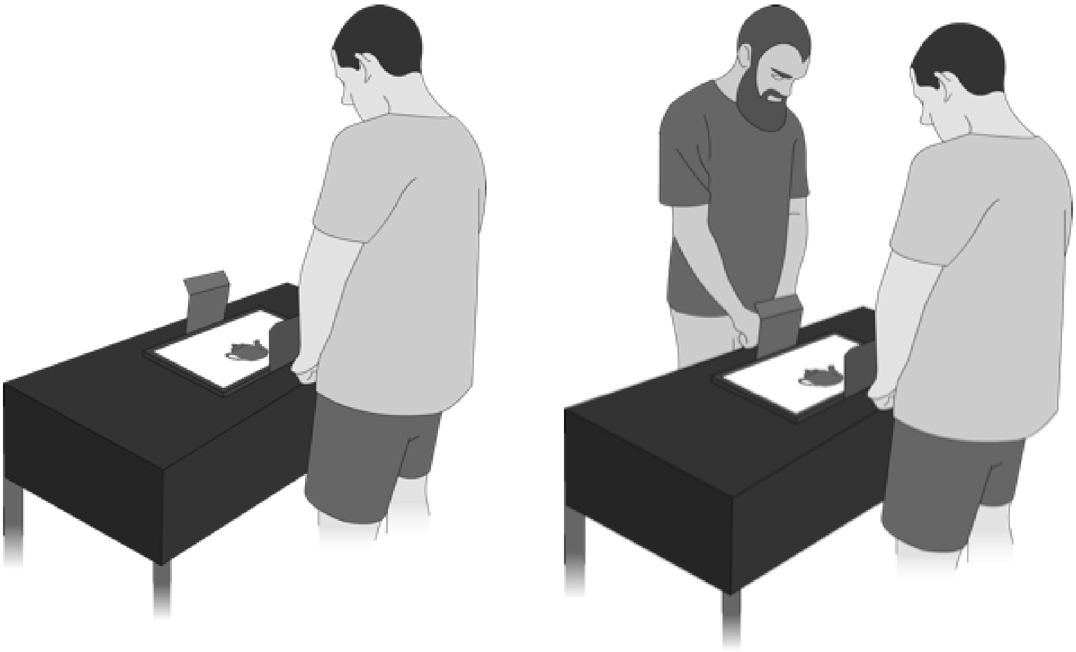

Figure 1. Illustration of the experimental set-up when participants performed the task alone (left panel) and with the confederate (right panel).

Apparatus. Stimuli were presented with a Dell Optiplex 745 PC and a LCD 23'' monitor (5182mm x 2921mm) using E-prime 2.0 software (Psychology Software Tools, Inc.; www.pstnet.com/E-prime/e-prime.htm). The monitor was embedded in a table, facing upwards, 790mm from the floor (see Figure 1). The table was 1200mm long and 600mm wide. A sufficiently narrow table was necessary for two reasons: a) to ensure the actors were in close proximity, encroaching on one another's personal space (Kennedy et al., 2009; Lloyd, 2009; Szpak et al., 2016; Tajadura-Jiménez et al., 2011), and b) to confirm object stimuli were in the reachable, peripersonal space of both actors (Cardellicchio et al., 2011; Costantini et al., 2010; De Stefani et al., 2014). Responses were recorded via a numeric keypad, located at the participant's mid-sagittal plane, in line with the screen's horizontal centre. The confederate responded via an identical keypad but his responses were not recorded. The keypads were placed within black cardboard boxes to obscure responses from the other’s view. We wanted the actors to focus on the experimental display, rather than attending to one another’s responses. The experimenter monitored the session using a small closed-circuit video camera.

Stimuli. Stimuli were colour photographs of 30 highly graspable objects (e.g., kettle, mug, watering can) which had an objectively correct upright orientation during use. A single, colour photograph of each object was obtained from Shutterstock’s online database. All objects afforded a single-handed grasp and appeared with handles facing left or right. Object location was varied distally with respect to the participant, with objects’ inner edges 20mm from centre. Owing to the narrow table, all objects were in the participant’s reachable space (within a range of approximately 150mm-450mm) but were relatively near to or far from the participant. Each object appeared in two horizontal orientations (handle facing participant’s left, right), two vertical orientations (upright, inverted) and two locations (near participant, far from participant), resulting in 240 unique trials. Objects ranged in size to be in approximate proportion to one another, for example, the hand saw (210mm x 72mm) was considerably larger than the vegetable peeler (100mm x 17mm).

Procedure. Participants entered the laboratory to find the confederate (male, aged 21) already present. The confederate was described as “the other participant”. He was instructed to maintain a neutral demeanour throughout the session and not to initiate any conversation or engage greatly with the participant. The experimenter explained to the participant and confederate (henceforth referred to as the actors) that the experiment comprised three blocks, one each that they would perform alone and one together, although in reality only the two blocks including the participant were performed. The actors then gave informed consent to participate.

The experiment began with 12 practice trials, which the actors completed together, followed by two experimental blocks, each comprising 240 trials (30 objects x 2 horizontal orientations x 2 vertical orientations x 2 locations). Thus, each object appeared eight times in each block. In the context of other studies employing the object inversion task, this degree of stimulus repetition is comparable to Tucker and Ellis (1998), and far less than Iani et al. (2011), who repeated each stimulus 80 times. Blocks varied by alone/joint condition (alone, with confederate), the order of which was counterbalanced across participants. The Flinders Handedness Inventory was completed in between blocks, when participants were also offered a short break.

The actors were asked to respond to each object's "normal" or "inverted" appearance as quickly and accurately as possible, regardless of object location. Responses were left and right key presses, with response mapping counterbalanced across participants. The actors stood during the task, primarily because there was not sufficient room under the narrow table to accommodate a seating position for both actors during the joint block. Actors were asked to stand with their thighs touching the table so that their viewing position remained constant throughout the experiment. Stimulus presentation order was randomised.

In the joint block, participant and confederate responded to each stimulus concurrently, giving opposing correct responses given their contrasting viewpoints.

Only the participant's responses were recorded, however. Owing to the width of the table, when performing the task together the actors stood approximately 600mm apart, with a distance of approximately 450mm between their hands. The confederate was quiet and focused on the task, paying little attention to the real participant, and maintained a constant gaze on the experimental display to encourage the participant to behave likewise.

Each trial began with a central fixation cross (18mm x 18mm), shown for 500ms, followed by the stimulus, which remained on screen for 1500ms or until the participant responded. If no response was made (missed trials), on-screen text feedback reminded the actors to respond as quickly as possible. This message, displayed for 2000ms, appeared in two orientations so it could be read by both participant and confederate. Where participants responded in time, the inter-trial interval was 500ms. This trial procedure is consistent with previous versions of the object inversion task (e.g., Iani et al., 2011; Pappas, 2014; Riggio et al., 2008; Saccone et al., 2016; Tucker & Ellis, 1998) including the use of fixed inter-trial intervals and the lack of catch trials.

After the two experimental blocks were completed, participants were told that there would not be a third block and that the experiment was finished. Participants were debriefed appropriately and thanked for their time.

Results and discussion

Data analysis. For simplicity, and because we were interested in spatial congruency effects relating to object handle and response, data were collapsed across response (left, right) and object handle side (left, right) to create the factor of handle (congruent, incongruent). Congruent trials were those in which the response and handle side matched and incongruent trials were those in which they conflicted. Although this congruency effect reliably manifests in response speed, error rates often fail to produce an effect (e.g., Constable et al., 2011; Iani et al., 2011; Riggio et al., 2008; Saccone et al., 2016). Furthermore, research suggests that affordance processes are not the primary mechanism underlying the effect in errors when it is found (Saccone et al., 2016). Accordingly, only the RT data are reported in the current manuscript. Analyses with respect to error rates are available in the supplementary material. The key interaction, representing the study's experimental hypothesis was not significant.

Although the factors of participant sex and stimulus upright/inverted orientation did not inform the study's a priori hypothesis, it was considered they could influence responses. In light of the social nature of the paradigm and given that only a male confederate was used, it is possible that participant sex in particular could be of interest to some readers. However, including these additional variables would result in a highly complex factorial design and a 5-factor ANOVA model that would be difficult to interpret. Accordingly, these additional factors are not included in the analysis presented below, but results from the larger, 5-factor ANOVA model are available in the supplementary material. Of note, there was no main effect of participant sex and neither sex nor upright/inverted orientation interacted with alone/joint condition and therefore do not counteract the study's key hypothesis. All significant effects detailed below remained significant in the larger, 5-factor ANOVA model.

Data from two male participants were excluded from all analyses owing to error rates above chance, which were also above three standard deviations from the sample mean (16.350%, *SD* = 18.534). Once these participants were removed the group error rate was 12.490% (*SD* = 8.025).

RTs. A 2 (alone/joint condition; alone, confederate present) x 2 (handle; congruent, incongruent) x 2 (object proximity; near participant, far from participant) repeated measures ANOVA was conducted on mean RTs from correct trials. There were main effects of alone/joint condition and handle, displayed in Figure 2. Participants made faster responses in the presence of the confederate (*M* = 563.193, *SD* = 72.335) than when performing the task alone (*M* = 603.196, *SD* = 75.248), *F*(1, 36) = 11.828, *p* = .001, η^2_p = .247. This likely reflects a social facilitation effect (Zajonc, 1965), whereby performance is enhanced in the presence of others. Mean RTs also showed the typical handle effect (Iani et al., 2011; Pappas, 2014; Riggio et al., 2008; Saccone et al., 2016; Tucker & Ellis, 1998) in that participants were faster to respond with the hand that was congruent with the object's handle (*M* = 576.660, *SD* = 67.669) rather than incongruent (*M* = 598.730, *SD* = 63.265), *F*(1, 36) = 16.647, *p* <.001, η^2_p = .316. There was no main effect of object proximity, *F*(1, 36) = 0.684, *p* = .414, η^2_p = .019 and no significant 2-way interactions, all *F*s <0.945, *p*s >.337, but there was a significant 3-way interaction between alone/joint condition, handle and object proximity[5], *F*(1, 36) = 4.451, *p* = .042, η^2_p = .110.

To explore the significant 3-way interaction, separate 2 (handle) x 2 (object proximity) repeated measures ANOVAs were performed for the alone/joint conditions. There was no significant interaction between handle and object proximity for the alone condition, *F*(1, 36) = 0.649, *p* = .426, η^2_p = .018, indicating a comparable handle effect for both near (congruent *M* = 597.141, *SD* = 74.244; incongruent *M* = 608.765, *SD* = 76.440) and far objects (congruent *M* = 594.702, *SD* = 83.864; incongruent *M* = 612.177, *SD* = 77.301). There was, however, a significant interaction between handle and object proximity for the confederate condition, *F*(1, 36) = 6.554, *p* = .015, η^2_p = .154. Paired sample t-tests revealed that, when the confederate was present, the handle effect was elicited by near objects (congruent *M* = 555.806, *SD* = 75.942; incongruent *M* = 574.579, *SD* = 74.105), *t*(36) = 3.731, *p* = .001, *d* = 0.614, but not far objects (congruent *M* = 558.989, *SD* = 77.818; incongruent *M* = 563.399, *SD* = 68.257), *t*(36) = 1.095, *p* = .281.

Given the importance of the above contrasts to the study's hypothesis, confirmatory Bayesian statistics were conducted. These analyses produced Bayes factors, which can be interpreted as odds ratios, quantifying the likelihood of the data under one hypothesis compared to another (Wetzels et al., 2011). Bayesian ANOVAs were conducted in JASP (JASP Team, 2017) using default priors. For the alone condition, the model without the handle*object proximity interaction term was

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[5] Of note, this interaction was also significant in the larger, 5-factor ANOVA detailed in the supplementary material, *F*(1, 34) = 4.957, *p* = .033, η^2_p = .127.

preferred to the model including it, with a Bayes factor of 3.340. This finding confirms that the handle effect was comparable for near and far objects when participants were alone. Conversely, for the confederate condition, the model that included the handle*object proximity interaction was favoured by a Bayes factor of 3.141. This finding supports a significant difference in the handle effect for near and far objects in the confederate condition. Thus, Bayesian analyses accord with the results described above.

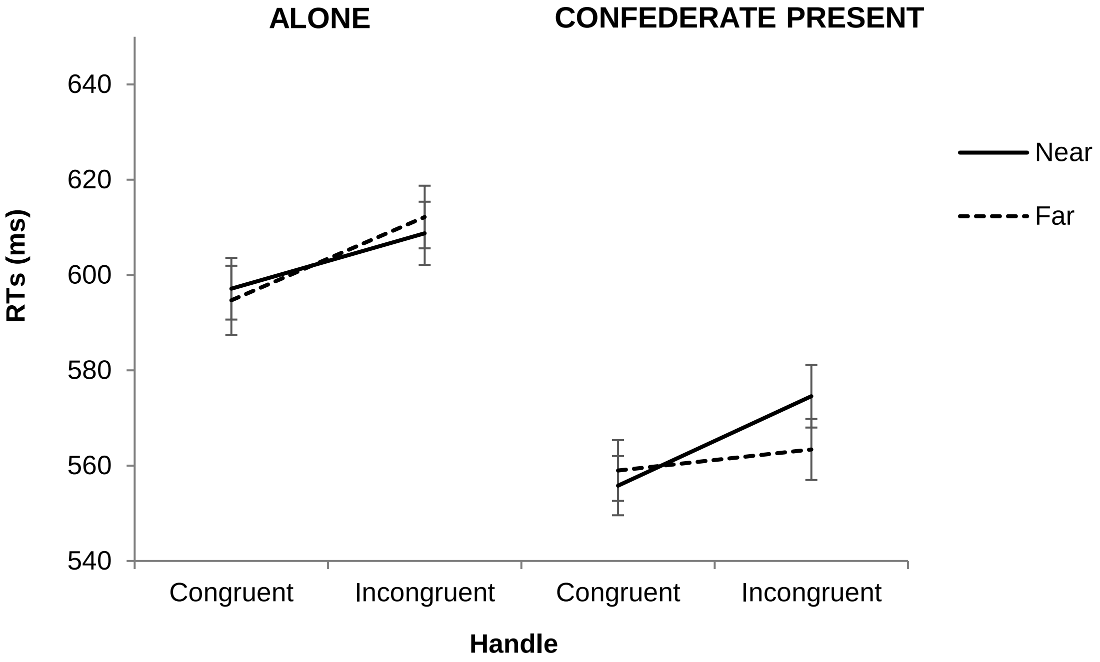

Figure 2. Mean correct RTs (ms) across handle and proximity factors for the alone condition (left) and the confederate condition (right) in Experiment 1. Error bars represent a standard error of the mean calculated within-subjects for each condition.

These findings support the study's central hypothesis. All objects were located within near-body, reachable space of participants but when a stranger was acting in close proximity, only nearer objects elicited the handle effect. When participants were alone, however, the effect was evident for both near and far objects. In line with evidence for modulated processing of action-relevant stimuli in social space (Constable et al., 2015; Teneggi et al., 2013), and given that humans are instinctively motivated to preserve personal space boundaries (Evans & Wener, 2007; Hirsch & Thompson, 2011; Soper & Karasik, 1977), in Experiment 1 it seems that another actor in close proximity led to a perceptual division of social space, such that far objects no longer produced the same degree of lateralised, affordance-related motor activation.

One consideration is that responses made by the confederate may have influenced participants' performance in the joint condition. In particular, participant responses could have been slowed in instances where the confederate gave a response that did not match the participant's (Tsai, Kuo, Jing, Hung, & Tzeng, 2006). We feel that this is unlikely to be a concern for the following reasons. First, the actors' hands were occluded and so the visible movement cues as to the response given were slight at most. Second, the experimental procedure was such that trials moved quickly from one to the next to ensure that the actors' gaze and attentional focus were maintained on the display. Furthermore, the experimenter monitored the session from outside the testing room to ensure the actors were performing the task in this manner. Last, owing to the actors' opposing viewpoints, a leftward object handle from the participant's perspective was in fact a rightward handle from the confederate's (see Figure 1). Given that the actors gave opposing correct responses (i.e., upright versus inverted), and these responses were made with opposing response hands (e.g., left for upright, right for inverted), a correct, handle-congruent or –incongruent response for one actor was in fact likewise for the other. Thus, the confederate's responses were unlikely to have slowed participant responses or represented a confound in the joint condition.

We have interpreted the current findings as a social phenomenon, but alternatively it is possible that a non-social joint condition would produce the same pattern of results. Perhaps the human, biological agency of the confederate was not critical in eliciting these effects. The confederate may simply have served as a distractor that participants attempted to ignore, leading them to neglect near-confederate space and stimuli within it (Tipper, 1985). Certainly it is possible that the close proximity of the confederate caused an inward or proximal withdrawal of the participant's attention (Szpak et al., 2015), although such a process would not necessarily preclude the proposed mechanism of a perceptual division of social space. Critically, in Experiment 1, social presence differentially influenced RTs *only with respect to object affordance*, with no overall reduced RT for far objects. In other words, if a simple distractor mechanism explained the current results, one would expect slower responses overall for far objects in the joint condition, which was not the case. Even if there was an element of attentional withdrawal or an attentional mechanism, therefore, it only affected the visuomotor processing of stimuli (i.e., motor congruency between responses and objects' affordances), not object identification overall. As such, the findings speak against a general attentional or distractor mechanism.

Although the data are not consistent with a simple distractor explanation, it is nonetheless important to provide stronger evidence that these findings represent a social phenomenon. In order to confirm a social mechanism underlying Experiment 1's key interaction, two further experiments were conducted, each employing a non-human distractor object in the joint condition instead of a human confederate. We adapted a methodology from Dolk et al. (2013), as described below, whereby the social nature of the distractor objects was reduced in a stepwise manner across the experiments. As we were distinguishing between a social rather than general, attentional mechanism, highly visually and/or aurally salient distractor objects were chosen for the joint conditions in the following two experiments.

Experiment 2

Experiment 2 was conducted to determine whether Experiment 1's key finding was truly a social effect, dependent on the human, biological agency of the confederate. The joint condition in Experiment 2 was adapted from the spatial compatibility literature, in which a similar issue has arisen. To explain, Sebanz et al. (2003) conducted a collaborative task between participant pairs, whereby each member was asked to respond to one of two stimulus colours. They found participants sitting on the left were faster to respond to left- rather than right-located stimuli and vice versa for participants sitting rightward. This stimulus-response spatial compatibility disappeared when participants performed the task alone, even though participants were still sitting in left or right locations. Dolk et al. (2013) subsequently tested whether this joint task effect was truly social in nature with a series of experiments employing visually and/or aurally salient, non-human objects in the joint condition[6]. The authors systematically reduced the "socialness" of the objects across each of their experiments. The first, most social of these non-human items was a gold, Japanese waving cat statue (see Figure 3).

Thus, Experiment 2 employed the method from Experiment 1 but in the joint condition participants performed the task in the presence of a small, gold, waving cat statue rather than a human stranger. In line with Dolk et al.'s (2013) reasoning, the statue was a sufficiently visually and aurally salient non-human object due to its moving arm.

The following predictions were made. If the finding from Experiment 1 was driven by a general attentional, distractor mechanism, then similar results were expected in Experiment 2. Specifically, the critical 3-way interaction from Experiment 1 would be replicated, whereby the joint (cat) condition elicited a handle effect for near but not far objects, whereas the alone condition produced the effect for objects in both locations. If the key finding from Experiment 1 did in fact represent a social phenomenon, reflecting visuomotor modulation within social space, then Experiment 2 was not expected to produce a 3-way interaction between alone/joint condition, handle and object proximity. In this case it was expected that objects in both locations would elicit handle effects, regardless of alone/joint condition.

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[6] To clarify, although we have adapted Dolk et al.'s (2013) methodology to investigate a social mechanism, we note the different applications of this methodology across their study and ours. Dolk et al. employed non-human objects to investigate a referential, event coding account of the joint task effect in their study, rather than the attentional, distractor account we have proposed.

Figure 3. Photograph of the cat statue and digital metronome employed in the joint conditions of Experiments 2 and 3, respectively.

Method

Participants. Forty-one right-handed (20 female, mean age 21.98 years) Flinders University students participated for a small reimbursement. Handedness was measured by the Flinders Handedness Inventory (Nicholls et al., 2013). Participants were English speakers who reported normal or corrected-to-normal vision and gave written, informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus and stimuli. All apparatus and stimuli were identical to Experiment 1 with the addition of the cat statue (displayed in Figure 3). The cat measured 205mm high, 120mm wide and 110mm deep, and its left arm waved at a frequency of 0.55 Hz, accompanied by a soft, rhythmic noise.

Procedure. Procedures were the same as Experiment 1 except with respect to the confederate. Rather than performing the task with another person, participants were asked to complete two experimental blocks, one in the presence of the cat statue. During the joint condition, the cat was positioned on the table in place of the confederate's key pad, to ensure it was sufficiently visually salient.

Results and discussion

Data analysis. The factor of participant sex was not included in the following analyses. Although some evidence points to sex differences in cognitive processing (e.g., Stoet, 2010), Experiment 1 did not reveal any effects in relation to participant sex and so it was considered unlikely to be a variable of interest in Experiment 2. This reasoning notwithstanding, preliminary analyses performed on RT data from Experiment 2 revealed neither a main effect nor any interactions with the factor of participant sex.

Data from two male participants were excluded from analyses owing to error rates greater than three standard deviations from the group mean (10.520%, *SD* = 7.896). After removing these two participants, the group error rate was 9.220% (*SD* = 5.492). Analyses of error rates are presented in the supplementary material. The study's critical 3-way interaction was not significant.

RTs. A 2 (alone/joint condition; alone, cat present) x 2 (handle; congruent, incongruent) x 2 (object proximity; near participant, far from participant) repeated measures ANOVA was conducted on mean RTs from correct trials (see Figure 4). Unlike Experiment 1, there was no main effect of alone/joint condition (alone *M* = 609.806, *SD* = 62.927; joint *M* = 605.635, *SD* = 79.310), *F*(1, 38) = 0.106, *p* = .747, η^2_p = .003, suggesting the effect from Experiment 1 was in fact social facilitation. There was a significant main effect of handle, *F*(1, 38) = 11.225, *p* = .002, η^2_p = .228, reflecting the typical response speed advantage for congruent (*M* = 601.798, *SD* = 62.995) over incongruent handles (*M* = 613.642, *SD* = 57.643) as seen in Figure 4. The main effect of object proximity was not significant, *F*(1, 38) = 1.037, *p* = .315, η^2_p = .027, and there were no significant 2-way interactions, all *F*s <0.019, *p*s >.890.

The critical 3-way interaction between alone/joint condition, handle and object proximity was not significant, *F*(1, 38) = 3.613, *p* = .065, η^2_p = .087, but it was close to the conventional cut-off for statistical significance. As seen in Figure 4, there appears to be a trend for a weaker handle effect for far compared with near objects in the cat present condition, which is consistent with Experiment 1. In light of this pattern, and given its theoretical importance to the study, this non-significant 3-way interaction was investigated further. Separate 2 (handle) x 2 (object proximity) repeated measures ANOVAs were performed for the alone/joint conditions. The interaction between handle and object proximity was neither significant in the alone, *F*(1, 38) = 1.981, *p* = .167, η^2_p = .050, nor cat present conditions, *F*(1, 38) = 2.059, *p* = .159, η^2_p = .051.

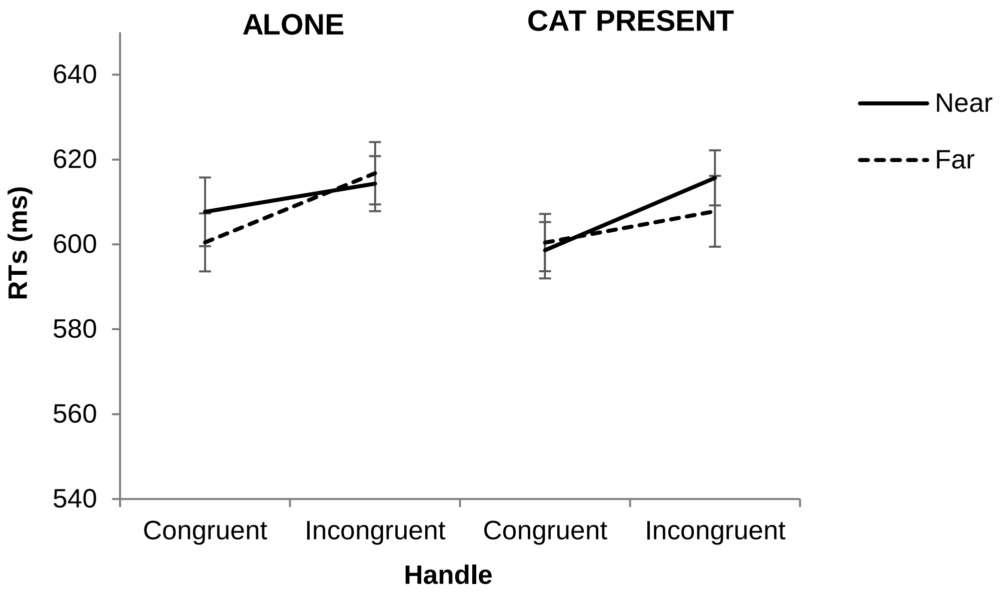

Figure 4. Mean correct RTs (ms) across handle and proximity factors for the alone condition (left) and the cat condition (right) in Experiment 2. Error bars represent a standard error of the mean calculated within-subjects for each condition.

Bayesian ANOVAs were once again conducted for these contrasts. The model excluding the handle*object proximity interaction term was preferred for both the alone (Bayes factor = 1.917) and joint conditions (Bayes factor = 2.119). These results provide further evidence for statistically comparable handle effects for near and far objects in both the alone and cat present conditions, consistent with analyses described above.

Last, it was considered the visual asymmetry of the cat's waving left arm might represent a confound and influence responses in the cat present condition. It was particularly important to establish that this asymmetry did not affect responses because in Experiment 1 the participants' hands were occluded. Accordingly, the original 2 (alone/joint condition) x 2 (handle) x 2 (object proximity) repeated measures ANOVA model was performed again but with the factor of handle (congruent, incongruent) replaced with response hand (left, right) and object orientation (handle facing left, right). Results from this larger, 4-factor model are available in the supplementary material. Importantly, the critical 4-way interaction between alone/joint condition, object proximity, response hand and object orientation remained nonsignificant, $F(1, 38) = 3.495$, $p = .069$, $\eta^2_p = .084$, and alone/joint condition did not interact with any other factors, Fs <1.891, ps $>.177$. These results strongly suggest that the cat's waving arm did not asymmetrically bias participants' attention during the cat present condition.

Overall, these findings support a social interpretation of Experiment 1's data. Experiment 2 did not replicate the key finding from Experiment 1, suggesting the presence of a human is necessary to elicit the results. The data are, however, not as convincing as expected. The cat present condition produced a similar pattern of data to that elicited by the human confederate in Experiment 1, although this effect was not statistically significant. Bayesian analyses likewise pointed against any meaningful differences across alone/joint conditions. Given that human-like features and movement can lead to anthropomorphising of mechanical devices (Prakash & Rogers, 2015), we suggest that the anthropomorphic features of the cat statue (i.e., face, moving arm) may have introduced a social context to Experiment 2 to a degree, but not strongly enough to produce a statistically significant effect. This suggestion is in line with Dolk et al.'s (2013) reasoning regarding the element of socialness association with the cat. Moreover, as in Experiment 1, on-screen instructions appeared in two orientations, facing both toward and away from the participant. Having instructions directed to the cat statue may have encouraged its anthropomorphisation.

On balance, Experiment 2 provides support for a social account of the data from Experiment 1. More convincing evidence is required, however, to draw stronger conclusions about the mechanism underlying the study's key finding. Accordingly, Experiment 3 included a joint condition employing a distractor object with no human-like features at all.

Experiment 3

Experiment 3 determined whether a salient but inanimate object with equivocally no social features would produce results similar to Experiment 1. Once again, based on methodology from Dolk et al. (2013), a digital metronome was chosen for the joint condition in Experiment 3, as shown in Figure 3. A metronome is completely devoid of human-like features, does not move but is a highly salient object due to its auditory output.

In terms of predicted results, if Experiment 1's key finding is explained by a general attentional, distractor mechanism, then Experiment 3 was expected to reproduce the critical 3-way interaction from Experiment 1. Specifically, in the joint (metronome) condition, near but not far objects would elicit the handle effect whereas objects in both locations would produce the effect in the alone condition. If Experiment 1's key finding is truly a social phenomenon, then Experiment 3 was expected to elicit a comparable handle effect regardless of alone/joint conditions and object proximity, with no significant a 3-way interaction.

Method

Participants. Thirty-six right-handed (32 females, mean age 21.69 years) Flinders University students participated for a small reimbursement. Handedness was measured by the Flinders Handedness Inventory (Nicholls et al., 2013). Participants were English speakers who reported normal or corrected-to-normal vision and gave written, informed consent to participate. The study was approved by the Flinders University Social and Behavioural Research Ethics Committee.

Apparatus, stimuli and procedure. All apparatus, stimuli and procedures were identical to Experiment 2 except for the inclusion of a small, black, digital BOSS DB-30 metronome (Figure 3) in place of the cat statue. Lying flat, the metronome measured 15mm high, 60mm wide and 88mm long. The metronome was placed face-down on the table such that its visual display was hidden and it served primarily as an auditory distractor. It beeped audibly at a rate of 80 beats per minute (Dolk et al., 2013).

Results and discussion

Data analysis. Error rates from every participant fell within three standard deviations from the group mean (12.008%, *SD* = 5.423) and so all participants' data were analysed. Analyses of error rates are presented in the supplementary material. The study's critical 3-way interaction was not significant.

RTs. A 2 (alone/joint condition; alone, metronome present) x 2 (handle; congruent, incongruent) x 2 (object proximity; near participant, far from participant) repeated measures ANOVA was conducted on mean RTs from correct trials. There was a significant main effect of alone/joint condition, *F*(1, 35) = 6.497, $p = .015$, $\eta^2_p =$ .157, reflecting faster responses when the metronome was present (*M* = 593.676, *SD* = 81.078) than absent (*M* = 623.253, *SD* = 94.151; see Figure 5). The reason for this finding is unclear, as it contrasts both Dolk et al. (2013), who found *slower* responses in their metronome condition, and also the current Experiment 2, in which there was no difference in RTs across alone and cat present conditions. It is possible that the metronome had an especially altering or arousing effect, which can lead to faster RTs, particularly in the case of loud auditory stimuli (Ulrich, 1996). This explanation is consistent with arousal or alertness accounts of social facilitation effects (Strauss, 2002; Zajonc, 1965), such as that observed in our Experiment 1, and also in Constable et al. (2015), who found the greatest degree of social facilitation in the active co-actor condition, and the least in the passive, indirect observer condition. There was also a significant main effect of handle, *F*(1, 35) = 11.457, $p = .002$, $\eta^2_p =$ .247, with the typical response speed advantage for congruent (*M* = 600.676, *SD* = 80.319) over incongruent handles (*M* = 616.092, *SD* = 83.238). This finding is consistent with both Experiments 1 and 2. The main effect of proximity was not significant, *F*(1, 35) = 0.181, $p = .673$, $\eta^2_p = .005$, and there were no significant 2-way interactions, all *F*s <1.879, *p*s >.179. Most importantly, the 3-way interaction between alone/joint condition, handle and object proximity was not significant, *F*(1, 35) = 0.115, $p = .737$, $\eta^2_p = .003$.

For consistency across experiments, Bayesian analyses were again performed. The model excluding the handle*object proximity interaction term was preferred for both the alone (Bayes factor = 4.150) and joint conditions (Bayes factor = 4.456).

These results confirm the comparable handle effects for near and far objects in both the alone and metronome conditions in Experiment 3.

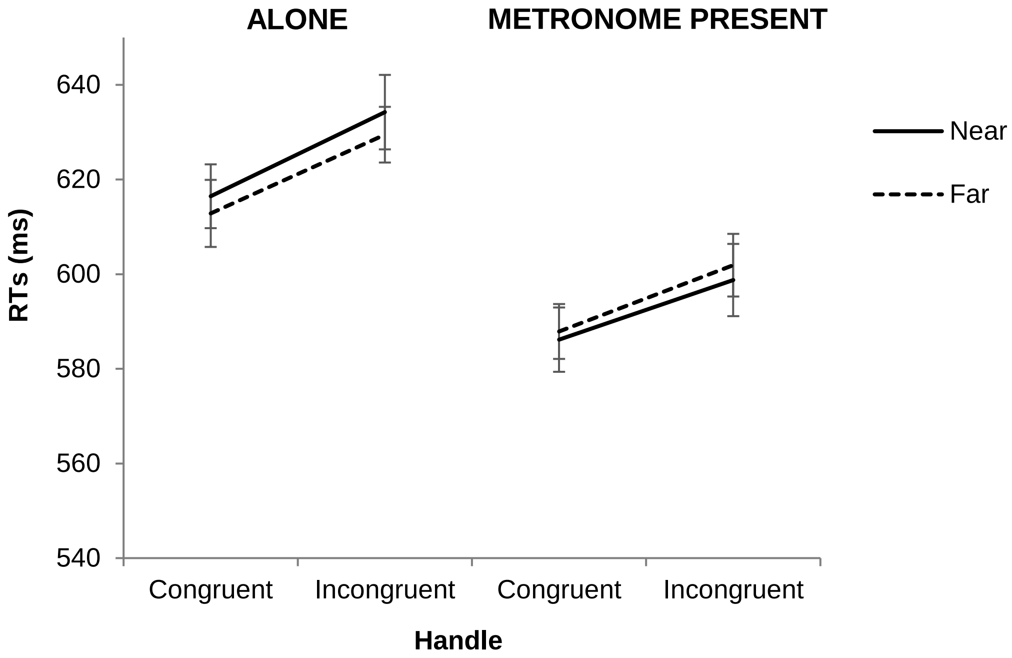

Figure 5. Mean correct RTs (ms) across handle and proximity factors for the alone condition (left panel) and the metronome condition (right panel) in Experiment 3. Error bars represent a standard error of the mean calculated within-subjects for each condition.

Overall Experiment 3's results support a social interpretation of Experiment 1's key finding. The findings suggest that an entirely non-social, aurally salient distractor object does not differentially affect affordance-related visuomotor processing of near and far objects. These findings also indicate that the somewhat ambiguous results from Experiment 2 are most likely attributed to the anthropomorphic features of the cat statue. Although the cat also differed from the metronome in that it was visually as well as aurally salient, the main effect of alone/joint condition in Experiment 3 demonstrates that the metronome was a highly salient distractor object, which captured participants' attention but had no impact on the handle effect.

One final consideration with respect to the results produced in the study is that differences in overall response speed could account for the divergent findings across experiments. To investigate this possibility, we examined the temporal development of the handle effect in all three joint conditions. We employed Symes, Ellis, and Tucker's (2005) method, in which participant mean quartile RTs were calculated for congruent and incongruent handle trials, as seen in Figure 6. Critically, the overall time course of responses is highly consistent across all three joint conditions, demonstrating that global differences in response speed do not account for the divergent findings across experiments. Of further note, the time course of the handle effect is remarkably consistent for the joint conditions of Experiments 2 and 3, whereas it appears weaker in Experiment 1. This weaker overall effect in Experiment 1 reflects the statistically significant difference between near and far objects, and in particular, the absent handle effect for far objects when the confederate was present.

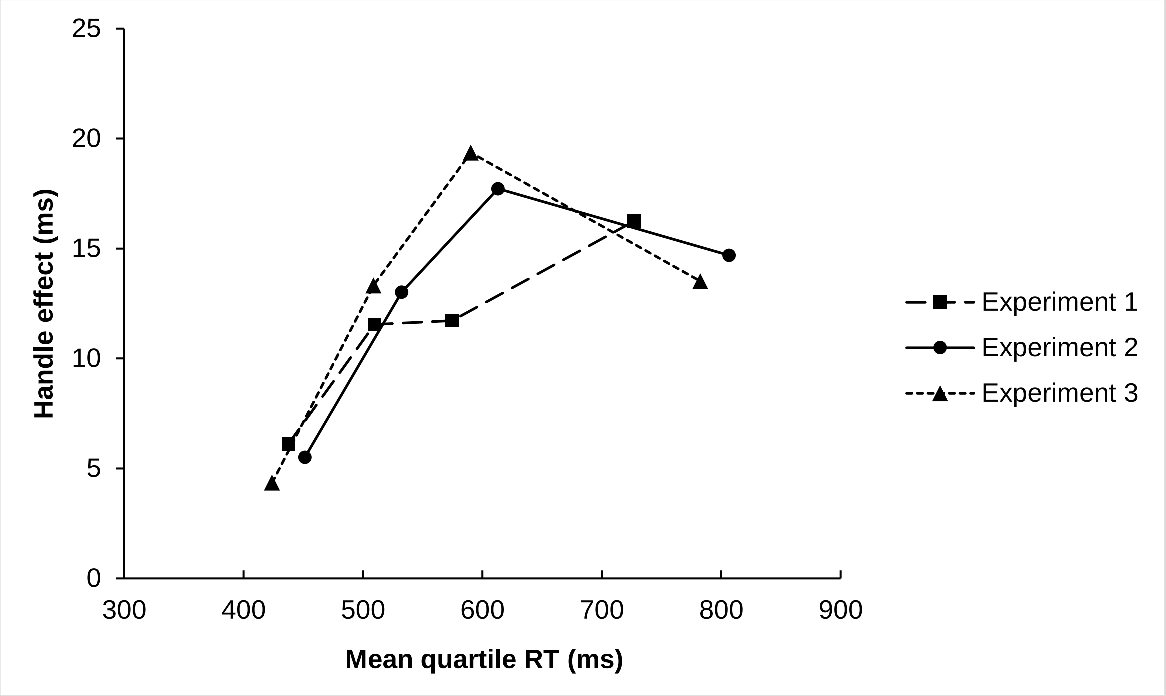

Figure 6. Mean quartile RTs (ms) for the handle effect (incongruent – congruent) for the joint conditions of Experiments 1, 2 and 3.

General Discussion

The present research determined how close interpersonal proximity influences visuomotor processing of manipulable objects in social space between two strangers. As the first study to investigate Tucker and Ellis' (1998) handle congruency effect in a paradigm with two human co-actors, these findings are an important extension of previous research employing single participant designs. For most humans, social encounters occur frequently throughout each day and accounting for the people around us is critical to successful and socially appropriate interactions with the environment. As such, investigating how social presence modulates the perception of action possibilities is critical to understanding these processes in a real-world context. The current set of experiments has demonstrated that although nearby objects typically elicit visuomotor congruency effects, objects that are within reach but are closer to a stranger do not activate affordance-related motor codes to the same degree. These results suggest that space shared between two human strangers can be divided to preserve one another's near-body space, and in turn this process influences visuomotor coding of stimuli within that social space.

Converging evidence from the three current experiments rules out an alternative, general attentional account of Experiment 1's key finding. When participants were alone, all objects within near space evoked the handle effect, whereas in the presence of the confederate, only objects nearer the participant produced affordance-related motor activation strongly enough to elicit the effect. It was considered that the confederate may have simply served as a distractor that participants attempted to ignore, leading to reduced attentional processing of stimuli in his proximity. If this were the case, we would have expected inhibited responses overall for far stimuli in the joint condition, but instead the confederate differentially affected responses with respect to affordances only for far objects. Moreover, the decreasingly social, non-human, visually and aurally salient joint conditions of Experiments 2 and 3 did not replicate the critical finding from Experiment 1.

In demonstrating that affordance-related processing can be socially modulated, these findings invite numerous interesting questions regarding the nature of social space, and how other social and action variables might affect visuomotor processes in this context. First, how might the current findings be modulated by other factors relating to interpersonal distance? There are individual differences in preferred social distance, which could affect coding of near-body space and action processes within it (de Vignemont & Iannetti, 2015). To illustrate, Iachini et al. (2015) showed that trait measures of anxiety and extraversion correlated with preferred social distance, as well as reachability estimates. Social comfort distances may also vary across cultures, related to crowding norms and attitudes (Evans et al., 2000), or with the nature of the actors' social relationship, in that friends typically engage at closer distances than strangers (Hall, 1966).

Although the precise mechanism underlying our results remains unknown, the research reviewed above could point to a powerful role of discomfort in social space coding. Indeed, de Vignemont and Iannetti (2015) argued that anxiety induced by social proximity might reflect an instinctive, adaptive motivation to protect one's body, which could induce a contraction of peripersonal, action space. This proposal is in line with findings indicating an association between trait anxiety and near-body space coding (Iachini et al., 2015; Sambo & Iannetti, 2013). Szpak et al. (2015) similarly demonstrated that for two strangers in close proximity, attentional withdrawal was most pronounced for those displaying the most physiological arousal. Therefore, discomfort may have played a role in Experiment 1's findings, especially given that the confederate was instructed to maintain a neutral, rather than friendly, demeanour and to engage minimally with the participant. The current study did not obtain measures of participant state or trait anxiety or social discomfort; accordingly, we cannot provide direct evidence for this idea. It is, however, a plausible explanation in light of the research and arguments reviewed here and the proposed adaptive motivation for social distances in general. This potential mechanism provides an interesting and promising avenue for future research into social space coding and the nature of visuomotor processing within this space.

In considering social discomfort, then, it is likely that other social, contextual variables would also affect visuomotor processing in shared space. As mentioned, two friends might not demonstrate the same perceptual division of social space evident in the current study, as they typically have closer social comfort distances (Hall, 1966). Strangers who collaborate on a task might likewise feel more comfortable with one another than in the current paradigm. As de Vignemont and Iannetti (2015) note, coordinating action with another person requires a degree of trust, and so space between two people who perform an action together (e.g., one passing a cup of coffee to the other) could be coded very differently than for two strangers acting independently, for example. Pezzulo et al. (2013) likewise argued for a merging (rather than dividing) of actors' near-body spaces when they collaborate to achieve a common goal. Richardson et al. (2007) have in fact demonstrated that the way we act upon objects changes in an explicitly collaborative social context. Perhaps a collaborative, turn-taking paradigm, or a task in which actors' responses complement one another might not elicit the same perceptual division of space that we found, especially given that these factors have produced variable effects in joint action paradigms (e.g., Jordan & Knoblich, 2004).

Aside from considering how social, contextual factors impact social space, a further complication is that the way in which social space is coded could conversely influence actors' social interactions. That is, perceptual division of space between two actors could in fact *incite* collaboration between them in a natural, social context. For example, refraining from entering another's near-space to obtain an object could result in a request for the object to be handed from one person to the other. Considerable future research is required to investigate how social, contextual and task-related factors influence and interact with social space coding, and in turn how these potentially highly complex interactions affect visuomotor processing and subsequent social interactions within that space.

It is likewise unknown how *action*-related variables influence object affordance processing in social space. Perhaps varying the motor capabilities or goals of the actors would influence visuomotor processes in this shared space (Pezzulo et al., 2013). Consistent with this idea, Witt et al. (2012) demonstrated that our reported experience of an object is not only affected by our ability to act on it, but also by the ability of others to act on it. Accordingly future research could investigate the visuomotor processing of object stimuli in social space when the co-actor's motor capabilities were somehow restricted. Furthermore, findings from Constable et al. (2015) suggested that an active-co-actor affects visuomotor processing in shared space differently than when the experimenter stands in as a passive but direct observer. The experimenter did not encroach on the participant's near-body space in the same way as the active co-actor in Constable et al.'s (2015) study, though. Regardless, including such a condition would have been a useful experiment in the context of the present study and we acknowledge that not doing so represents a limitation in our work. Investigating affordance processing in space shared with a passive observer would have informed on the degree to which our findings were contingent on the actions of the confederate, and the particular nature of the social mechanism underlying our results. In general, it remains unclear how established social action effects might interact with social space coding, especially in light of the proposed role of discomfort in preserving near-body space boundaries. Perhaps such an instinctive, adaptive mechanism is so powerful that it renders these other factors irrelevant. This possibility could further explain the findings of the current Experiment 2, in which the cat statue, a moving stimulus with human-like features, elicited a similar, but statistically nonsignificant, pattern of results to the confederate in Experiment 1.

It is likewise not yet clear how visuomotor modulation in shared space interacts with other mechanisms that can operate within social action contexts. Findings from some joint tasks indicate, for example, that participants not only understand the spatial perspective of a co-actor but that this perspective can manifest behaviourally. That is, participants' responses to the experimental stimuli can in fact sometimes reflect another's allocentric viewpoint, rather than their own, egocentric perspective (Böckler et al., 2011; Tversky & Hard, 2009). This phenomenon may be particularly likely in paradigms where participant pairs collaborate while standing opposite one another (Frischen et al., 2009) and view images in more than one orientation (Surtees et al., 2016). Interestingly, though, Experiment 1 comprised of such a paradigm but participants' responses evidently did not reflect the confederate's spatial perspective, given that stimulus upright/inverted orientation did not interact with alone/joint condition (see the supplementary material). Perhaps actor pairs standing opposite one another only take the other's perspective when acting in a collaborative task or context, as in studies by Frischen et al. (2009) and Surtees et al. (2016). Freundlieb and colleagues (Freundlieb, Kovács, & Sebanz, 2016; Freundlieb, Sebanz, & Kovács, 2017) have in fact demonstrated strong evidence for perspective taking when both actors are independently identifying the location of a target stimulus; however, in these experiments the confederate was sitting at a 90° angle to the participant and in most cases the stimulus display was spatially congruent with the confederate's response configuration, and never with the participant's. Further research is therefore needed to determine which conditions are necessary to elicit a perspective taking mechanism and, moreover, how this process interacts with social space coding. If discomfort does indeed play a role in preserving independent near-body space boundaries, then perhaps this adaptive process is sufficiently strong as to prevent perspective taking. Overall, action planning and selection within social contexts - including the mapping of social space and affordances within it - likely reflects a complex and dynamic interplay of many social and action-related variables (Brincker, 2015; Pezzulo et al., 2013). The current study has highlighted the complex nature of this interaction and the considerable further research that is required to understand this phenomenon.

One last point relates to the distinction between *social*- and *action*-related representations of near-body space. We have discussed personal, social space separately from peripersonal, action space because historically they are informed by discrete bodies of literature. Furthermore, it was important to highlight the relevance of both social and action processes to near-body space. In reality, however, it is unknown whether a functional distinction between social and action space representations exists. In terms of conceptual overlap, both representations refer to the space surrounding the body and serve to protect the body from and facilitate interaction with (animate or inanimate) stimuli in the environment and recent papers suggest the two representations may in fact be functionally distinct (de Vignemont & Iannetti, 2015; Patané et al., 2016). This issue is highly complex, though, and its resolution awaits considerable further, exciting research.

The present study provides an important step forward in understanding the ease with which we can navigate our complex, dynamic environment. Perceiving and interacting with stimuli in the physical world is an essential skill for any biological agent and for most humans, the people around us represent dynamic stimuli that we encounter and share space with every day. Accounting for other people in our motor planning is critical – not only for keeping our bodies safe but also for engaging in successful and socially appropriate interactions. Accordingly, there must be a complex interplay between social and visuomotor processes that translates to our seemingly effortless co-existence with the physical world and the other people in it. The present research represents an important step toward understanding this phenomenon.

Appendix D: Supplementary ANOVA results from Experiment 10

Inferential statistics from the 2 (alone/joint condition; alone, confederate present) x 2 (affordance; congruent, incongruent) x 2 (object proximity; near participant, far from participant) x 2 (stimulus upright/inverted orientation; upright, inverted) x 2 (participant sex; male, female) mixed model measures ANOVA conducted on mean RTs from correct trials in Experiment 10.

Effect	*Statistic*
Sex	$F(1,34) = 1.519$, $p = .226$, $\eta^2_p = .043$
Alone/joint condition	$F(1,34) = 15.847$, $p <.001$, $\eta^2_p = .318$
Alone/joint condition*Sex	$F(1,34) = 0.005$, $p = .946$, $\eta^2_p <.001$
Object proximity	$F(1,34) = 0.604$, $p = .442$, $\eta^2_p = .017$
Object proximity*Sex	$F(1,34) = 0.011$, $p = .919$, $\eta^2_p <.001$
Upright/inverted	$F(1,34) = 38.942$, $p <.001$, $\eta^2_p = .534$
Upright/inverted*Sex	$F(1,34) = 0.879$, $p = .355$, $\eta^2_p = .025$
Affordance	$F(1,34) = 18.664$, $p <.001$, $\eta^2_p = .354$
Affordance* Sex	$F(1,34) = 5.228$, $p = .029$, $\eta^2_p = .133$
Alone/joint condition*Object proximity	$F(1,34) = 0.804$, $p = .376$, $\eta^2_p = .023$
Alone/joint condition*Object proximity*Sex	$F(1,34) = 0.617$, $p = .438$, $\eta^2_p = .018$
Alone/joint condition* Upright/inverted	$F(1,34) = 0.506$, $p = .482$, $\eta^2_p = .015$
Alone/joint condition* Upright/inverted*Sex	$F(1,34) = 0.036$, $p = .850$, $\eta^2_p = .001$
Object proximity* Upright/inverted	$F(1,34) = 3.263$, $p = .080$, $\eta^2_p = .088$
Object proximity* Upright/inverted*Sex	$F(1,34) = 0.067$, $p = .797$, $\eta^2_p = .002$

Alone/joint condition*Object proximity*Upright/inverted	*F*(1,34) = 0.415, *p* = .524, η^2_p = .012
Alone/joint condition*Object proximity*Upright/inverted*Sex	*F*(1,34) = 0.183, *p* = .672, η^2_p = .005
Alone/joint condition*Affordance	*F*(1,34) = 0.166, *p* = .686, η^2_p = .005
Alone/joint condition*Affordance*Sex	*F*(1,34) = 1.049, *p* = .313, η^2_p = .030
Object proximity*Affordance	*F*(1,34) = 0.492, *p* = .488, η^2_p = .014
Object proximity*Affordance*Sex	*F*(1,34) = 2.032, *p* = .163, η^2_p = .056
Alone/joint condition*Object proximity*Affordance	*F*(1,34) = 4.957, *p* = .033, η^2_p = .127
Alone/joint condition*Object proximity*Affordance*Sex	*F*(1,34) = 3.983, *p* = .054, η^2_p = .105
Upright/inverted*Affordance	*F*(1,34) = 5.771, *p* = .022, η^2_p = .145
Upright/inverted*Affordance*Sex	*F*(1,34) = 3.135, *p* = .085, η^2_p = .085
Alone/joint condition* Upright/inverted*Affordance	*F*(1,34) = 2.493, *p* = .124, η^2_p = .068
Alone/joint condition* Upright/inverted*Affordance*Sex	*F*(1,34) = 0.450, *p* = .507, η^2_p = .013
Object proximity*Upright/inverted*Affordance	*F*(1,34) = 0.599, *p* = .444, η^2_p = .017
Object proximity*Upright/inverted* Affordance*Sex	*F*(1,34) = 0.052, *p* = .820, η^2_p = .002
Alone/joint condition*Object proximity*Upright/inverted*Affordance	*F*(1,34) = 0.397, *p* = .533, η^2_p = .012
Alone/joint condition*Object proximity*Upright/inverted*Affordance*Sex	*F*(1,34) = 0.429, *p* = .517, η^2_p = .012

Note: One further participant was excluded from this ANOVA model owing to missing in more than one cell.

Appendix E: Supplementary ANOVA results from Experiment 11

Inferential statistics from the 2 (alone/joint condition; alone, cat present) x 2 (object proximity; near participant, far from participant) x 2 (response hand; left, right) x 2 (object orientation; handle facing left, handle facing right) repeated measures ANOVA conducted on mean RTs from correct trials in Experiment 11.

Effect	*Statistic*
Alone/joint condition	$F(1,38) = 0.090$, $p = .766$, $\eta^2_p = .002$
Object proximity	$F(1,38) = 1.036$, $p = .315$, $\eta^2_p = .027$
Object orientation	$F(1,38) = 0.082$, $p = .766$, $\eta^2_p = .002$
Response hand	$F(1,38) = 0.012$, $p = .915$, $\eta^2_p = .000$
Alone/joint condition*Object proximity	$F(1,38) = 0.033$, $p = .858$, $\eta^2_p = .001$
Alone/joint condition* Object orientation	$F(1,38) = 0.388$, $p = .537$, $\eta^2_p = .010$
Object proximity* Object orientation	$F(1,38) = 0.426$, $p = .518$, $\eta^2_p = .011$
Alone/joint condition*Object proximity* Object orientation	$F(1,38) = 2.050$, $p = .160$, $\eta^2_p = .051$
Alone/joint condition* Response hand	$F(1,38) = 0.002$, $p = .964$, $\eta^2_p <.001$
Object proximity* Response hand	$F(1,38) = 6.196$, $p = .017$, $\eta^2_p = .140$
Alone/joint condition*Object proximity* Response hand	$F(1,38) = 1.891$, $p = .177$, $\eta^2_p = .047$
Object orientation * Response hand	$F(1,38) = 10.404$, $p = .003$, $\eta^2_p = .215$
Alone/joint condition* Object orientation * Response hand	$F(1,38) = 0.038$, $p = .847$, $\eta^2_p = .001$
Object proximity* Object orientation * Response hand	$F(1,38) = 0.001$, $p = .976$, $\eta^2_p <.001$

Alone/joint condition*Object proximity* Object orientation * Response hand	$F(1,38) = 3.495$, $p = .069$, $\eta^2_p = .084$