Disentangling the Grasp and Functional use Mechanisms in the Processing of Real Tools and Pictures of Tools

by

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Table of Contents

Abstract

Object features affording actions, such as those related to the grasp and/or functional use properties of tools have been shown to influence various behavioural processes. However, the majority of studies exploring this area of research have presented stimuli in a 2-Dimensional (2D) pictorial format, yet tools usually appear in a real 3-Dimensional (3D) format in the real world. The aim of this thesis was to understand the ways in which the grasp and functional use actions of real tools and pictures of tools are processed, and how this applies to how we pantomime, name and manipulate tools with similar affordances.

First, I investigated whether the repeated visual presentation of action related properties such as those related to grasping and the functional use actions of pictures of tools can facilitate pantomiming. This was achieved by using a priming paradigm in which the grasp and functional use features between tool pairs were either the same or different, and measuring the reaction times and accuracy of pantomiming movements to each presented tool. The results revealed that participants were slower at pantomiming the target tool relative to the prime regardless of whether the grasp and functional use action of the tools were the same or different- except when the prime and target tools consisted of identical tools. I also found a decrease in accuracy of performing functional use actions for the target tool relative to the prime when the two differed in functional use actions but not grasp.

Next, I investigated whether the differences in how 3D real tools compared to 2D pictures of tools are processed by the brain could influence the naming of tools. This was again achieved by using a priming paradigm in which the functional use features between tool pairs were either the same or different and measuring the reaction times and accuracy of naming responses of each presented tool. The results revealed that the format in which the prime tool was presented (i.e., a picture or real tool) had no influence on the participants' response times to naming the target tool (i.e., always a real tool). Furthermore, participants were faster at naming target tools relative to prime tools when the exact same tool was presented as both prime and target. There was no difference in response times to naming the target tool relative to the prime when they were different tools, regardless of whether the tools' functional actions were the same or different- except when the prime and target tools consisted of identical tools.

Finally, I investigated whether there are differences in how real tools compared to pictures of tools may facilitate how we grasp and functionally use tools with similar functional use attributes. This was achieved by using a priming paradigm in which the functional use features between tool pairs were either the same or different and measuring the reaction times, accuracy and movement times of functional use actions performed on target tools. The stimuli included a

prime tool that was either in a real or pictorial format followed by a target tool that was always in a real format. The results revealed that participants were faster at initiating functional use actions to the target tool when the prime tool was a picture of a tool compared to a real tool. However, there were no differences in response times to initiating functional use actions when the two stimuli differed or shared the same functional action.

I propose that the lack of facilitation I observed in how participants processed the grasp and/or functional use properties between the prime and target tools in these tool processing outputs was due to participants identifying the target tool as a novel tool relative to the prime. This develops our understanding of the similarities in the mechanisms that contribute to the processing of real and pictorial stimuli, and how the affordances of action related properties between tool pairs may not be actively processed when perceptually analysing tools that are presented in quick succession. These results contribute to our understanding of how we are able to carry out tasks that are part of a fundamental cognitive ability that we utilize in our daily lives.

Listing of Figures

Listing of Tables

Contribution of the Authors

I was responsible for designing, conducting and analysing the experiments. I also wrote the manuscripts for publication. A/Prof. Philippe Chouinard and Dr. Elizabeth Saccone made important contributions to all aspects of my work, especially for the experimental design, analysing and interpreting the results and manuscript preparation. Prof. Sheila Crewther and Prof. Melvyn Goodale also contributed to manuscript preparation.

Study 1 : A pantomiming priming study on the grasp and functional use actions of tools.
Authors: Mutindi C. Kithu, Elizabeth J. Saccone, Sheila G. Crewther, Melvyn A. Goodale, Philippe A. Chouinard

Study 2: A priming study on naming real versus pictures of tools.
Authors: Mutindi C. Kithu, Elizabeth J. Saccone, Sheila G. Crewther, Melvyn A. Goodale, Philippe A. Chouinard

Study 3: The initiation of actions based on the functional use similarities of tools: A priming study with primes presented as real tools or in a pictorial format
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Publications and Presentations

All publications and presentations completed during this candidature are detailed below.

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Statement of Authorship

Except where reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis accepted for the award of any other degree or diploma. No other person's work has been used without due acknowledgment in the main text of the thesis. This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

Christine Mutindi Kithu

This thesis is dedicated to David Mwatu Azenga.

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P.S. **BLACK LIVES MATTER**

Chapter One

Introduction

It is argued that one of the most fundamental advancements in human evolution was the creation of 3- Dimensional (3D) real tools (Wilkins, Schoville, & Brown, 2014). As such, the way in which humans make and use tools is what sets our species apart in many ways (Baber, 2003; Lee & Almeida, 2021). As a result of these advancements, humans have also developed a method in which these tools can be represented through 2-Dimensional (2D) images such as a picture of a tool. The capacity in which the same tools can be represented in differing modalities creates an interesting avenue for research as it develops our understanding of how we interact with, and process tools within our environment.

Tools are unique in that they have specific properties which determine how they can be manipulated for an intended purpose. Moreover, many tools can have different functions but still have a similar shape or form determining how they are grasped and/or manipulated for different purposes (i.e., a squeegee and a paint roller). In this view, tools have specific action-related properties that influence the way we successfully perform a given action. At the same time, there are also different ways in which we communicate tool related processes. For instance, this can be done via gesturing a tool's use by pantomiming its actions, or via language that names and describes a tool. Therefore, an important aspect of tool perception and processing is how the brain processes visual information for the successful communication of tool related processes. Hence tool processing mechanisms include the integration of multiple networks in the brain that are essential for specific aspects of higher motor functions (Almeida et al., 2014; Chao & Martin, 2000; Garcea, Chen, Vargas, Narayan, & Mahon, 2018; Watson & Buxbaum, 2015).

As a result, it is worth developing our understanding of how we perceptually process the action-related attributes of real tools and pictures of tools (i.e., how they are grasped and/or how we manipulate them to perform their function), and how this contributes to the different ways in which we pantomime, name, or manipulate tools. My aim was to disentangle the nature of how the brain processes these functions, and the extent to how they influence the reaction times, movement times, and number of correct actions towards tools with similar action related properties. The purpose of this chapter is to provide a theoretical background of the role of the visual system in tool processing. It will also review evidence of the neural and functional distinctions of the visual system and provide evidence relating to the differences in how we process 3D compared to 2D objects from infancy to adulthood. Lastly, it will introduce the cognitive mechanisms that contribute to our understanding of tool use through different behavioural tasks including pantomiming, naming, and manipulating tools.

I. Visual perception and action

In humans and primates alike, vision is a richly represented sensory modality in the cortex. However, we have evolved complex cognitive systems in which we use vison to create representational systems of how we perceive the world. As such, embodied theories of cognition claim that the interactions between bodily experiences and the environment influence how we develop abstract cognitive processes and structure the mind (Barsalou, 2010; Clark, 1998; Lakoff, Johnson, & Sowa, 1999; Pecher & Zwaan, 2005; Wilson, 2002).

An important aspect of the embodied cognition perspective is that there is a relationship between perceptual and motoric processing, and that this is an important component in which the physical body successfully interacts within the environment. One of the most relevant and influential theories of motor perception is the theory of “affordances” by Gibson (1979). This approach posits that we perceive possible actions and interactions with objects within our environment (Gibson, 1979). For example, perceiving a flight of stairs would afford climbing, just the same way the perceptual processing of the physical properties of tools guides the way we select actions for that particular tool. These suggestions of how visual processes may be functionally linked with the motor system are supported by the activation of the occipitotemporal, intraparietal, and ventral premotor cortex in both humans and monkeys when they view graspable objects and also when they perform the action on the object (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, 2008; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Kohler et al., 2002; Peeters et al., 2009; Rizzolatti & Fadiga, 1998). Furthermore, in humans, functional magnetic resonance imaging (fMRI) studies have demonstrated a network of areas within the parietal lobe (specifically the left supramarginal gyrus (SMG)) and premotor cortex that are activated during 1) the planning and execution of object-oriented actions (Johnson-Frey, 2004; Johnson-Frey, Newman-Norlund, & Grafton, 2004) in the absence of actual movements such as in tool naming (Chao & Martin, 2000) and 2) the retrieval of the conceptual knowledge of how tools are used (Boronat et al., 2005; Buxbaum, 2017; Gallese & Lakoff, 2005). In line with embodied theories and Gibson’s view of the integration of perception and action, the activation of similar populations of neurons in the monkey, and the increased activation in the left SMG provide support for these views as they selectively respond to sensory input that is associated with action relevant properties that correspond to motoric outputs. Taken together, these theories and findings have been influential in current understanding of embodied theories of cognition especially with regard to action understanding.

II. Neuroanatomical and functional specialisation within the visual system

Among the various theories related to the relationship between perception and action, there is evidence that suggests that there are two functionally and anatomically distinct visual processing systems/streams that enable our ability to successfully perform visually guided actions. Mishkin and Ungerleider (1982) first distinguished these two streams in the macaque monkey by demonstrating the "what" and "where" visual processing routes devoted to visual identification and spatial localization, respectively. These findings contributed to the current understandings of the organisation and functions of the visual system and how the processing of information within these systems is very important in enabling successful visually guided action. Evidence of the brain anatomy from neuroimaging studies has demonstrated the underlying integration between the two visual pathways through white matter tracts between superior/middle temporal and inferior parietal regions (Budisavljevic, Dell'Acqua, & Castiello, 2018; Catani, Jones, & Ffytche, 2005; De Benedictis et al., 2014; Lin et al., 2020). Furthermore, fMRI studies have shown functional connectivity between the two streams through shared target brain regions in tool naming and tool execution, and through continuous cross talk connections between the two streams (Almeida et al., 2018; Budisavljevic et al., 2018; De Schotten et al., 2011; Grafton, Fadiga, Arbib, & Rizzolatti, 1997; Grezes & Decety, 2001).

Perhaps more prominently, though with similar functions, the Two Visual System Hypothesis (TVSH) proposed by Goodale and Milner (1992) is also characterized by two distinct visual processing systems, with a "vision for perception" system and a "vision for action" system (Goodale & Milner, 1992; Milner & Goodale, 2008). The ventral stream (vision for perception system), also referred to as the "what" stream, incorporates visual areas in the primary visual cortex that project to the inferior temporal cortex. This stream mediates the processing of visual information for object recognition and association of meaning to visually perceived experiences (e.g., object shape, texture). The second stream, the dorsal stream (vision for action system), incorporates visual areas from the primary visual cortex that project to the posterior parietal cortex. This stream is now referred to as the "how" stream as it mediates processing visual information for the online control of skilled motor actions, such as reaching out and grasping objects based on the object's form and structure. The dorsal stream was initially coined the "where" pathway by Mishkin and Ungerleider (1982), however Goodale and Milner (1992) renamed it to the "how" pathway by highlighting that other object properties such as an object's size, orientation and form, including the position of the object relative to the observer, are relevant in visually guided actions (Cavina-Pratesi, Goodale, & Culham, 2007; Chen, Snow, Culham, & Goodale, 2018; Cuijpers, Smeets, & Brenner, 2004; Rice, Valyear, Goodale, Milner, & Culham, 2007).

With this in mind, evidence from neurological and neuropsychological literature on brain damaged patients has highlighted the differences in how visual information is processed between these two visual streams. For example, patients with optic ataxia (i.e., psychic paralysis of gaze; Balint, 1909), who have lesions in the dorsal stream, specifically the superior part of the posterior parietal cortex, have deficits with the visual control of hand and limb movements, such as using visual information to reach out and form grasps towards presented objects (Chechlacz & Humphreys, 2014; Harvey & Milner, 1995). At the same time, they have no difficulty in recognizing and describing objects, or even using other sensory modes such as audition or proprioception to guide their movements towards objects (Goodale, Milner, Jakobson, & Carey, 1991). On the other hand, damage to areas of the ventral stream show the opposite pattern of deficits and may result in visual form agnosia (Carey, Harvey, & Milner, 1996; Ganel & Goodale, 2019; Milner et al., 1991). Arguably, the most fascinating case is patient DF, who suffered brain damage due to anoxia from carbon monoxide poisoning in 1988 (Ganel & Goodale, 2019; Goodale, Milner, Jakobson, & Carey, 1991; Milner, Ganel, & Goodale, 2012). Due to irreversible damage to areas of the lateral occipital cortex within the ventral stream, DF had severe deficits in indicating the size, shape, and orientation of common objects. However, when asked to reach out and pick up objects of different widths and sizes, DF successfully adjusted her grip aperture towards the objects as she proceeded to pick them up when tested in 1991 by David Milner and his colleague Mel Goodale (Goodale et al., 1991). Additionally, DF had difficulty in verbally or manually rotating a hand-held envelope to indicate the orientation of a large post office like box slot presented to her. Nonetheless, she showed no difficulty adjusting the posture of her hand to match the orientation of the slot towards which she was reaching, even though she was unable to verbally report the orientation of the slot. Such data reinforces the idea that there is a functional specialization and a segregation between the two processing streams. However, the integration of these two systems is important for the visuomotor processing of information throughout our daily lives, especially regarding the ability to successfully perform behaviours such as skilled hand actions (Creem & Proffitt, 2001; Milner, 2017).

More recently, seminal psychophysical and neuroanatomical work in how we process action related information has provided evidence of additional anatomical subdivisions of the longitudinal fasciculi arising from parietal areas to form the dorsal stream (Buxbaum, 2001; De Schotten et al., 2011; Ishibashi, Pobric, Saito, & Lambon Ralph, 2016). More broadly, based on neurophysiological evidence from the macaque brain it is proposed that the dorsal stream is subdivided into the ventro-dorsal and dorso-dorsal streams based on cortical connections with the inferior and superior parietal lobule, respectively (Rizzolatti & Matelli, 2003). Moreover, according to the "Two Action Systems Plus Account" (2AS+) neurocognitive model by Buxbaum, Binkofski and colleagues (Binkofski & Buxbaum, 2013; Buxbaum, 2017), the ventro-dorsal stream mediates the processing of visual information to form a representation of the stored knowledge of how objects are manipulated (Goldenberg & Spatt, 2009; Hermsdörfer, Li, Randerath, Roby-Brami, & Goldenberg, 2013). On the other hand, similarly to Goodale and Milner's TVSH, the dorso-dorsal stream mediates the processing of visual information for the online control of actions (i.e., reaching and grasping). Symptoms relating to object use errors in patients with apraxia highlight damage to areas in the ventro-dorsal stream (Osiurak, 2013). Some patients have deficits in the ability to integrate visually presented information of objects into the stored knowledge of how the objects are manipulated. Note that they can still successfully identify visually presented objects which is mediated by ventral stream processes and are also able to configure their hand to reach out and grasp the object, which is mediated by dorsal stream processes (Buxbaum, Kyle, Tang, & Detre, 2006; Frey, 2007; Goldenberg, 2009; Haaland, Harrington, & Knight, 2000).

Taken together, these findings further highlight the dissociation of the mechanisms involved in how we successfully use visual information for the successful performance of visually guided actions. More importantly, the segregated yet integrated organisation of the visual processing systems highlights the complexity of how the brain processes visual information for achieving specific action related goals. Furthermore more, these neurocognitive models challenge some theories of embodied cognition that state that cognition is grounded in sensorimotor experiences (Gallese & Lakoff, 2005; Glenberg, 1997; Lakoff et al., 1999). Although partially true, the segregated organization of the visual processing systems show us that there are two functionally and anatomically distinct visual processing systems/streams meaning that cognition may not be soley grounded in sensorimotor experiences. This highlights the importance of the communication between these processing streams, especially for the successful execution of complex behaviours such as skilled hand actions, including tool use (Haaland et al., 2000).

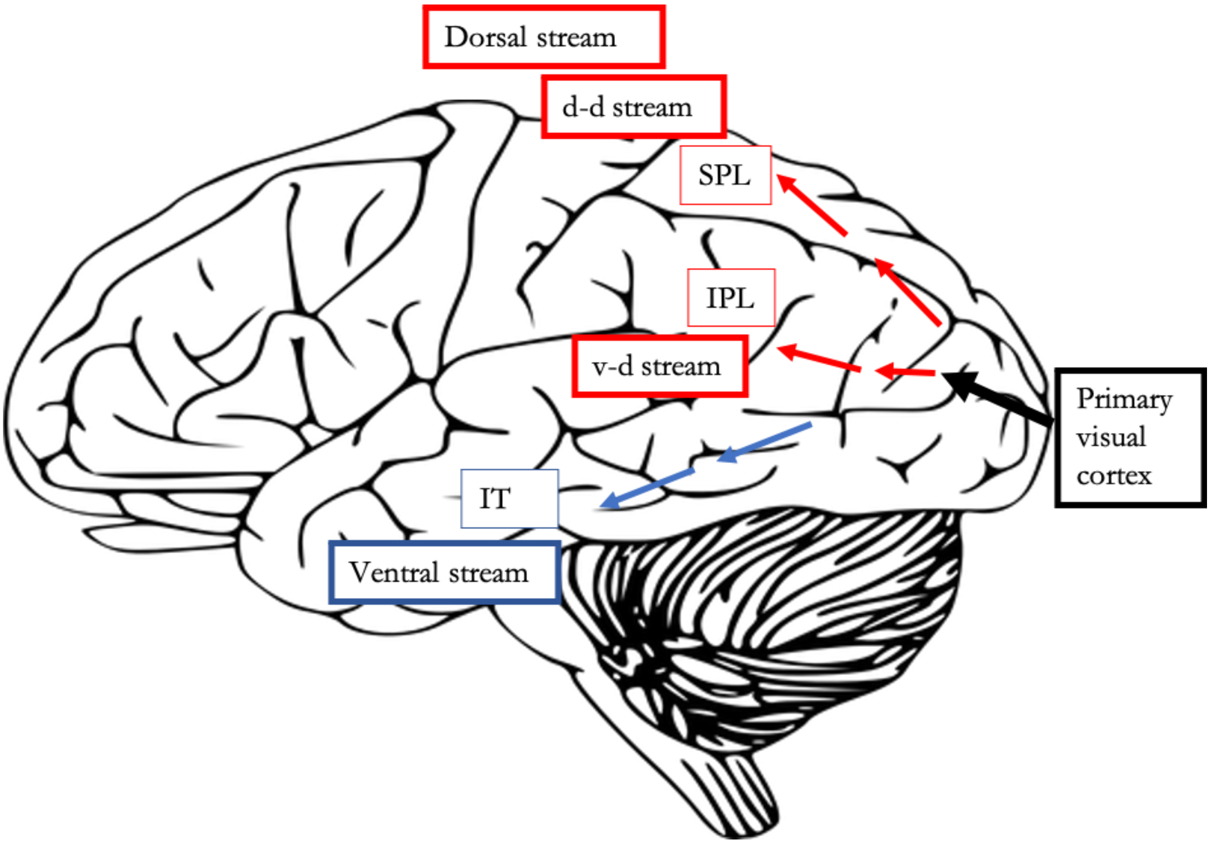

Figure. 1. Visual processing streams in the human brain.The Dorsal stream is subdivided into the Dorso- dorsal ('d–d'), Ventro-dorsal ('v–d') streams according to Binkofski and Buxbaum (2013). The d- d stream comprises projections from the primary visual cortex to areas of the superior parietal lobule (SPL). The v-d stream receives comprises projections from the primary visual cortex to areas of the inferior parietal lobule (IPL), and the ventral stream receives information from higher visual areas in the primary visual cortex to areas of the inferior temporal cortex (IT).

III. Processing of 3D objects and 2D pictures of objects

The perceptual processing of 2D pictures of objects and real 3D objects differ in some respects (Snow and Culham 2021). For instance, real objects have stereoscopic depth cues which include an object's shape or size depending on the object's distance from the viewer. On the other hand, unlike real objects, pictures provide conflicting depth cues to the brain. This means that there is conflict between the cues that tell the brain that the picture is flat (e.g., oculomotor cues) and cues that indicate that we are viewing the picture in a 3D or "real" space (e.g., pictorial cues). Lastly, although pictures of objects are a very prevalent part of our daily lives and are an important mode of stimuli presentation in experimental research, such images of tools cannot be physically manipulated nor offer the potential for actions such as grasping and manipulating (Cauquil, Trotter, & Taylor, 2006; Gomez, Skiba, & Snow, 2018; Li & Zaidi, 2000; Millar, 2006; Pizlo, 2010). Alternatively, one similarity between viewing 2D pictures of objects and real objects is that they have been shown to activate similar neural networks including parietal, fronto-parietal, and temporal regions of the brain (Binkofski & Buxbaum, 2013; Chao & Martin, 2000; Chouinard & Goodale, 2010; Valyear, Culham, Sharif, Westwood, & Goodale, 2006). Another similarity between the processing of real objects and pictures of objects such as tools is that in adults, they both activate the same brain areas that are related to representations of what experience has taught individuals the tool is used for (i.e., we still know how a knife is grasped and what it is functionally used for when we perceive both a real knife and a picture of a knife). However, although the processing of images and real tools may still invoke the concept of the tools' affordances, we could never cut a slice of cheese with a picture of a knife. In view of this, various studies have highlighted these differences and similarities in the cognitive processing of real objects compared to pictures of objects from infancy to adulthood. This body of evidence is summarised below.

3D vs 2D objects in infants

Research exploring the processing of real objects compared to pictures of objects in infants has shown that an infant's preference for interacting with real objects compared to images of the same object develops from as early as 7- 9 months old (DeLoache, Pierroutsakos, Uttal, Rosengren, & Gottlieb, 1998; Gerhard, Culham, & Schwarzer, 2016; Gerhard, Culham, & Schwarzer, 2021). For example, DeLoache et al. (1998) explored the ages at which the competence of a pictorial representation of an object versus a real object develops in infants. The authors found that when the 9-month-old infants were simultaneously presented with a picture of an object and a real object, the infants touched the real objects 95% of the time as opposed to 48% for pictures of the objects. Consequently, when they presented 9- and 19-month-olds only pictures of objects, the 9-month-olds actively reached out and tried to grasp the object in the picture, whereas the 19-month olds typically responded by pointing at the image as if to acknowledge its identity. This suggests that even though younger infants cannot discriminate between the concept of a picture of an object as something that is not tangible or real, the exposure to a real object is always prioritized as something to manually explore over a picture of the object (Yonas, Cleaves, & Pettersen, 1978; Yonas, Elieff, & Arterberry, 2002). This highlights that the ability to process dimensional properties through depth cues and various viewpoints and contexts starts from an early age (Newman, Atkinson, & Braddick, 2001).

On the other hand, the neural processing for real objects compared to pictures has also been shown to be faster in infants (Carver, Meltzoff, & Dawson, 2006). For example, Carver et al. (2006) used event related potentials (ERPs) to examine 18-month-old infants' recognition of familiar and unfamiliar real and pictorial objects. Although the authors found differentiation in recognition between familiar versus unfamiliar pictures of objects, the differentiation of attention latency components in the group of infants that observed real objects occurred in early ERP components. In contrast, the differentiation of latency in the group of infants that observed pictures of the objects occurred in middle ERP components. In other words, the timing to recognise and process the presentation of a picture of an object, even if it is familiar took longer than a real picture in 18-month-old infants, suggesting that the timing of that recognition is influenced by the dimensional format in which the object is presented. Furthermore, the infants in this study were at an age where they could understand that pictures are different from real world objects and could therefore understand that pictures are only a symbolic representation of what the object is.

Overall, these lines of evidence show us that the behavioural and neural differences in how infants process and respond to pictures of objects is through their cognitive development and experiences. As they get older, pointing to the picture of the object shows that they comprehend that it is a picture and that it cannot be actively manipulated. Therefore, the aspects of the internal representations of how an object may be grasped or manipulated develops with time.

3D vs 2D objects in adults

When we look at the visual perception of real objects and pictures in adults, there is functional magnetic resonance imaging (fMRI) literature that demonstrates that real objects elicit differential neural activation than pictures of objects (Snow et al., 2011). Using functional magnetic resonance imaging (fMRI), Snow et al. (2011) employed an event-related adaptation paradigm to examine whether the repeated presentation of pictures of tools elicit the differential neural responses for real objects. Adaptation, also known as repetition suppression, is a functional neuroimaging technique that has been widely used to analyse specific neuronal populations that are, or are not, affected by changes in the repetition or successive presentation of a particular stimulus (Grill-Spector & Malach, 2001). Usually, when a certain visual stimulus or action is repeated which in this case were real objects or visually matched photographs, the hemodynamic response in areas such as the lateral occipital cortex (LOC) and posterior fusiform sulcus (pFS)) that are specific for pictures or real tools is *reduced* (Snow et al., 2011). They found strong adaptation effects elicited by the repetition of pictures of objects in various object-selective areas, whereas adaptation effects were very weak when presented with real life exemplars. This finding suggests that there is a difference in how pictures of objects and real-life objects are processed. Given that the shape of real objects has different stereoscopic, monocular and binocular cues than pictures of objects do, this finding raises a question as to whether displays involving 3D structure may influence the degree to which the pattern of neuronal activity may be sensitive to the observed stimulus. In this view, the perception of real objects creates the potential for real interaction with the object, whereas pictures of objects are dependent on the presentation on a flat surface that requires no action consequences.

In addition, behavioural studies have also highlighted the differences in how we process real objects compared to pictures of the same items. For example, Snow, Skiba, Coleman, and Berryhill (2014) investigated whether real objects influenced the recall and recognition of objects more than pictures and black and white line drawings of the same items. After the testing phase, participants had to recall as many objects as they could remember by writing the names of the objects, and also had to discriminate names of objects that were either included in the study from distractor objects that were not. They found that recall and recognition performance was better for real objects than pictures or line drawings presumably due to the associated increase in BOLD response. Another line of evidence that highlights these differences is from patients with visual form agnosia that show that performance in recognising objects is better with real objects compared to line drawings (Chainay & Humphreys, 2001). In a single case study, Chainay and Humphreys (2001) examined patient HJA who had visual agnosia, prosopagnosia, alexia without agraphia, achromatopsia, and topographical impairments. Nevertheless, his most severe impairment was in object recognition. They presented HJA real objects and line drawings and observed how depth information about real objects influenced HJA's ability to recognise and correctly name real objects and line drawings. They found that HJA demonstrated better recognition with real objects relative to line drawings as what they described as a real-object advantage. The findings from Snow et al. (2014) and patient HJA suggest that the depth cues and texture information provided by the real objects may make it easier to associate various properties of the objects in order to correctly identify and remember them. Alternatively, pictures of objects have also been shown to elicit similar facilitation effects as real objects. For example, Squires, Macdonald, Culham, and Snow (2015) used a priming paradigm to investigate how pictures of objects primed future actions compared to real objects. They presented participants with a prime object that was either the same (i.e., spatula-spatula) or different (i.e., spatula-whisk) picture or real object to the target object. This was then followed by a real target tool, which participants physically grasped either to move it to a nearby pad (i.e., grasp to move) or to demonstrate its functional use (i.e., grasp to use). They demonstrated a greater degree of priming in the grasp-to-move than the grasp-to-use condition, but there were no differences whether the prime object was a picture or a real object. These lines of evidence highlight that although the same areas of the brain are activated when perceiving both real objects and pictures of objects, the differences in how they are processed may be due to the depth information that real objects provide.

IV. Tool processing outputs

There are various ways in which we as humans are able to use different outputs to communicate with and interact with objects or tools within our environment. For example, we are able to interpret someone gesturing the actions associated with using a phone or a hammer without them tangibly having the object in their hand or them naming it. This is because we are able to perceptually process these gestures and retrieve the stored conceptual knowledge that we have learned to associate with the action related attributes of how the tool is manipulated. Another way in which we can also communicate tool attributes is through naming them. We can name or recognise a particular tool or object and will associate that object with its intended use. Lastly, we can physically manipulate tools for various purposes. This again relates to how we perceptually analyse these tools and use this information to retrieve the stored conceptual knowledge that we have learned to associate the action-related attributes of how we manipulate the tool. With all this in mind, these differing tool processing outputs shed light on the complex ways in which the brain processes tools or objects within our environment. This creates an interesting avenue for research as it contributes to our understanding of how we are able to carry out tasks that are part of a fundamental cognitive ability that we utilize in our daily lives. This body of tool processing output mechanisms is summarised below.

Pantomiming tool use

We define pantomiming here as an act of expressing actions associated with an object or tool as if it were in the hand, but without the object actually being there. The act of pantomiming is an interesting avenue for research as it involves the link between how we select actions based on the instrumental actions of the actual use of the objects. One key aspect in the ability to successfully and correctly perform pantomiming actions of tools is the integration of specific learned components of a skill, such as the control of actions that have been previously learned in order to perform an appropriate movement (i.e., how the tool is grasped and used), and the recognition of the visual characteristics of the object that influence the way we select an appropriate action to a particular object (Gibson, 1979).

Various lesion studies have attempted to distinguish the neural structures associated with the production of tool use gestures and have found that the left lateralized areas of the inferior frontal, temporal, as well as the inferior parietal regions play a major role for pantomiming tool use (Buxbaum & Randerath, 2018; Buxbaum, Shapiro, & Coslett, 2014; Goldenberg, Hermsdörfer, Glindemann, Rorden, & Karnath, 2007; Goldenberg & Randerath, 2015; Króliczak & Frey, 2009). The associations between actual tool use and pantomiming are highlighted after brain damage in patients with apraxia. There are various classifications of apraxia, and inconsistencies between studies on brain lesion localizations, contradictory results, and assessments of apraxia. This highlights the complexity in our understanding of the disorder. However, pantomiming the use of tools has developed to be a key clinical test for apraxia. Some patients with ideomotor apraxia tend to perform more poorly when asked to pantomime how to use familiar tools than when asked to reach out and grasp the same objects (Haaland, Harrington, & Knight, 1999; Sunderland, Wilkins, Dineen, & Dawson, 2013). In contrast, patients with ideational apraxia show deficits in retrieving semantic knowledge of how familiar tools are typically used but can still pantomime their use on command or imitation (Buxbaum, 2001; Goldenberg, 2003; Goldenberg, 2009; Heilman, 1973; Motomura & Yamadori, 1994; Smania, Girardi, Domenicali, Lora, & Aglioti, 2000). These dissociations highlight how different systems in the brain are involved in processing the perceptual and action related properties of tools for the purposes of gesturing their use.

Based on the neurocognitive models of visual processing, lesions within regions of the ventro-dorsal stream have shown deficits in pantomiming tool use (Binkofski & Buxbaum, 2013; Buxbaum, 2001). This is because the ventral stream plays a role in the processing of visual information for the retrieval of stored knowledge of how the tool is used is needed in order to associate the appropriate hand actions related to the object's use (Binkofski & Buxbaum, 2013). Moreover, the classical dorsal stream plays a role in the motor aspects of the pantomime of tool use, such as the spatial configuration of the body, hands and their movements. On the other hand, the ventral stream is important for the recognition of the visual characteristics of the object in order to select the appropriate actions associated with pantomiming the tool's use (Buxbaum & Saffran, 2002; Finkel, Hogrefe, Frey, Goldenberg, & Randerath, 2018; Garcea & Buxbaum, 2019; Johnson-Frey et al., 2004). With this in mind, growing evidence of studies exploring pantomiming paradigms in healthy subjects have reported that the act of pantomiming tool use activates similar neural networks when actively using tools, imagining using tools and even passively viewing tools

(Chen et al., 2018; Garcea et al., 2018; Hermsdörfer, Terlinden, Mühlau, Goldenberg, & Wohlschläger, 2007; Moll et al., 2000).

In light of this, behavioural studies using priming paradigms have shown that object affordances can influence the execution of actions towards subsequent objects (Castiello, 1996; Rosenbaum et al., 2009; Tucker & Ellis, 2001). Furthermore, the functional and causal relationships between actions and objects has been shown to facilitate in their recognition (Mounoud, Duscherer, Moy, & Perraudin, 2007). For example, Mounoud et al. (2007) used a priming paradigm in which participants first viewed a prime pantomiming action (i.e., drive a nail) followed by a target picture of a tool (i.e., a hammer). The target tool was either typically associated or not associated with the preceding action (i.e., driving a nail followed by a hammer versus driving a nail followed by a broom). They found that target tools that were associated with a corresponding pantomiming action were identified faster than tools that were not. These findings show that the affordances invoked by the similarities in action related properties of tools can influence how objects are identified. This creates an avenue for research as it raises the question as to whether this effect would still be the same if the tools that are different but share the same action related properties could influence the responses to how they are both pantomimed.

Naming tools

Naming entities is an important aspect of our development and linguistic skills. This involves the processing of stored information connected to a particular word, or the processing of visually perceived stimuli that activates lexical outputs (Jolicoeur, Gluck, & Kosslyn, 1984). In order to successfully name a tool, an individual has to first recognise the tool from its visual properties, such as its shape and visual texture and then retrieve the semantic representation of the tool to recall the lexical label of the tool (Rothi, Raymer, Maher, Greenwald, & Morris, 1991). As such, the semantic representation of a tool can be based on two properties; a) the physical properties of the tool (i.e., visual attributes such as its shape or colour) and b) the functional properties (i.e., abstract attributes that are not defined by the tool's physical structure; Thompson-Schill & Gabrieli, 1999).

According to the embodied cognition perspective, the conceptual knowledge that represents the meaning of words is grounded in sensorimotor experiences (Gallese & Lakoff, 2005; Glenberg, 1997; Lakoff et al., 1999). In this view, sensorimotor processes play an interactive role in mediating semantic knowledge. This view is consistent with various behavioural studies exploring this effect (Bub, Masson, & Bukach, 2003; Helbig, Graf, & Kiefer, 2006; Helbig, Steinwender, Graf, & Kiefer, 2010; McNair & Harris, 2012; Myung, Blumstein, & Sedivy, 2006; Zwaan, Madden, Yaxley, & Aveyard, 2004). For example, studies using a priming paradigm have shown that participants respond faster to names of objects that are preceded by names of objects that require a similar motor response in the way that they are manipulated ("typewriter" followed by "piano"; Myung et al., 2006). This has also been demonstrated by the grasp properties and functional actions associated with an image of a tool facilitating the subsequent recognition of a different tool with similar grasp and/or functional use properties (McNair & Harris, 2012). Similarly, neuroimaging evidence has also shown that areas within dorsal stream areas are activated when passively viewing and naming tools (Chao & Martin, 2000; Grafton et al., 1997). These results as proposed by embodied theories suggest that motor representations are not entirely separate from aspects of semantic knowledge about words and objects.

On the other hand, based on the TVSH (Goodale and Milner 1992), the successful naming of tools depends on the tool's identification, and therefore is predominantly processed in the ventral stream. This has been demonstrated by Chouinard and Goodale (2010) who found that naming tools elicits greater neural responses to different areas in the ventral stream compared to naming animals, but also engages dorsal stream areas that are associated with tool use (Chouinard & Goodale, 2010). While neuroimaging evidence has shown that both the dorsal and ventral streams may play a role in the naming of objects (Almeida, Mahon, & Caramazza, 2010), the dorsal stream is not crucial for the successful identification and naming of tools. In other words, if there is damage to dorsal stream processing areas, the ability to identify and name visually perceived objects may still be unaffected. As such, the various ways in which sensorimotor processes have been shown to play a role in tool naming gives us an opportunity to explore how the similarities of action-related properties of tools can influence how real compared to pictures of tools are recognised for the purposes of naming.

Manipulating tools

We are constantly manipulating objects and tools, many of which vary in the number of ways in which they are used to satisfy an intended purpose. More importantly, the way in which we reach out to grasp a tool is a fundamental part of how we plan to manipulate the tool. For example, the shape, size, mass, orientation, and the location of a tool relative to the observer influences the way one would configure their hand to grasp the tool correctly (Chainay, Naouri, & Pavec, 2011; Chen et al., 2018; Cuijpers et al., 2004; Eastough & Edwards, 2007; Witt, Proffitt, & Epstein, 2005)

According to the TVSH (Goodale and Milner 1992), grasping a tool or object relies on the online control of actions which heavily rely on dorsal stream functioning. Despite evidence for the independence of the dorsal stream in object-directed actions such as grasping (see Goodale et al., 1991), the learned information about an object's identity is also crucial for selecting the correct way in which an object should be grasped, especially with objects such as tools. For instance, a knife has specific physical features (i.e., a blade with a handle). In order to safely grasp the handle of the knife in the case that that the blade was facing us, we would have to identify the blade from the handle in order to select the appropriate way to configure our hand and posture to be able to grasp the handle correctly. Therefore, areas of the ventral stream are required for selecting the correct way in which a tool is used. This is supported by evidence from patient DF mentioned above (see page 15). Due to anoxic damage in her ventral stream areas but an intact dorsal stream, she was able to successfully orient her hand to grasp tools of different orientations, however she was not be able to make perceptual judgements to distinguish the orientations between objects (Whitwell, Milner, & Goodale, 2014). Therefore, in the hypothetical case of a knife, patient DF would most likely be unable to identify the blade of a knife from the handle unless she was able to have some sort of haptic feedback. This means that damage to her ventral stream would inhibit her from identifying the tool based on its physical properties.

With this in mind, behavioural evidence has shown the dissociation between grasping a tool based on its physical properties (i.e., the handle shape or orientation) from grasping a tool based on intending to use it from the knowledge of its functional action (Valyear, Chapman, Gallivan, Mark, & Culham, 2011). For example, it takes longer to initiate actions towards grasping a tool to demonstrate its use compared to grasping a tool in order to either move it when it is preceded by a tool with the same functional use actions (Squires et al., 2015; Valyear et al., 2011). This is because grasping a tool for the purposes of using the tool requires more extensive planning as it requires the retrieval of the conceptual knowledge of how the tool is functionally manipulated. This shows us that grasping a tool for the purposes of using the tool requires more cognitive effort and therefore takes longer. These findings highlight that the processing of the functional use properties of tools are differentially activated in response to the processing of tool stimuli, particularly with regard to object directed actions.

V. Present investigation

The aim of this thesis was to investigate how responses to pantomiming, naming and manipulating tools is influenced by how we process the action related properties of real tools and pictures of tools. Namely, how tools are grasped and the ways in which we manipulate them to perform their function (also known here as functional use actions). This thesis explored two elements. The first was to examine whether there are any differences in how the action related properties of tools are processed between tools presented in a real 3D format compared to tools presented in a pictorial format. The second was to examine whether 3D tools compared to 2D tools that shared the same action related properties but that were different in identity would facilitate the response times to initiating a pantomiming action, naming a tool, or manipulating tools that share the same affordances.

The first study, entitled "*A pantomiming priming study on the grasp and functional use actions of tools*" examined whether the repeated visual presentation of object features such as those related to grasping and their functional use can facilitate pantomiming. This was achieved by using a priming paradigm in which the grasp and functional use features between tool pairs were either the same or different and measuring the reaction times and number of correct pantomiming movements of each presented tool (also known here as the accuracy). The second study, entitled "*A priming study on naming real versus pictures of tools"* examined whether the differences in how 3D real tools compared to 2D images of tools are processed by the brain could influence the naming of tools. This was achieved by using a priming paradigm in which the functional use features between tool pairs were either the same or different and measuring the reaction times and accuracy of naming responses of each presented tool. The third study, entitled "*The initiation of actions based on the functional use similarities of tools: A priming study with primes presented as real tools or in a pictorial format*" examined whether real tools that afford action related responses may facilitate the processing of tools with similar functional use attributes than pictures of tools. This was achieved by using a priming paradigm in which the functional use features between tool pairs were either the same or different and measuring the reaction times, accuracy and movement times of functional use actions towards target tools. The overarching hypothesis across all three studies in this thesis is that tools that share the same action related properties but that are different in identity will invoke motor representations that underpin the implicit retrieval of conceptual knowledge of how a tool is grasped and or functionally used. Futhermore, presenting tools that have similar affordances and in real 3D format will invoke these motor representations that will result in positive priming effects. However, the degree to which these priming effects are influenced by the experimental task is unclear, and this is what will be investigated in this thesis.

Chapter Two

Choice of methods and design.

VI. I. Why use a behavioural priming paradigm?

Priming has been widely used in various aspects of cognitive research as it is a useful way of assessing how various changes in our environment influence cognition and behaviour. For example, priming has been used to explore whether behavioural responses such the accuracy or reaction time to recognizing subsequent stimuli is either interfered with or facilitated by the preceding stimulus (Huber, 2008; Molden, 2014; Neely, 1991). According to Graf, Squire, and Mandler (1984) priming is an example of implicit memory in which our behaviours are influenced by previous experiences, even in the absence of conscious awareness (Graf et al., 1984). In this view, there are various types of priming, many of which work in a specific way and have differing effects (Graf & Schacter, 1985; Roediger, 1990; Schacter, 1987; Tulving & Schacter, 1990; Schacter & Buckner, 1998). This includes the way in which we perceptually process objects or linguistic stimuli. For example, we are usually faster to recognise a picture of a nail if it is preceded by a picture of a hammer compared to an unrelated prime such as a broom (Xavier Alario, Segui, & Ferrand, 2000). Similarly, we are also more likely to be faster to recognise the word banana if it is preceded by the word yellow compared to an unrelated prime such as blue (Heurley & Vermeulen, 2017). Therefore, positive priming effects (i.e., facilitation) are associated with a faster and more accurate behavioural response to a repeated stimulus, whereas negative priming effects (i.e., interference) are associated with a slower, more inaccurate behavioural response to a repeated stimulus.

Moreover, positive priming effects have also been demonstrated in the reduced amplitude of neuronal responses to repeated stimuli in a number of adaptation studies (Chouinard & Goodale, 2009; Chouinard, Morrissey, Köhler, & Goodale, 2008; Huettel & McCarthy, 2000; Valyear et al., 2006). As mentioned in Chapter one, neuronal adaptation is based on stimulus specific reduction in neural activity (Grill-Spector, Henson, & Martin, 2006). This means that neuronal populations that respond to a stimulus show reduced amplitude of activation to the subsequent presentation of that stimulus and can result in a faster processing of stimuli or the identification of a repeated stimulus to occur faster (James & Gauthier, 2006; Wiggs & Martin, 1998). This increase in processing efficiency has been distinguished through different neural adaptation models. For example, according to the predictions of the facilitation model of neural adaptation (Grill-Spector et al., 2006; James & Gauthier, 2006), shorter durations or shorter latencies of neural firing are a result of faster processing of repeated stimuli (Henson, Price, Rugg, Turner, & Friston, 2002). This means that the latency of neural activity shortens for repeated presentations of a stimuli, which in turn reduces the amplitude of the BOLD signal. Another example is the sharpening model of neural adaptation that predicts that the faster processing of repeated stimuli is caused by a broader more sparse distribution of neural activity that selectively responds to the subsequent presentation of a stimulus (Desimone, 1996; Freedman, Riesenhuber, Poggio, & Miller, 2006; Wiggs & Martin, 1998). Namely, neuronal populations that code for features that may be unrelated to the identification of a stimulus (Grill-Spector et al., 2006). This 'sharpening' of neural responses has been observed in response to familiarity of the stimulus as a result of learning processes (Wolfram & Kistler, 2002). Note that the causes of the magnitude of adaptation effects may vary depending on the stimuli and task requirements, however, based on these models, the differences in response times when responding to the presentation of the subsequent target stimuli can be a reflection of the increased efficiency of neural processing in the brain.

With this in mind, recent work involving motor priming has also demonstrated neural adaptation in response to faster rection times to initiating repeated actions (Valyear and Frey, 2014; 2015). For example, Valyear and Frey, 2015 used fMRI to investigate the neural efficiency for successive actions made with the same hand towards objects. Participants were required to respond to a prime followed by a target object by using either their left or right hand to reach out, grasp and perform rotation movements of the objects depending on a set of conditions. The found faster response times to initiate successive actions when the same hand was repeated which was accompanied by reduced neural activation parietal regions of the brain. The authors concluded that neural adaptation and the effects of having the actions involved with same hand used in succession provides a sort of motor history where hand selection is sensitive to recent movement experience. This provides some support for the idea that reaction times to initiating actions and the efficiency of neaural activity is linked. Therefore, with respect to the repeated presentation of action related properties such as those related to the grasp and/or functional use actions between tool pairs, we can assume that the same neuronal populations are activated when processing both the prime and the target tool, thus an increased efficiency of neural processing at a circuit level may lead to a faster response to the target tool (i.e., facilitation effects; Korzeniewska et al., 2020). I define priming here as a faster reaction time, movement time or increased accuracy in behavioural responses following prior exposure to a tool which in turn influences the way an individual names, pantomimes or performs an action to a subsequent target tool. More importantly, and as discussed in chapter one, priming paradigms have also been widely used to investigate the effects of action related properties of objects on accuracy of object recognition and the speed of manual responses towards subsequent tools (Bub & Masson, 2006; Craighero, Fadiga, Umiltà, & Rizzolatti, 1996; Helbig et al., 2010; McNair & Harris, 2012; Squires et al., 2015; Tucker & Ellis, 2004; Valyear et al., 2011; Wiggs & Martin, 1998). These findings have highlighted the facilitation effects of how differing object properties can influence how accurately or quickly subsequent tools are processed. As such, this illustrates how using a priming paradigm is an effective methodological approach to investigating how the functional use action of tools can influence the way an individual names, pantomimes or performs an action to a subsequent target tool.

A priming paradigm was selected for use in the studies of this thesis as it is an effective way of investigating whether pantomiming, naming, and manipulating tools share similar underlying brain mechanisms when processing the repeated presentation of action related properties between tool pairs (i.e., faster response times to target stimuli following changes in efficiency of neuronal populations). Furthermore, using such a paradigm also enabled the exploration of whether facilitation effects caused by specific action related properties of tools are a result of the different ways in which we perceptually process the format in which the prime tools are presented (i.e., in a real 3D or 2D pictorial format).

In view of this, the action related properties such as those related to the grasp and/or functional use of tools can be similar to a number of other tools that differ in their identity. For example, a squeegee and a paint roller have different uses but are grasped in a similar manner and share similar manipulations while achieving specific functions (i.e., a similar functional use). However, these tools are used for different purposes in that the former is used for cleaning windows and the latter is used for painting. This creates an interesting avenue for research as it raises the question as to whether the repeated presentation of action related properties between tool pairs that have different defined identities facilitate or interfere with how participants respond to subsequent tools. Furthermore, this raises the important question as to whether the dimensional modality in which the prime tool is presented (i.e., a real tool compared to a picture of a tool) influences how the similarities in action related properties between the tools are processed? The present thesis tried to answer these questions by incorporating a variety of tool stimuli that were different in identity but either shared or did not share the same grasp and/or functional use properties and were presented in a real 3D and/or 2D pictorial format. This enabled the investigation of a more ecological perspective of how tools are usually processed as we interact with real tools in our daily life, however not many lines of research investigating the effects of tool affordances on cognitive processes have compared the differences in how the action related properties of real compared pictorial tool stimuli are processed.

Behavioural priming effects have been shown to occur within an SOA (stimulus onset asynchrony) of as short as 50 milliseconds (Perea & Gotor, 1997; Perea & Rosa, 2002). More importantly, priming effects have also been demonstrated in the reduced hemodynamic response to a second stimulus in a pair within 2 or more seconds (Chouinard & Goodale, 2009; Chouinard et al., 2008; Huettel & McCarthy, 2000; Van Turennout, Bielamowicz, & Martin, 2003). Although typical priming research tends to demonstrate stronger effects with shorter SOAs (Hermans, Spruyt, & Eelen, 2003), the neural mechanisms of priming can still occur with relatively longer SOA's, therefore, the response times towards target stimuli can still be influenced by what is processed 2 or more seconds earlier. In the present thesis, the SOAs in each study were manipulated differentially. For example, both Study 2 (chapter four) and Study 3 (chapter five) included an SOA of 3-4 seconds. This was chosen to accommodate the time it took for the replacement of the prime tool for the target tool. On the other hand, Study 1 (chapter 3) included two tasks with an SOA of either 2 or 3 seconds. The use of two SOAs allowed adequate time for participants to comfortably respond to the stimuli and enabled comparison of the differences of priming effects as a consequence of SOA. As a result, including different SOAs provided an effective and valuable tool to examine the importance of how participants process the affordances for selecting either a pantomiming action, a name for a tool, or a functional action to be performed on a tool. Apart from the use of different SOAs in the studies within this thesis, the type of responses that were made to the prime and/or the target stimulus also differed. In both studies 1 and 2 participants were required to respond to both the prime and target tool as they appeared. Conversely, in Study 3 participants were required to view the prime tool then respond only to the target tool. The differences in the priming paradigms between studies was due to the differential ways in which the motor representations of the action related properties between tool pairs were invoked.

It is also worth considering that the task demands involved in the studies in this thesis were not examining participants maintenance of information in working memory. I define working memory here as the maintenance of information held in memory for more than several seconds as first described by Miller, Galanter and Pribram in 1960 (Miller, Galanter, & Pribram, 1960). This pertains to remembering and repeating back sequences of digits such as a telephone number which has been shown to be deficient in patients with brain damage to areas of the frontal lobe (Baddeley & Hitch, 1974). As such, the task demands involved in this thesis were measuring facilitation effects arising from the increased efficiency of neural processing at a circuit level, meaning that the behavioural responses that were demonstrated was not a result of participants having to maintain specific information to later respond to a stimulus, but rather the change in efficiency of the activation of sensorimotor circuits in response to the motor representations that were invoked by the prime tool.

To examine priming effects, three types of responses were measured. The first was participants' reaction time. This allowed the observation and recording of the time between stimulus onset when participants began viewing the tool stimulus to when they released a response button when responding to the stimulus. The second measurement was participants' accuracy/errors. Specifically, the number of correct responses on each task was quantified. Furthermore, it enabled the measurement of participants' reaction times and movement times to correct trials only, and reduced variance in results due to errors. The last measurement was participants' movement time in study 3, which included manipulating real tool stimuli. This allowed measurement of the speed of the actions/movements towards the target tools. This was calculated as the time between when the participant initiated the response, to when the movement of the action performed on the tool that was recorded by the camera was complete. Taken together, using all three types of measures and different priming paradigms was intended to develop our understanding of the various ways in which priming effects may facilitate or interfere with the behavioural responses towards changes in the repeated presentation of the action related properties of tools.

Chapter Three

A pantomiming priming study on the grasp and functional use actions of tools.[1]

Mutindi C. Kithu, Elizabeth J. Saccone, Sheila G. Crewther, Melvyn A. Goodale, Philippe A. Chouinard

I. Prelude

Study 1 examined whether the repeated visual presentation of object features, such as those related to grasping and their functional use, can facilitate pantomiming. This was achieved by using a priming paradigm in which the grasp and functional use actions between tool pairs were either the same or different and measuring the reaction times and accuracy of pantomiming movements of each presented tool. I hypothesised that pantomiming movements of the second object (target) would be facilitated by the first movement (prime) if it had similar grasp and/or functional use actions.

II. Abstract

It has previously been demonstrated that tool recognition is facilitated by the repeated visual presentation of object features affording actions, such as those related to grasping and their functional use. It is unclear, however, if this can also facilitate pantomiming. Participants were presented with an image of a prime followed by a target tool and were required to pantomime the appropriate action for each one. The grasp and functional use attributes of the target tool were either the same or different to the prime. Contrary to expectations, participants were slower at pantomiming the target tool relative to the prime regardless of whether the grasp and function of the tool were the same or different – except when the prime and target tools consisted of identical images of the same exemplar. We also found a decrease in accuracy of performing functional use actions for the target tool relative to the prime when the two differed in functional use but not grasp. We reconcile differences between our findings and those that have performed priming studies on tool recognition with differences in task demands and known differences in how the brain recognises tools and performs actions to make use of them.

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III. Introduction

We are constantly using tools such as keys, knives, pens, and other objects throughout our daily lives. The ability to perceive, grasp, and select a functional action to employ with each tool requires a complex series of mechanisms. Certain physical properties of tools, called affordances, influence the way we select an action to apply to a particular tool (Gibson, 1979). For instance, a pair of scissors has certain physical features (e.g., two blades with handles) that afford it being used as a cutting instrument. Considerable research has also demonstrated that even more basic properties, such an object's shape, size, and weight, can also influence the way we perform actions with tools when using them (Chainay, Brüers, Martin, & Osiurak, 2014; Cuijpers, Smeets, & Brenner, 2004; Tucker & Ellis, 1998).

How a tool is grasped can also determine how we wield it once it is in our hand. For instance, grasping a tool based on the orientation of its handle relative to our bodies affects the movements we select to use it (Creem & Proffitt, 2001; Ellis & Tucker, 2000). In the case of grasping scissors, when the blades are pointing towards us, we typically select an awkward but functional posture to safely grasp the handles. Grasping has been widely studied in both humans and monkeys using various tasks and techniques (Castiello, 2005; Grafton, Arbib, Fadiga, & Rizzolatti, 1996). This work has revealed that non-human primates scale the grip aperture of their grasping hand to match the goal object's physical dimensions (Jeannerod, 1981; Jones-Engel & Bard, 1996; Marzke & Wullstein, 1996; Napier, 1960; Preuschoft & Chivers, 2012). The processes involved in a successful grasp of an object requires the transformation of the intrinsic properties of the object into an appropriate posture for the grasping hand (Wood, Chouinard, Major, & Goodale, 2017). Processing these object properties has been shown to be done in real-time immediately before the grasp is initiated (Goodale, Jakobson, & Keillor, 1994; Goodale, Milner, Jakobson, & Carey, 1991; Milner & Goodale, 2008; Westwood & Goodale, 2003). This makes sense when we consider that the location of our bodies relative to an object rarely remains static. The selection of the appropriate action to use a tool as intended, such as grasping scissors by the handles regardless of their position relative to our bodies, requires an understanding of the nature of the object and the current context. Processing this kind of information takes longer than that required for picking up a non-tool given it requires the retrieval of long-term conceptual knowledge of how the tool is used (Jax & Buxbaum, 2010; Valyear, Chapman, Gallivan, Mark, & Culham, 2011). As a result, the proper handling of a tool relies on both the processing of visual input on how to configure the hand on the object, which occurs in real-time, and other properties that require the retrieval of conceptual knowledge, which takes longer.

To further explore this area of research, McNair and Harris (2012) used a priming paradigm to investigate whether the grasp (e.g., configuring the hand on the handles of scissors) and the corresponding action associated with a tool (e.g., the snipping of scissors; hereafter called *functional use*) facilitates the subsequent recognition of a different tool with a similar grasp and / or functional use. They presented participants with a picture of a prime followed by a picture of a target tool in which the grasp and functional use could be similar or different. Participants were then asked to identify the tools they saw from an array of different tools presented throughout the study. The authors found that the target tools affording the same grasp as the prime were identified more accurately than those that did not. Conversely, they found that the target tools affording the same functional use as the prime did not present a similar advantage. Based on these findings, the authors concluded that target tools that are preceded by primes affording a similar grasp can facilitate their recognition because the process of selecting grasps is more readily and automatically assessed.

However, similar to a number of studies in this area (Helbig, Graf, & Kiefer, 2006; Kiefer, Sim, Helbig, & Graf, 2011), McNair and Harris (2012) used object identification responses as opposed to a motor task to draw inferences about affordances. This approach is limited in scope because it does not directly examine how the properties of the tools might actually influence real actions. Perhaps a better way to examine this issue is to have participants pantomime the grasp and functional use of tools instead of identifying them verbally. The act of pantomiming consists of performing an action without the physical interaction of an actual tool. As it turns out, functional neuroimaging reveals a common network of brain areas that are engaged when people execute (Hermsdörfer, Terlinden, Mühlau, Goldenberg, & Wohlschläger, 2007), imagine (Grezes & Decety, 2001), and pantomime (Johnson-Frey, Newman-Norlund, & Grafton, 2004) tool-use actions. These mechanisms are complex and entail an interaction between different systems devoted to 1) the perceptual recognition of objects, and 2) the online control of actions (Goodale et al., 1994).

According to Goodale and Milner's Two Visual System Hypothesis (TVSH; Goodale & Milner, 1992), the processing of visual information for the online control of skilled actions (e.g., reaching and grasping on object) is carried out by the dorsal stream, which includes areas in the posterior parietal cortex that receive projections from the early visual cortex. The processing of visual information for recognition and associating conceptual meaning to stimuli, is driven by the ventral system, which includes visual areas in the inferior temporal cortex that receive projections from the early visual cortex. With this in mind, neuropsychological studies of patients with apraxia underscore the complex nature of these interacting ventral and dorsal systems. Some patients have difficulty selecting actions to perform communicative gestures and pantomiming the use of tools (Goldenberg, 2009; Wheaton & Hallett, 2007) – highlighting the need to investigate how different systems in the brain are involved in processing the perceptual / cognitive and motor-based properties of tools.

According to TVSH, the object identification approach used by McNair and Harris (2012) taps mostly into ventral stream processes, whereas pantomiming tool use taps into both ventral and dorsal processing streams. Although pantomiming does not involve the online control of reaching and grasping actions on a real object, rather, the online control is used to re-enact the grasp and functional use of an imaginary object that is not really there. At the same time, having participants encode different properties of tools and thereafter turn them into motor movements requires the integration of these two visual processing streams. Thus, a pantomiming task could possibly enable one to better examine how the grasp and functional use properties of tools can influence real actions.

The current study used a priming paradigm to investigate how the repeated visual presentation of object features affording grasps and functional use might facilitate pantomiming. We adopted a priming paradigm similar to the one used by McNair and Harris (2012) except we had participants pantomime the action of the prime and target tools as they appeared rather than identifying them from an array afterwards. We asked participants to pantomime the movements to both the prime and target objects as soon as they appeared, rather than having them hold the objects in memory, which would tap into ventral stream processes even more. We hypothesised that pantomiming movements of the second object (target) would be facilitated by the first movement (prime) if it had similar grasp and / or functional use actions. This facilitation, or priming, would be indexed by a decrease in reaction times and an increase in accuracy. The image pairs we used were identical to those used by McNair and Harris (2012), which have already been matched along several nuisance variables by the authors (for more details, see Methods). Using the same set of stimuli also allows one to draw comparisons between our studies more easily. The tools either had a) the same grasp and the same functional use (SGSA), b) the same grasp and a different functional use (SGDA), c) a different grasp and the same functional use (DGSA), d) a different grasp and a different functional use (DGDA), or e) were identical (SAME). Comparing these conditions allowed us to determine if earlier encounters with tools with similar grasps and / or functional use properties might facilitate pantomiming actions.

IV. Method

Overview

The study included two experimental tasks that differed in stimulus onset asynchronies (SOA). In this study, SOA refers to the amount of time between the onset of the prime and target stimuli. There was a 2-s interval between the prime and target tool in the first task and a 3-s interval between the prime and target tool in the second task. Because typical priming research tends to demonstrate stronger effects with shorter SOAs (Hermans, Spruyt, & Eelen, 2003), the 2-s SOA task was included in an attempt to maximise priming effects while still allowing sufficient time for participants to complete the movements (Hermans et al., 2003). Although this interval turned out to be sufficient, there was nonetheless a concern at the beginning of data collection that this amount of time might potentially be too short for participants to complete the action and return to the starting position naturally. Therefore, we also included a second task with a longer SOA of 3-s. We did not have a fully within-subjects design because we had a limited number of stimuli and wanted to limit the number of times we repeated each one to reduce habituation and maximise our ability to demonstrate priming effects. The 2-s SOA task lasted 35 minutes while the 3-s SOA task lasted 45 minutes. The experimental paradigm is illustrated in Figure 3.1. An example of a pantomiming movement to a stimulus is displayed in Figure 3.2.

Participants

Twenty-seven right-handed participants with reported normal or corrected-to-normal vision participated in the study. The 2-s SOA task included 15 participants (7 females, mean age: 24 years, age range: 18 - 44 years) and the 3-s SOA task included 12 participants (7 females, mean age: 26 years, age range:18- 57 years). Scores ranging from -100 to +100 from the Edinburgh Handedness Inventory (Oldfield, 1971) indicated that 13 participants were strongly right-handed (mean score = 85, range: 61 - 100) while 3 were mildly right-handed (mean score = 46, range: 38 - 53) in the 2-s SOA task. All participants in the 3-s SOA task were strongly right-handed (mean score = 94, range: 76-100). All participants provided written informed consent and all procedures were approved by the Human Research Ethics Committee of La Trobe University in accordance with the Declaration of Helsinki. Participants were compensated for their time with gift vouchers.

Materials and procedure

The stimuli consisted of 40 grey-scale images of tools (200 × 200 pixels, 120 DPI) from the Hemera Technologies Inc. Photo Object Database (Hull, Quebec, Canada). The same stimuli were also used by McNair and Harris (2012). The stimuli were presented as pairs with a 'prime' followed by a 'target' tool (Figure. 3.1). The presentation order within the pairs of tools was counterbalanced such that each stimulus appeared as often as the prime as it did the target. The image pairs consisted of tools with either the same grasp and same functional use action (SGSA), the same grasp and different functional use action (SGDA), different grasps and the same functional use action (DGSA), and different grasps and different functional use action (DGDA). Finally, there was a fifth condition in which the same tool image was presented as the prime and target (SAME). The tool pairs across the different conditions were previously matched for grasp, action, shape, and contextual similarities (McNair & Harris, 2012). We used E-Prime 2.0 (Psychology Software Tools, Pittsburg, PA, USA) to present the stimuli on a 15" Dell Precision M6800 laptop computer (Dell Inc., Hopkinton, MA, USA). The participants were seated 40 cm away from the computer screen, which had a resolution of 1024 × 768. The stimuli subtended a visual angle of 5.5°.

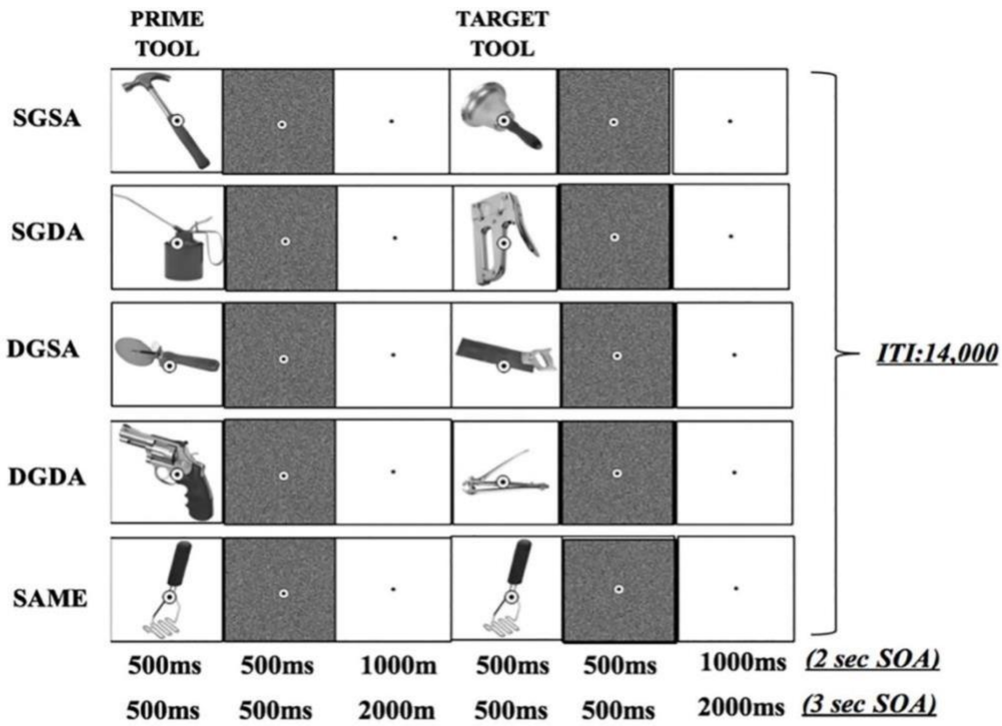

Figure 3.1. Experimental design and timing parameters. This figure displays examples of pairs of tools used in the different pantomiming conditions: SGSA (same grasp and same functional use action), SGDA (same grasp and a different functional use action), DGSA (different grasp and same

functional use action), DGDA (different grasp and different functional use action) and SAME (same image). Each trial included the presentation of the prime tool presented for 500 ms (where participants responded with pantomiming the grasp and functional use action of the tool), followed by a mask for 500 ms, and then by a fixation for 1000 ms for the 2-s SOA and 2000 ms for the 3-s SOA. Thereafter, the target tool was presented for 500 ms (where participants responded by pantomiming the grasp and functional action of the tool again) followed by a mask for 500 ms. Each trial was then followed by a 14-s inter-trial interval (ITI) where participants maintained central fixation. The participants were instructed to perform the actions as quickly and accurately as possible.

The experiment began with a small practice session with 10 trials consisting of pairs of tools from the main procedure chosen at random. The main procedure was divided into four blocks (A, B, C and D), each one consisting of 26 trials. The presentation order of the blocks and objects within each block was counterbalanced across participants to control for order effects. The SAME condition was presented 10 times per block (40 trials in total, each trial consisting of a different image). Conversely the other conditions were each presented 4 times per block (16 trials in total for each condition).

The participants were seated comfortably in front of the computer screen with their right elbow on the table. They were instructed to maintain fixation on a central dot, which remained on the screen at all times, and were asked to perform a pantomiming action as quickly and accurately as possible every time they saw an image of a prime or target tool. Between movements, their index finger rested on the first blue button of a Chronos response pad (Psychology Software Tools, Pittsburg, PA, USA). This device was used to measure the reaction time (RT) to initiate a pantomiming action. Specifically, it recorded the time between stimulus onset and the release of the button. As shown in Figure 3.1, each trial began with the presentation of the prime for 500 ms followed by a mask for 500 ms. This was then followed by a fixation period of 1000 ms for the 2-s SOA task or a fixation period of 2000 ms for the 3-s SOA task. Afterwards, the target tool was presented for 500 ms followed by a mask for 500 ms. Each trial was then followed by a 14-s inter-trial interval (ITI) in which participants continued to maintain central fixation.

We used a Casio EX-FH100 high-speed video camera (Casio Electronic Manufacturing Co., Ltd, Saitama, Japan) to record movements so that we could assess their grasp and functional use accuracy. The field of view was restricted to the participant's hand. The recordings had a temporal resolution of 420 frames per second and a spatial resolution of 224 × 168 pixels. Adobe Premiere Pro software (Adobe Systems Incorporated, San Jose, CA, USA) was used to analyse the recordings offline. The accuracy of each movement was defined as the action we expected participants to make for each tool. This was pre-determined in advance of scoring the videos based on the classifications made by McNair and Harris (2012). The accuracy of the grasp and functional use components for each pantomiming action to either a prime or target tool was evaluated in a binary manner as either 0 for incorrect and 1 for correct. Overall accuracy scores for grasping and functional use actions were then calculated as the percentage of correct responses.

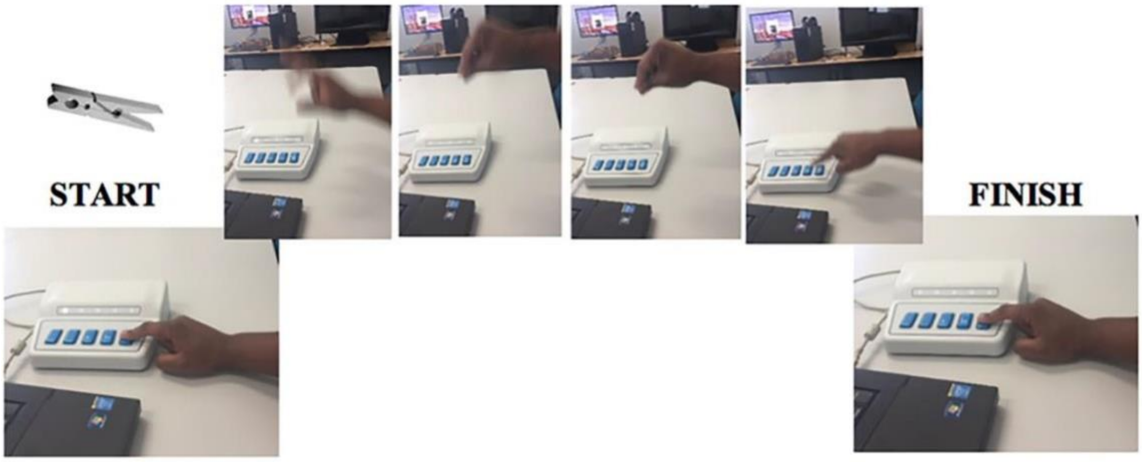

Figure 3.2. Example of an action. The figure provides video frames of a pantomiming action to a photograph of a clothes-peg. 'Start' corresponds to the stimulus onset. This was then followed by the pantomiming of the grasp then the functional use action of the tool. "Finish' corresponds to the end of the movement. At the end of the movement, the participant returned their index finger to the response pad and waited for the next stimulus presentation.

Inter-rater reliability for accuracy scoring

Two raters independently analysed the videos. One rated accuracy for all participants while the other scored a subset of participants (5 participants in the 2-s SOA task and 5 participants in the 3-s SOA task). Both raters were aware of the tool that was presented and the expected response. From their scores, we then calculated the percentage agreement between the number of instances that received the same ratings by both raters. The two raters independently coded 86% grasping and 79% functional use actions in the same manner. The statistics below were performed on the accuracy scores from the first rater who scored all participants.

Statistical analyses

The data were analysed using the Statistical Package for Social Sciences (SPSS) version 23 (IBM Corporation; Armonk, NY, USA), JASP software version 0.8 (University of Amsterdam,Amsterdam, Netherlands), and GraphPad Prism version 6 (GraphPad Software Inc., La Jolla, CA, USA). Three dependent variables were analysed. The first was RT priming for accurate responses only. This measurement was calculated as the percentage change in RT between the prime and target (((prime object RT – target object RT) / prime object RT) *100). The second was the change in grasp accuracy between the prime and target (grasp accuracy for the target – grasp accuracy for the prime). The third was the change in functional use accuracy between the prime and target (functional accuracy for the target – functional accuracy for the prime). The means and standard deviations for RT, grasp accuracy, and functional use accuracy for both the prime and target are also reported.

2 × 5 analyses of variance (ANOVA) were performed for each dependent variable with SOA (2 levels: 2 s, 3 s) as a between-subject factor and Pantomiming Condition (5 levels: DGDA, DGSA, SAME, SGDA, SGSA) as a within-subject factor. *T*-tests, corrected for multiple comparisons using the Bonferroni method, were performed to further evaluate significant main effects and interactions. One-sample *t* tests, also corrected for multiple comparisons using the Bonferroni method, were performed to determine if RT priming, changes in grasp accuracy, and changes in functional accuracy differed from zero. All reported *p* values represent corrected values unless specified otherwise. Significance was established at an alpha level of .05.

A Bayesian analysis was also performed using the same 2 (SOA) x 5 (pantomiming condition) ANOVA model as above. The Bayes factor we report (BF_{10}) quantified the likelihood that the data supports the alternative relative to the null hypothesis as a ratio between the two. We considered a BF_{10} value of 3 or above as substantial evidence in favour of the alternative hypothesis and values of 0.33 or less as substantial evidence in favour of the null hypothesis (Jeffreys, 1998). One sample Bayesian *t*-tests were also performed to determine if RT priming, changes in grasp accuracy, and changes in functional used accuracy differed or not from zero. There was no need to correct for multiple Bayes factors given that they do not reflect probabilities (Gelman, Hill, & Yajima, 2012). The Bayesian analyses allowed us to determine if a different statistical approach might converge with the more traditional ANOVA, which would provide more confidence in the findings, and also draw more definite inferences from null results.

V. Results

RT priming

In brief, we observed negative priming in all conditions except the SAME condition. In other words, participants were slower to initiate a pantomiming action to a target tool relative to a prime when the two stimuli differed – regardless of whether the two afforded similar grasping and/or functional use actions. Conversely, this interference was not present when the exact same tool was presented twice. This was true for both the 2-s and 3-s SOA tasks. The results are shown in Figure 3.3. Table 3.1 provides descriptive statistics for the absolute RT measurements for primes and targets.

Classical ANOVA demonstrated a main effect of Pantomiming Condition ($F_{(4,100)} = 10.20$, $p < .001$, $\eta_{r}^{2} = 0.29$). Pairwise comparisons revealed that RT priming in the SAME condition differed from all the other pantomiming conditions (DGDA vs. SAME: $p = .003$, DGSA vs. SAME: $p < .001$, SGDA vs. SAME: $p < .001$, SGSA vs. SAME: $p < .001$). All other pairwise comparisons did not differ (all $p > .500$). There was no main effect of SOA ($F_{(1,25)} = 1.93$, $p = .177$, $\eta_{r}^{2} = 0.07$) nor was there an interaction between Pantomiming Condition and SOA ($F_{(4,100)} = 0.39$, $p = .813$, $\eta_{r}^{2} = 0.02$). One-sample classical *t*-tests revealed that RT priming was lower than zero in all the pantomiming conditions except the SAME condition (DGDA $t_{(26)} = -3.36$, $p = .002$; DGSA $t_{(26)} = -2.91$, $p = .007$; SGDA $t_{(26)} = -3.41$, $p = .002$; SGSA $t_{(26)} = -4.75$, $p < .001$; and SAME $t_{(26)} = 1.02$, $p = .324$).

The Bayesian analyses yielded similar results. Bayesian ANOVA demonstrated substantial support for a main effect of Pantomiming Condition ($BF_{10} = 78{,}169.72$), inconclusive support for or against a main effect of SOA ($BF_{10} = 0.73$), and substantial support against a Pantomiming Condition and SOA interaction ($BF_{10} = 0.10$). One-sample Bayesian *t*-tests confirmed the lack of RT priming in the SAME condition ($BF_{10} = 0.32$) and the presence of negative priming in the DGDA ($BF_{10} = 15.78$), DGSA ($BF_{10} = 6.06$), SGDA ($BF_{10} = 17.53$), and SGSA ($BF_{10} = 394.23$) conditions.

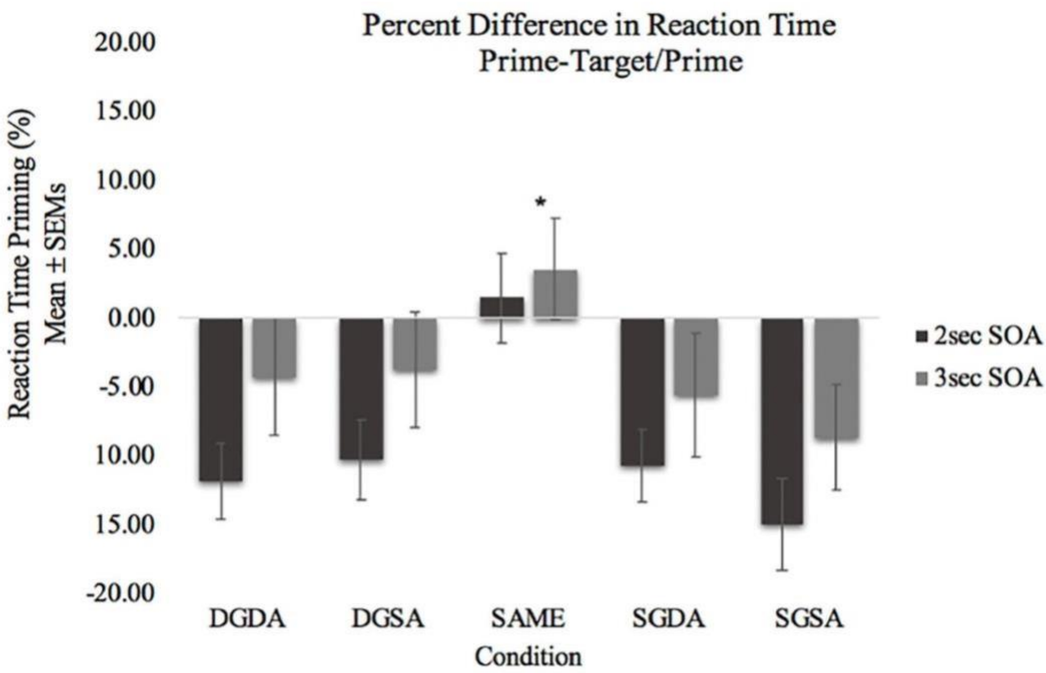

Figure 3.3. RT priming results.The graph displays the mean ± SEM RT priming scores in the 2-s (black bars) and 3-s (grey bars) SOA tasks. RT priming was calculated as: (prime tool RT – target tool RT) / prime tool RT) *100. A main effect of Pantomiming Condition was found. Asterisks (*) denotes a significant difference with the SAME condition compare to all the other conditions after correcting for multiple comparisons ($p < 0.05$).

Grasp accuracy difference

Figure 3.4 shows the mean difference in the accuracy of grasp movement scores between the prime and target tools while Table 1 provides descriptive statistics for the absolute accuracy measurements for the primes and targets. In summary, grasp accuracy difference scores did not differ between any of the conditions.

Classical ANOVA revealed no main effect of Pantomiming Condition ($F_{(4,100)} = 0.43$, $p = .789$, $\eta_p^2 = .017$), no main effect of SOA ($F_{(1,25)} = 2.58$, $p = .121$, $\eta_p^2 = 0.09$), and no Pantomiming Condition and SOA interaction ($F_{(4,100)} = 2.11$, $p = .085$, $\eta_p^2 = 0.08$). Averaging all conditions together and performing a one-sample t-test against zero to determine if there were any changes in overall accuracy between the prime and target tools revealed no difference ($t_{(26)} = 1.26$, $p = .221$).

Likewise, the Bayesian ANOVA demonstrated substantial support against a main effect of Pantomiming Condition (BF_{10} = 0.13) as well as inconclusive support for or against a main effect of SOA (BF_{10} = 2.11) and a Pantomiming Condition and SOA interaction (BF_{10} = 2.11). A one-sample Bayesian t-test comparing the average difference between prime and target tools across all conditions against zero was inclusive (BF_{10} = 0.413).

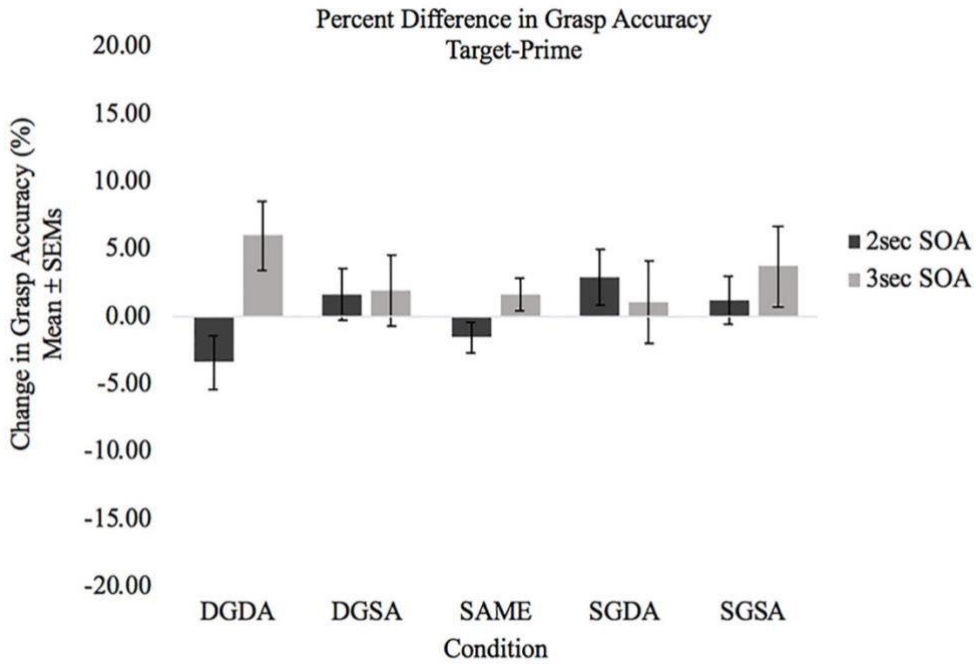

Figure 3.4. Grasp accuracy difference results. The graph displays the mean ± SEM percentage of grasp accuracy difference scores in the 2-s (black bars) and 3-s (grey bars) tasks. Grasp accuracy differences scores were calculated as the grasp accuracy for the target tool minus the grasp accuracy for the prime tool. There were no differences between conditions.

Functional use accuracy difference

Figure 3.5 shows the mean difference in functional use accuracy between the prime and target tools while Table 3.1 provides descriptive statistics for the absolute functional use accuracy measurements for the primes and targets. In summary, accuracy diminished when participants pantomimed a target that had the same grasp but a different functional use action than the prime but only in the 3-s SOA task. In other words, performing a different action with a similar grasp causes interference when there is a longer delay.

Classical ANOVA revealed an interaction between Pantomiming Condition and SOA ($F_{(4,100)}$ = 2.79, p = .030, η_p^2 = 0.10). This interaction was driven by a drop in accuracy in the 3-s relative to the 2-s SOA task in the SGDA condition (p = .019). This drop also differed from zero (p =.015) and changes in the SGSA condition in the 3-s SOA task (p = .034). There were no differences from zero in any of the other conditions (all $p > 0.1$). The main effects of Pantomiming Condition ($F_{(4,100)}$ = 2.42, p = .054, η_p^2 = 0.09) and SOA ($F_{(1,25)}$ = 0.08, p =.785, η_p^2 = 0.00) were not significant.

The Bayesian analyses yielded similar results. The Bayesian ANOVA confirmed substantial support for the interaction between Pantomiming Condition and SOA (BF_{10} = 3.18), inconclusive support for or against a main effect of Pantomiming Condition (BF_{10} = 0.95), and substantial support against a main effect of SOA (BF_{10} = 0.24). One-sample Bayesian t-tests were performed for both the 2-s SOA and 3-s SOA tasks. The 2-s SOA Bayesian t-test revealed inconclusive support for or against a difference from zero in all Pantomiming Conditions; DGDA (BF_{10} = 0.736), DGSA (BF_{10} = 0.734), SAME (BF_{10} = 0.345), SGDA (BF_{10} = 0.341), SGSA (BF_{10} = 2.281). Additionally, the 3-s SOA Bayesian t-test also revealed inconclusive support for or against a difference from zero in all Pantomiming Conditions; DGDA (BF_{10} = 0.432), DGSA (BF_{10} = 0.380), SAME (BF_{10} = 0.623), SGDA (BF_{10} = 1.847), SGSA (BF_{10} = 0.360).

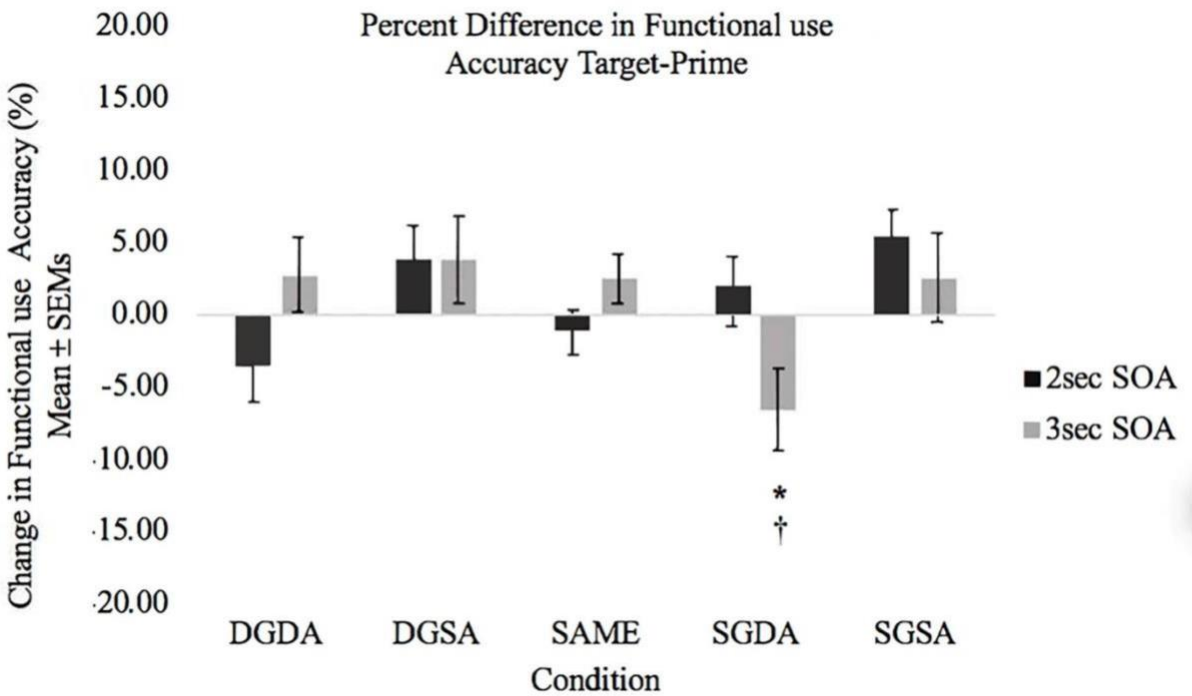

Figure 3.5. Functional use accuracy results. The graph displays the mean ± SEM percentage of functional use accuracy scores in the 2-s (black bars) and 3-s (grey bars) SOA tasks. Functional-

use accuracy differences scores were calculated as the functional-use accuracy for the target tool minus the functional use accuracy for the prime tool. An interaction between Pantomiming Condition and SOA was found. Asterisks (*) denote a difference between the SAME and SGDA conditions in the 3-s SOA task while a dagger (†) denotes a difference between the 2-s and 3-s SOA task in the SGDA condition after corrections were made for multiple comparisons (both $p < .05$).

VI. Discussion

The present study examined if pantomiming the use of tools can be facilitated by earlier encounters with different tools affording similar grasps and functional use actions. We hypothesised a facilitation in pantomiming when participants performed a second movement that had a similar grasp and / or functional use action as the first, and that this facilitation would reflect a decrease in reaction time and an increase in accuracy. Contrary to this hypothesis, participants took longer to initiate movements to the target tool in all conditions except for the one in which the prime and target were identical. In other words, participants were slower rather than faster at pantomiming the target tool relative to the prime regardless of whether their grasp and functional use were the same or different. We also found a decrease in functional use accuracy for the target tool relative to the prime when the two differed in functional use properties but not in grasp at an SOA of 3-s. Taken together, our results demonstrate an interference in pantomiming two different tools presented in succession, even when they shared similar grasp and functional-use properties. The question then arises: Why would presenting a different image create interference even when it is supposed to afford a similar grasp and / or functional use? We propose that images intrinsically do not afford these properties in the same way as real objects do. This is not a new idea. As the French surrealist painter René Magritte (1926) pointed out in his *Ceçi n'est pas une pipe* (translation: *This is not a pipe*) painting, the image of a pipe is a pictorial representation and not the actual pipe itself. One cannot physically place their hand on the pipe. A three-dimensional structure is required for this purpose. Moreover, the functional use action associated with the pipe is based on a combination of conceptual knowledge and its three-dimensional structure. An alien, naïve to smoking, seeing this painting for the first time may not know what the pipe is for but would perhaps figure it out if a real one was placed in front of them. Thus, this painting provides an example of how two-dimensional images may not necessarily afford grasping or functional use actions in the strictest Gibsonian sense (Gibson, 1979) as there is no way to interact with them physically. If this assertion is correct, then there is a fundamental problem with presenting images or words of tools as a medium for investigating grasping and functional use affordances.

In addition, there is growing evidence demonstrating that the brain processes real objects differently than images of these same objects. For example, using functional magnetic resonance imaging (fMRI), Snow et al. (2011) employed an event-related adaptation paradigm to determine whether neural populations that show repetition suppression for pictures of objects might also show similar responses for real objects. As expected, the authors found strong adaptation to the repetition of pictures of objects in the lateral-occipital complex (LOC). However, adaptation was weaker in this same area when real three-dimensional objects were presented. Given that binocular and oculomotor cues provide useful information about object shape for the latter but not the former, neural populations that process the shape of objects may differ depending on which of these two formats of presentation is used.

Note also that the computations required for physically interacting with a real object are different than those required for pantomiming an action in the air to the image of an object. For one thing, they utilise different spatial frames of reference. The former requires an egocentric frame reference, which is based on spatial coordinates relative to a person's body (Filimon, 2015). According to TVSH, the dorsal stream uses an egocentric frame of reference when configuring a person's hand to the geometrical properties of an object (Goodale & Haffenden, 1998). Namely, the physical structure of the object relative to one's body dictates the way one performs the grasp in real time. This information is missing when a person performs a pantomiming action in the air to a visually presented image – as was the case in our study. A different frame of reference must be used – one that is imaginary and based on some kind of memory. According to TVSH, this would require ventral stream processing in which a perceptual representation is invoked prior to the execution of the action (Foley, Whitwell, & Goodale, 2015). The perceptual analysis of an image is based on a sort of allocentric frame of reference in which the spatial information about different parts of the stimulus is encoded relative to each other as opposed to relative to one's self– and can vary considerably from trial to trial and person to person.

This idea is consistent with evidence from patient D.F. (Whitwell, Milner, & Goodale, 2014) whose ventral stream damage prevents her from pantomiming correctly when asked to show how she would pick up and use an imaginary object. This suggests that she is unable to invoke a perceptual representation of the object in order to engage with it in the absence of tactile confirmation. Conversely, patient D.F.'s successful ability to reach out and grasp objects relies on processes carried out by the visuomotor networks in her dorsal stream. Therefore, we argue that pantomiming the grasp or functional use of an object relies heavily on memory and ventral stream processes.

Neuroimaging evidence from patients with apraxia arising from brain damage further highlight the integral involvement of a fronto-temporo-parietal cortical network in the pantomiming of tool use (Vry et al., 2015). Various researchers share the view that pantomiming tool use is the result of the integration of multiple streams that are essential for specific aspects of higher motor functions (Watson & Buxbaum, 2015). According to TVSH, the ventral stream is critical in selecting actions for tool use given that these actions require the recognition of tools while the dorsal stream is more concerned with the more motoric aspect of these actions (Goodale & Milner, 1992). So, although we have raised some important limitations earlier about pantomiming actions to two-dimensional objects, it does still hold some validity for understanding tool use particularly with regards to action selection. Functional neuroimaging reveals that some of the same brain areas that are engaged in pantomiming tool use are also engaged when participants select actions on real tools (Hermsdörfer et al., 2007). Furthermore, pantomiming tool use is sometimes used clinically to assess if patients might show signs of apraxia (Cassidy, 2016). Several methodological differences between the present investigation and the McNair and Harris (2012) study should be considered. We had participants respond to both the prime and the target as soon as they each appeared while they had participants match stimuli from an array presented at the end of each trial necessitating memory of the prime and target. We had participants respond to both as they appeared because we wanted to invoke motor representations to the primes to the same extent as when people perform motoric actions. Although we did not find facilitation, there have been a number of studies that have asked participants to respond to both the prime and the target as they each appeared and found strong behavioural priming and fMRI adaptation (Chouinard & Goodale, 2009, 2012; Chouinard, Morrissey, Köhler, & Goodale, 2008; Helbig et al., 2006). Therefore, this methodological difference cannot explain why we obtained interference while McNair and Harris (2012) obtained facilitation. In addition, McNair and Harris (2012) had a considerably shorter SOA (276 ms) than the SOAs used in our study. We included longer SOAs to allow for sufficient time for participants to perform pantomiming actions to both stimuli. It should be noted that there are a number of studies that have used an SOA of 2 seconds or more and have successfully shown both behavioural priming and fMRI adaptation (Chouinard & Goodale, 2009, 2012; Chouinard et al., 2008; de Groot, Thomassen, & Hudson, 1986). Therefore, the longer SOAs in the present investigation does not explain why we obtained different results than the McNair and Harris (2012) study either. We are left to conclude that differences in results between studies probably arose from a combination of differences between the computational demands required to perform the tasks and differences in time intervals between seeing the stimuli and making a response.

On a different note, our functional use accuracy data revealed a considerable interference effect when participants had to pantomime tools that had the same grasp but a different functional use (i.e., SGDA condition). Namely, they made more errors pantomiming the functional use action of a target when the preceding prime shared the same grasp. This finding suggests that grasps and functional use actions are not fully dissociable from each other and how an object is grasped is an inherent aspect of how it is functionally used. Alternatively, it is also possible that the functional use action to the prime is encoded as a memory trace irrespective of the grasp and that participants might just get stuck on the functional use action (Zhang, Gordon, Fu, & Santello, 2010). Furthermore, this interference effect was much stronger in the 3-s relative to the 2-s SOA. This suggests that a perceptual analysis of the image is required to select a pantomiming movement and that when this analysis is permitted to occur for a longer period of time then the interference effect will be stronger. Thus, the perceptual or semantic analyses of how we can grasp and functionally use objects may also be tightly coupled with each other.

Another methodological issue worth considering is how does one gauge a pantomiming action to be accurate. Selecting an action for a tool depends on context (Johnson-Frey, 2004). For instance, various tools can have more than one associated use. A spoon can be used for stirring soup, if the soup is too hot, or eating, after the soup cooled down. Nonetheless, for scoring purposes, we predetermined what action was expected for each image based on the criteria established in the McNair & Harris (2012) study. All expected actions were based on what they determined to be the most commonly associated action with each particular stimulus. For example, the expected action for a spoon was for eating and not for stirring. This scoring proved to show acceptable validity and reliability. In terms of validity, the mean ± SD accuracy was 93% ± 7% for grasping and 84% ± 9% for functional use. In terms of reliability, the two independent scorers showed 86% consistency for the grasp data and 79% consistency for the functional use data. Informing participants in the beginning of the testing session could have improved the reliability of our procedures; however, this would have introduced a memory component to the task. We did not opt for this option because we wanted participants to make the movements as natural as possible.

Given the above, this study provides a cautionary tale that images of objects might be processed differently from real objects and that pantomiming actions to them may involve mechanisms that differ from handling real objects. Further investigation that systematically compares these modalities is required.

VII. Tables

Table 1. Absolute reaction times and accuracy for primes and targets

A) 2-second SOA task

Condition	RT (milliseconds)				Grasp Accuracy (%)				Functional Use Accuracy (%)			
	Prime		Target		Prime		Target		Prime		Target	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
DGDA	570.59	112.07	617.80	91.83	90.81	8.13	94.17	6.87	86.58	10.58	90.00	8.11
DGSA	569.05	102.84	613.15	94.82	93.75	6.68	92.08	8.34	85.83	7.27	82.08	11.54
SAME	582.84	103.33	561.25	91.65	91.46	7.35	92.96	4.63	84.91	7.11	85.91	6.66
SGDA	561.70	92.78	609.81	84.79	96.25	5.18	93.33	8.00	86.25	7.91	84.17	6.63
SGSA	555.50	108.69	623.49	95.49	90.42	6.63	89.17	8.67	80.83	9.29	75.42	8.00
B) 3-second SOA task												
DGDA	646.11	118.67	634.48	97.28	95.07	6.13	90.52	8.63	89.06	12.23	87.78	10.08
DGSA	622.95	122.09	624.34	91.37	92.47	5.32	83.26	10.9	90.49	7.45	79.41	5.86
SAME	623.61	114.59	581.45	77.72	93.61	4.67	87.21	7.5	91.94	6.11	84.72	9.12
SGDA	606.07	114.5	613.81	92.5	96.35	6.23	83.33	12.44	95.31	10.02	89.93	10.08
SGSA	594.19	99.75	631.07	87.79	93.13	7.49	79.79	5.55	89.38	5.25	77.24	10.07

Chapter Four

A priming study on naming real tools versus pictures of tools. [2]

Mutindi C. Kithu, Elizabeth J. Saccone, Sheila G. Crewther, Melvyn A. Goodale, Philippe A. Chouinard

I. Prelude

Study 2 examined whether the differences in how 3D real tools compared to 2D images of tools are processed by the brain could influence the naming of tools. This was achieved by using a priming paradigm in which the functional use actions between tool pairs were either the same or different in tools and measuring the reaction times and errors in naming responses of each presented tool. The goal was to adjudicate between two competing hypotheses that the characteristics and volumetric cues presented by real tools would either 1) facilitate in object recognition, and therefore facilitate the naming of the target 3D tool when the prime and target tool shared similar functional actions or 2) have no influence on naming the target 3D tool when the prime and target tool shared similar functional actions.

II. Abstract

There is a growing body of literature demonstrating the relationship between the activation of sensorimotor processes in object recognition. It is unclear, however, if these processes are influenced by the differences in how real (3D) tools and 2-dimensional (2D) images of tools are processed by the brain. Here, we examined if these differences could influence the naming of tools. Participants were presented with a prime stimulus that was either a picture of a tool, or a real tool, followed by a target stimulus that was always a real tool. They were then required to name each tool as they appeared. The functional use action required by the target tool was either the same (i.e., squeegee-paint roller) or different (i.e., knife-whisk) to the prime. We found that the format in which the prime tool was presented (i.e., a picture or real tool) had no influence on the participants' response times to naming the target tool. Furthermore, participants were faster at naming target tools relative to prime tools when the exact same tool was presented as both prime and target. There was no difference in response times to naming the target tool relative to the

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prime when they were different tools, regardless of whether the tools' functional actions were the same or different. We also found more errors in naming target tools relative to the primes when different tools had a different functional action compared to when the same tool was presented as both the prime and the target. Taken together, our results highlight that the functional actions associated with tools do not facilitate or interfere with the recognition of tools for the purposes of naming. The theoretical implications of these results are discussed.

III. Introduction

A large body of literature has investigated the visual perception of objects and their unique influence on cognition and action (Gibson, 1979; Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel, 2012; Valyear et al., 2011). Embodied theories of cognition have provided an approach to understanding the link between human perception and action by proposing that the experiences of the body within our environment form the basis of our cognitive processing (Gallese, 2008; Lakoff & Johnson, 1999). Some examples of this include the activation of F5 canonical neurones in the macaque monkey when the monkey views an object or performs an action towards an object. Moreover, mirror neurons fire when the monkey both performs an action towards an object and when they observe another monkey perform the same action (Decety & Grèzes, 2006; Grèzes, Armony, Rowe, & Passingham, 2003; Rizzolatti & Arbib, 1998). Another example is the concept of "affordance", introduced by Gibson (1979), which posits that the physical properties of a tool influences the way we select actions for that tool (Gibson, 1979). These embodied cognition theories suggest that sensorimotor processes play a role in cognitive processing related to the understanding of actions and objects. This notion is supported by neuroimaging evidence that demonstrates that sensorimotor related areas of the brain are activated when people passively view (Grafton et al., 1997), imagine (Grezes & Decety, 2001), and name actions associated with objects (Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995).

Likewise, behavioural evidence suggests the involvement of action representations in cognitive processes such as object recognition (Helbig et al., 2010; McNair & Harris, 2012). We define *action representations* as the stored information about how we act upon and manipulate objects to perform their function. This involves the observer encoding information about a range of features such as an object's grip and/or gesture information to retrieve knowledge of how the tool is manipulated (Osiurak & Badets, 2017). With this in mind, Helbig et al. (2006) used a priming paradigm to investigate whether the action representations of a tool can facilitate visual object recognition. They presented participants with two pictures of objects that were either congruent (i.e., pliers - nutcracker) or incongruent (i.e., frying pan - banjo) in terms of how the objects are manipulated to perform their typical function (e.g., the snipping of scissors); hereafter called functional action. Participants were then instructed to name both objects in the order of presentation and the authors measured the participants' accuracy in responses. Reaction times (voice onset) were not recorded. The findings revealed that naming accuracy for object pairs that were congruent in their functional actions was greater than for incongruent pairs. Based on this, the authors concluded that action representations of objects can improve the recognition of other objects that involve similar motor interactions. These results demonstrate that processing of how a tool is functionally used can influence its recognition.

A second line of evidence suggesting that action representations can influence object recognition was provided by McNair and Harris (2012), who used a priming paradigm to investigate whether the grasp properties and functional actions associated with a tool can facilitate the subsequent recognition of a different tool with a similar grasp and/or functional use properties. For each trial, they presented participants with a picture of a prime tool followed by a picture of a target tool that either shared or did not share a similar grasp and/or functional action. Participants were then asked to identify the tools they had seen during the trial from an array of different tools presented throughout the study. The authors found that pairs of tools that had the same grasp were identified more accurately than those that differed in their grasp properties. In contrast, pairs of tools that had the same functional actions did not present a similar advantage. Based on these findings, the authors concluded that target tools that are preceded by primes affording a similar grasp can facilitate their recognition because the process of selecting grasps is more readily and automatically assessed than functional use properties. The findings from both McNair and Harris (2012) and Helbig et al. (2006) support embodied theories because they demonstrate that action representations of tools can facilitate the recognition of tools.

In contrast to embodied cognition theories, there is another influential model of visual object processing that posits a distinction between perception and action within the visual system (Goodale, Króliczak, & Westwood, 2005; Goodale & Milner, 1992). According to Goodale and Milner's two visual system hypothesis (TVSH; Goodale & Milner, 1992), the processing of visual information for object recognition (i.e., vision-for-perception) is mediated by the ventral visual stream, which includes visual areas in the occipito-temporal cortex that receives projections from the early visual cortex. On the other hand, the online control of actions such as reaching for and grasping objects (i.e., vision-for-action) is mediated by a functionally and anatomically distinct visual processing stream, the dorsal stream, which includes areas in the posterior parietal cortex that receive projections from the early visual cortex. In recent years, lines of evidence have expanded the two-visual system theory by suggesting an additional division in the posterior parietal cortex (Binkofski & Buxbaum, 2013; Buxbaum & Saffran, 1998; Osiurak & Badets, 2017; Rizzolatti & Matelli, 2003). According to Buxbaum (2001), the ventro-dorsal stream passes through areas in the inferior parietal cortex and mediates the long term retrieval of sensorimotor knowledge about tool manipulation. The more classical dorsal stream or dorso-dorsal stream (Binkofski & Buxbaum, 2013) mediates the online control of actions, which includes areas in the superior parietal cortex (Binkofski & Buxbaum, 2013).

The TVSH is supported by neuropsychological evidence from patients with brain damage to the ventral stream who present deficits in recognising objects but can still reach out and pick up objects of different widths and orientations (Carey et al., 1996; Milner et al., 1991). In contrast, patients with damage to the ventro-dorsal stream exhibit deficits in the ability to retrieve the conceptual knowledge about how we act upon and manipulate objects to perform their function but preserve the ability to name the same objects (Johnson-Frey, 2004). Patients with damage to the dorso-dorsal stream, or the more classical dorsal stream, exhibit deficits in reaching and grasping objects but are still able to recognize and discriminate between these same objects (Goodale et al., 1994; Goodale et al., 1991). Importantly, evidence for the TVSH challenges theories of embodied cognition because it demonstrates a dissociation between perception and action in the human visual system. The processing of visual information for retrieving stored sensorimotor knowledge about how to grasp and use a tool is distinct from recognising it.

The present study concerns the process of recognising an object for the purposes of naming it. In the case of naming an object, an individual has to first recognise the tool from its visual properties, such as its shape and visual texture and then retrieve the semantic representation of the tool in order to recall the lexical label of the tool for it to be named (Rothi et al., 1991). According to the TVSH, this process involves a heavy reliance on the ventral stream, whereas action representations, which are mediated by the dorsal stream, are not essential for this task. Conversely, theories of embodied cognition promote the involvement of action representations in tool identification.

Thus, the two theories make opposing predictions about whether or not action representations of tools are involved in the process of identifying and naming a tool. The TVSH predicts that a tool's action properties do not influence its identification and naming. The TVSH purports that naming a tool is purely a ventral stream process and identifying a tool is not aided by its action related information. Alternatively, embodied cognition theories predict that the action representations of the tools will aid in recognition for the purposes of naming. The current study aimed to test these predictions.

An important consideration is that the majority of studies within this area have employed 2-dimensional (2D) images as experimental stimuli. Yet, in the real world, tools are 3-dimensional that provide differential depth cues and structure. It is relevant that studies within this area also use real tool stimuli to draw inferences about how we process action representations of tools. The processing of real tools differ from 2D pictures of tools in various aspects (Gerhard et al., 2016; Snow et al., 2011; Snow et al., 2014; Squires et al., 2015). For instance, real 3D tools have depth information that provides volumetric cues to the viewer (Riddoch & Humphreys, 2001). Processing this kind of information leads to an understanding of the nature of the object and its position relative to our bodies to afford actions such as grasping and manipulating. Instead, pictures of tools are simply representations of tools displayed on a flat surface. They cannot be manually interacted with in the same way as a real tool. Research has also demonstrated that the differences in how we process real tools compared to pictures of tools can influence the recall of objects (Snow et al., 2014) and performance in the recognition of objects in patients with visual form agnosia (Chainay & Humphreys, 2001).

To further explore this area, Squires et al. (2015) used a priming paradigm to investigate how images of tools primed future actions compared to real tools. They presented participants with a prime tool that was either the same (i.e., spatula-spatula) or different (i.e., spatula-whisk) to the target tool. The prime was either a photograph or real a tool. The target was always a real tool, which participants physically grasped either to transport it to a nearby pad (i.e., grasp to move) or to demonstrate its functional use (i.e., grasp to use). They then measured reaction (i.e., the time to initiate the action) and movement (i.e., duration time of movements) of the manipulation of the target tool. The authors found that participants had faster reaction times to initiate actions in the grasp-to-move compared to the grasp-to-use condition when the same tool was presented as both the prime and target. Importantly, this difference was the same regardless of whether the prime was a picture or a real tool. Based on these findings, the authors concluded that target tools that are preceded by real tool primes that have volumetric cues elicit the same priming effects as pictures of tools. Their results demonstrate that the representations of action related information in pictures versus real tools can facilitate the manipulation of real tools in the same manner. However, it is still unclear as to whether or not pictures and real tools can lead to facilitation in a similar manner when having to name the tools.

The current study investigated whether the action representations of tools can facilitate object recognition for the purposes of naming. And if so, can this effect of facilitation be influenced by whether the preceding tool is a real tool or a picture of a tool? To answer these questions, our study adopted a similar priming paradigm to Squires et al. (2015) except we had participants name both the prime and target tools rather than having them perform an action towards the target tool. We also asked participants to name both the prime and target tool as soon as they appeared – a task that does not require participants to hold information in working memory. We also incorporated a variety of pairs of tools that either shared or did not share the same functional use actions. The tool pairs we used were matched along several variables as determined by a separate pilot study (for more details, see "*Pilot study*"). The pairs either had the same functional action (SA), a different functional action (DA), or were identical (SAME). We also had the prime tool in either a 2D pictorial format or 3D real format to allow us to determine how earlier encounters of the functional action properties of tools (i.e., same vs different functional actions) and also real (3D) vs pictorial (2D picture) format can influence naming responses to subsequent tools.

We had two competing hypotheses with respect to how the representations of action-related information offered by presenting real tools as opposed to pictures of tools had on the naming responses to those tools. The first hypothesis was that if we assumed a more embodied approach to how sensorimotor processes play a role in object processing for the purposes of facilitation in object recognition, then the characteristics of tools would facilitate the naming of the target 3D tool when the prime and target tool shared similar functional actions but were different tools. Namely, this facilitation, or priming, would be indexed by a decrease in reaction times and an increase in accuracy. We should also observe additional influences if the prime was the same format (i.e., a real 3D tool compared to when it was a picture of the same tool). Such a finding, however, would not imply that the dorsal stream is critical but rather that it can aid in object recognition, which is known to be mediated by ventral stream processes. The second hypothesis, in line with the TVSH, assumed a more hermetically sealed role for the ventral stream whereby the similarity of functional actions between the prime and target tool stimuli would have no influence on tool naming. Moreover, this latter hypothesis would predict that the characteristics and volumetric cues presented by real tools would have no influence on tool naming. In other words, it would predict no effect of the format of the prime tool on the naming responses of the target tool.

IV. Method

Overview

Our main experiment employed a priming paradigm where participants named each tool of the pair that was presented. The first tool (prime) was either a picture of a tool, or a real tool, while the second tool (target) was always a real tool. Our choice of real tools as the target stimulus was motivated by our interest in repeating similar measures applied by Squires et al. (2015). The pairs consisted of tools that either had the same functional action (SA) or a different functional action (DA). Lastly, there was a third condition in which the same tool stimulus was presented as both the prime and target (SAME). A pilot study was also performed for the purposes of determining pair stimuli in the main experiment in such a way that would ensure that the different conditions were matched along several extraneous variables (see *Pilot study*).

Pilot study

We conducted a pilot study to collect information about the tool stimuli to be included in the main experiment. This included familiarity (i.e., how familiar participants were with the use of the tool), functional use similarity between stimuli pairs (i.e., how similar the functional use actions were between two tools), and frequency of use in everyday life (i.e., how often the participant reported using the tool). The expected lexical labels for the tools in the main experiment were also based on the outcomes of this pilot study.

Pilot study: Participants

Ten right-handed individuals with reported normal or corrected-to-normal vision participated in the study (6 females, mean age: 24 years, age range: 18 – 27 years). All participants who participated in the pilot study were excluded from the main experiment. All participants provided written informed consent and all procedures were approved by the Human Research Ethics Committee of La Trobe University in accordance with the Declaration of Helsinki. Participants were compensated for their time with gift vouchers.

Pilot study: Stimuli

The stimuli consisted of 16 colored photographs of tools that all shared the same handle (see Fig. 1). The photographs were processed in Adobe Photoshop software (Adobe Systems Incorporated, San Jose, CA, USA). The images were resized to 200×200 pixels at 150 dpi on a 23” Dell monitor with a resolution of 1024 x 768. The picture size was 18.67cm x 10.57cm.

Participants were seated 40 cm away from the computer screen with the stimuli subtending a visual angle of 15°. E-Prime 3.0 (Psychology Software Tools, Pittsburg, PA, USA) was used to present the stimuli and to collect the data. A Shure X2u XLR to USB interface microphone (Shure Distribution UK, Essex, United Kingdom) was used to record participants' responses to naming the tools. Adobe Premiere Pro software (Adobe Systems Incorporated, San Jose, CA, USA) was used to analyze the recordings offline. The stimuli were presented under unlimited viewing conditions that enabled participants to initiate the next trial after each response.

Pilot study: Procedure

Our first objective was to come up with pairs of tools that had similar or dissimilar functional use actions. All possible pair combinations of tools from our stimulus set were presented. Participants viewed photographs of two tools side-by-side and were then asked to rate the degree of similarity between the actions associated with each stimulus in a pair (i.e., "how similar are the actions associated with these two tools?"). They were then instructed to respond using a Likert rating scale between 1 and 5 by pressing numbers on a keyboard (1= not at all, 2= slightly, 3=somewhat, 4= moderately and 5= extremely). The tools were then rank ordered into pairs based on the lowest and highest mean scores across participants. The rank order was used to help define the 'prime' and 'target' tool pairs for the same functional action (SA) and different functional action (DA) conditions in the main experiment, with the former consisting of object pairs with lower scores and the latter consisting of object pairs with higher scores.

Our second objective was to ensure that the prime and target tools matched within and between the SA and DA conditions for, familiarity, frequency of use in everyday life and frequency in which they are used in language. For familiarity ratings, participants were presented with a photograph of each individual tool and asked to rate its familiarity (i.e., "How familiar are you with the use of the tool?"). Namely, they were instructed to respond using a rating scale between 1 and 5 by pressing numbers on a keyboard (1= not at all, 2= slightly, 3=somewhat, 4= moderately and 5= extremely). For frequency of use ratings, participants were presented with a photograph of each tool and asked how frequently they used it (i.e., "How often do you use this tool?"). They were asked to respond using a Likert rating scale of 1 and 5 (1= never, 2= rarely, 3= occasionally, 4= frequently and 5= very frequently). For naming use in everyday language ratings, participants were presented with a photograph of each tool and instructed to name the tool. The lexicon for a particular stimulus was determined by identifying the tool name that was most consistently produced by the participants. These were then matched to names of tools in a database of frequency used in language based on TV and film subtitles (Subtlex-US; American English; subtitle frequencies). After scoring the stimuli in this manner, stimuli comprising the SA and DA conditions for the main experiment were adjusted as needed to ensure the above nuisance variables were matched (see Table 1 for means and standard deviations for controlled factors).

Pilot study: Statistical analysis

The data were analyzed using the Statistical Package for Social Sciences (SPSS) version 23 (IBM Corporation; Armonk, NY, USA) and JASP software version 0.8 (University of Amsterdam, Amsterdam, Netherlands). A 2 x 2 analyses of variance (ANOVA) was performed for each dependent variable (familiarity, frequency of use, naming use in everyday language and naming frequency in a Subtlex database) and Presentation (Prime vs. Target) and Action condition (SA vs. DA) as within-subject factors. Significance was established when the corrected *p* value was below .05.

Bayesian ANOVAs were also performed using the same 2 (Presentation) x 2 (Action Condition) analysis. The Bayesian analyses allowed us to determine if a different statistical approach might converge with the more traditional ANOVA, which would provide more confidence in the findings, and also draw more definite inferences from null results. The Bayes factor we report (BF_{10}) quantified the likelihood that the data support the alternative relative to the null hypothesis as a ratio between the two. We considered a BF_{10} value of 3 or above as substantial evidence in favour of the alternative hypothesis and values of 0.33 or less as substantial evidence in favour of the null hypothesis (Jeffreys, 1998). As per the default specifications for priors used in JASP, the r scales for the Bayesian ANOVA were set to 0.5 and 1.0 for fixed and random effects respectively. Bayesian *t*-tests using a Cauchy prior set at 0.707 was used to evaluate significant main effects and interactions.

Pilot study: Results

In brief, the pairs of tools in both the SA and DA conditions matched in familiarity, frequency of use, naming use in everyday language and naming frequency in the Subtlex database. All means and standard deviations for controlled factors are shown in Table 4.1.

The ANOVA revealed no main effect of Action Condition for familiarity of use ($F_{(1,24)}$ = 0.000, p >.99, $\eta_p^2 < .001$, BF_{10} = 0.353), frequency of use ($F_{(1,24)}$ = 0.298, p = 0.590, η_p^2 = 0.012, BF_{10} = 0.398), naming use in everyday language ($F_{(1,24)}$ = 0.018, p = 0.894, $\eta_p^2 < .001$, BF_{10} = 0.356) and naming frequency in the Subtlex database ($F_{(1,24)} = 0.000$, p >.99, η_p^2, < .001, BF_{10}= 0.353). There was also no main effect of Presentation for familiarity of use ($F_{(1,24)} = 0.009$, p = 0.927, η_p^2 = 0.005, BF_{10} = 0.354), frequency of use ($F_{(1,24)} = 0.429$, p = 0.519, η_p^2 = 0.018, BF_{10} = 0.419), naming use in everyday language ($F_{(1,24)} = 0.018$, p = 0.894, η_p^2 < .001, BF_{10} = 0.356) and naming frequency in the Subtlex database ($F_{(1,24)} = 3.479$, p = 0.074, η_p^2, = 0.127, BF_{10} = 1.379). Finally, there was no Action Condition X Presentation interaction for familiarity of use ($F_{(1,24)} = 0.106$, p = 0.748, η_p^2 = 0.004, BF_{10} = 0.439), frequency of use ($F_{(1,24)} = 0.107$, p = 0.746, η_p^2 = 0.004, BF_{10} = 0.433), naming use in everyday language ($F_{(1,24)} = 0.073$, p = 0.789, η_p^2 = 0.003, BF_{10} = 0.428) and naming frequency in the Subtlex database ($F_{(1,24)} = 0.003$, p = 0.984, η_p^2 = 0.100, BF_{10} = 0.410).

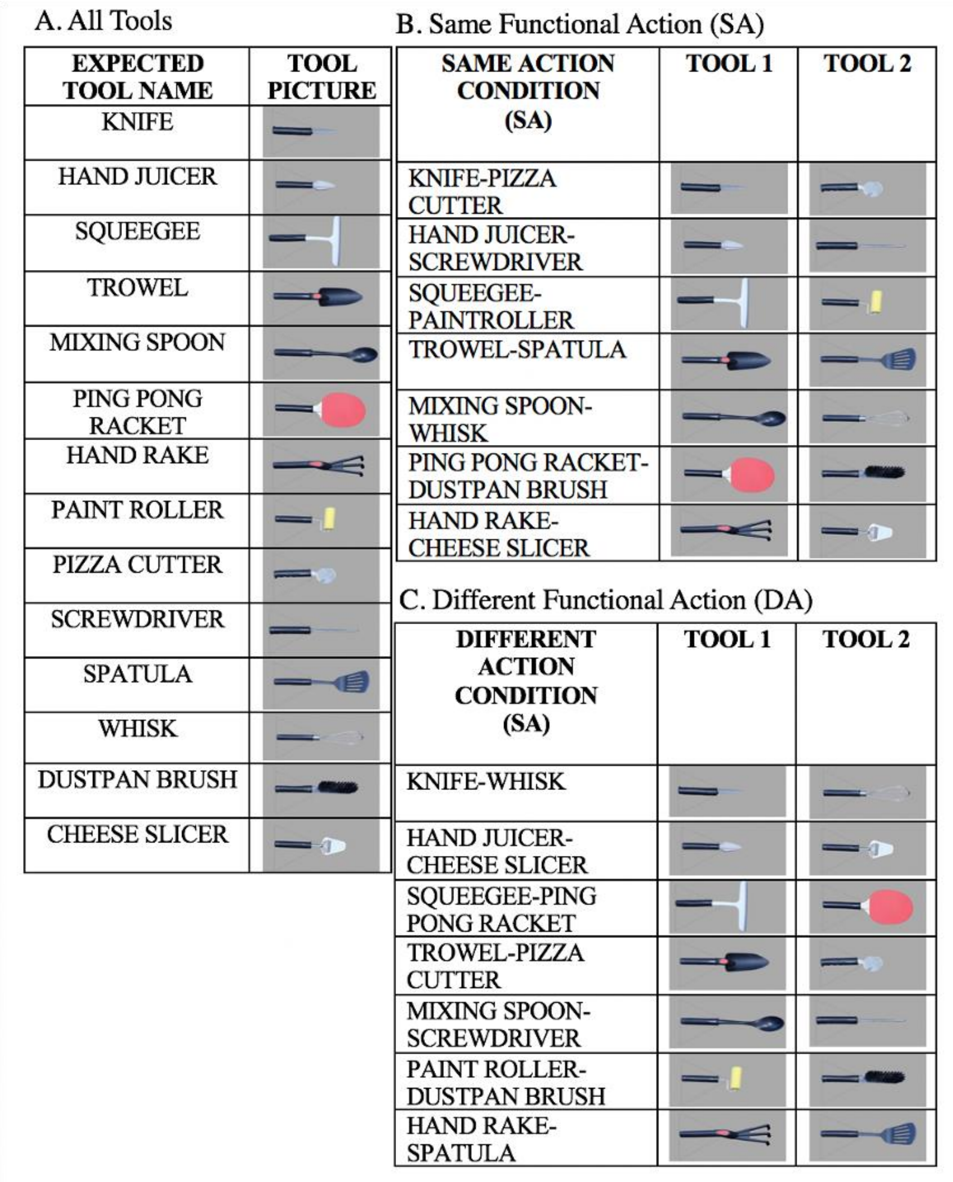
Main experiment: Participants

Sixteen right-handed individuals (11 females, mean age: 26 years, age range: 18-52 years) with reported normal or corrected-to-normal vision participated in the study. Scores from the Edinburgh handedness inventory (Oldfield, 1971; scores could range from -100 to +100) indicated that all participants were strongly right-handed (mean score 85, range: 60-100). All participants provided written informed consent and all procedures were approved by the Human Research Ethics Committee of La Trobe University in accordance with the Declaration of Helsinki. Participants were compensated for their time with gift vouchers.

Main experiment: Stimuli and materials

The stimuli consisted of 14 real tools and 14 pictures of the same tools. The picture stimuli were created by photographing each individual tool placed on top of the LCD (liquid crystal display) monitor used in the study. We then edited the photographs of the tools using Adobe Photoshop software and set the picture of the tools onto a grey background and matched the tool size to fit the exact dimensions as the real tools. All tools had identical handles so that they required the same grasp aperture (see Figure 4.1).

The stimuli were presented as pairs with a 'prime' tool appearing first followed by a 'target' tool. The prime tool stimulus either consisted of a real tool or a picture of a tool. The target tool was always a real tool. The image pairs consisted of tools that either had the same functional action (SA) or a different functional action (DA). Lastly, there was a third condition in which the same tool stimulus was presented as both the prime and target (SAME). The presentation order within the pairs of tools were counterbalanced such that each tool within a pair appeared as often as the prime as it did the target for each condition (e.g., paint roller-squeegee, squeegee-paint roller). For the prime stimuli, each tool appeared the same number of times as a 2D picture as often as it appeared as a real 3D object.



A. All Tools

EXPECTED TOOL NAME	TOOL PICTURE
KNIFE	
HAND JUICER	
SQUEEGEE	
TROWEL	
MIXING SPOON	
PING PONG RACKET	
HAND RAKE	
PAINT ROLLER	
PIZZA CUTTER	
SCREWDRIVER	
SPATULA	
WHISK	
DUSTPAN BRUSH	
CHEESE SLICER	

B. Same Functional Action (SA)

SAME ACTION CONDITION (SA)	TOOL 1	TOOL 2
KNIFE-PIZZA CUTTER		
HAND JUICER-SCREWDRIVER		
SQUEEGEE-PAINTROLLER		
TROWEL-SPATULA		
MIXING SPOON-WHISK		
PING PONG RACKET-DUSTPAN BRUSH		
HAND RAKE-CHEESE SLICER		

C. Different Functional Action (DA)

DIFFERENT ACTION CONDITION (SA)	TOOL 1	TOOL 2
KNIFE-WHISK		
HAND JUICER-CHEESE SLICER		
SQUEEGEE-PING PONG RACKET		
TROWEL-PIZZA CUTTER		
MIXING SPOON-SCREWDRIVER		
PAINT ROLLER-DUSTPAN BRUSH		
HAND RAKE-SPATULA		

Figure 4.1. The tool stimuli. A. All tool stimuli used in the main experiment with the expected tool names as determined by the pilot study. B. Tools used in the same functional action condition (SA). C. Tools used in the different functional action condition (DA). Tools that were the same exemplar presented as a pair (SAME). Each tool shown in TOOL 1 was only paired with the tool in TOOL 2. This meant that the tool pairs were never matched with a pair that was not pre-

determined as sharing or not sharing a functional use action (as determined by the pilot study). All tools had identical handles and similar grasp aperture to ensure that any differences between conditions would be attributable to the functional action of the tool, and not the grasp.

We used E-Prime 3.0 to present the picture stimuli on a 17" Acer LCD monitor screen (Acer Inc., Xizhi, New Taipei, Taiwan) that was positioned horizontally on a turntable apparatus with the screen facing upwards. The monitor had a resolution of 1024 x 768 and the picture stimuli was resized to 2300 x 1300 pixels at 314 dpi. The picture size was approximately 18.75 x 10.56 cm and subtended with visual angles of 15° horizontally and 26° vertically. The real tool stimuli were placed on top of the same LCD monitor.

Participants wore PLATO visual occlusion goggles (Translucent Technologies Inc., Toronto, Ontario, Canada) that allowed us to have millisecond precision timing over the visual access to the stimuli. The goggles transitioned from clear ('shutter open') to occluding ('shutter closed') throughout the experiment. Participants also wore Bose QuietComfort QC35 Noise Cancelling Headphones (Bose Corporation, Framingham, MA, USA) that played white noise throughout the experiment. This masked external noise during stimulus changeovers. Lastly, participants wore a Shure X2u XLR to USB interface microphone that recorded vocal responses.

Figure 4.2. Experiment set up. Participants sat facing the screen with their head held stationary on a chin rest. The visual occlusion goggles were coded to transition from transparent to occluded during the interstimulus interval (ISI) and inter-trial interval (ITI). The prime and target tools were either displayed on the LCD monitor or placed on top of the monitor. Participants wore noise-cancelling headphones that played white noise throughout the experiment and an interface microphone that recorded their verbal responses.

Main Experiment: Training session

The main experiment began with a training session that ensured that participants learned the correct names of each tool used in the study. Correct responses to tool names were defined and justified by the names of tools we established in the pilot study. Evidence from the training data revealed that 86% of participants named all the tools correctly in their first attempt, 92% in their second attempt, and 98% in their third attempt. The experimenter began the training session by reciting the names of each tool from a booklet that had pictures of the tools and their corresponding names printed below it. Thereafter, participants sat in front of a table that had the same real tools laid out in front of them (see Figure 4.3). They were then instructed to name each tool at which the experimenter pointed. Each tool had to be named correctly at least 3 times before the participant could proceed to the main experiment.

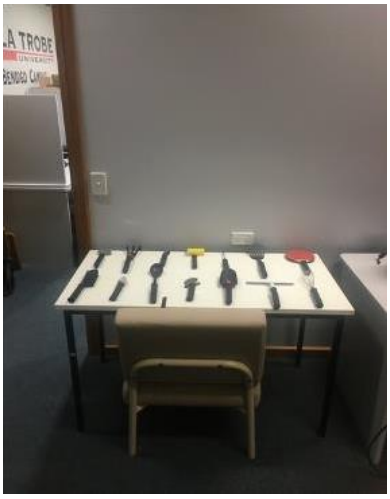


Figure 4.3. Training session set up. Participants sat facing the tools whilst the experimenter pointed to each tool. Thereafter, participant responded by naming each tool.

Main experiment: Procedure

The main experiment procedure included 95 trials. There were 27 trials for each condition (SA, DA and SAME), as well as 14 catch trials, in which participants were instructed to remain silent when a blank screen appeared instead of the target stimulus. We included catch trials to discourage the perseveration of repeating the same tool name twice. Participants sat with their chin resting on a chin rest that was positioned 40 cm above the monitor screen.

As shown in Figure 4.4, each trial began with participants sitting comfortably wearing occluded PLATO goggles. The googles opened and they viewed the prime for 500 ms and then named the tool as quickly and accurately as possible. The goggles then closed for a 3-s interval. The goggles then reopened and participants viewed the target tool for 500 ms and named it. Each trial was then followed by a 5-s inter-trial interval (ITI) in which the goggles remained closed, whilst the experimenter prepared the tools for the following trial. Each stimulus was presented in one of 3 different orientations (50°, 90° and 120°) relative to the centre of the monitor, and the primes and targets were always in the same orientation in a given pair. We presented the stimuli in three different orientations to avoid the predictability that would develop if all the tools were always presented in the same orientation. Figure 4.4 outlines the experimental layout and design employed in the experiment.

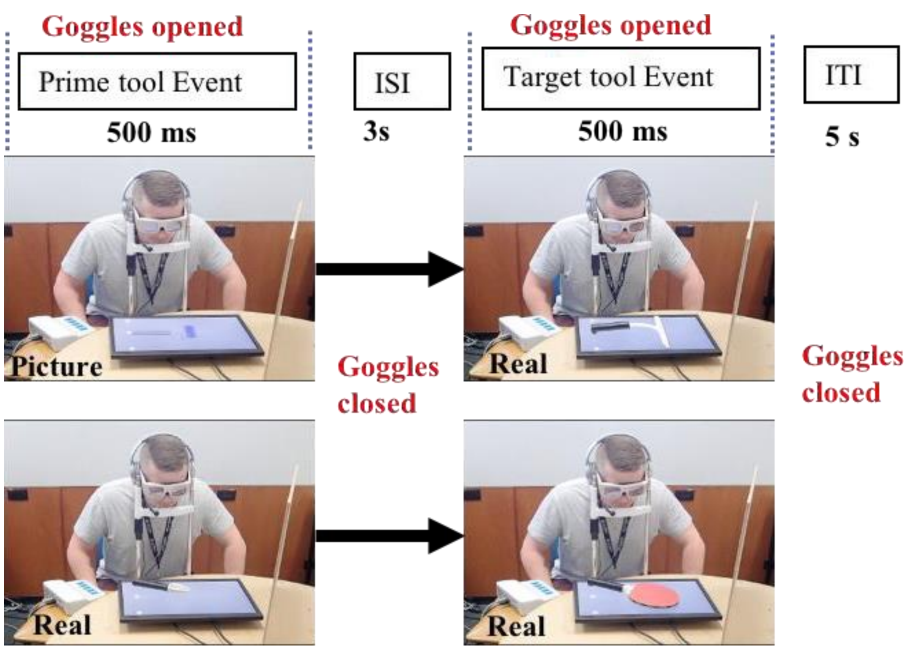


Figure 4.4. Experimental layout and design.The goggles opened for 500 ms to display the prime stimulus, which was either a picture of a tool displayed on the LCD monitor (in the same position as where the real tool would be placed) or a real tool placed on top of the monitor. The participant then named the prime tool from the onset of when the stimulus appeared. The goggles closed during the ISI for 3 s whilst the experimenter substituted the prime stimulus with the target tool. The goggles then re-opened and displayed the target stimulus to which the participants responded to by naming the tool. The trial was completed by the goggles closing again for an ITI of 5 s.

Main experiment: Statistical analyses

The Statistical Package for Social Sciences (SPSS) version 23 (IBM Corporation; Armonk, NY, USA), JASP software version 0.8 (University of Amsterdam, Amsterdam, Netherlands), and MATLAB (MathWorks Inc. Natick, MA, USA) were used to analyse the data. Two dependent variables were analysed. The first was mean reaction time (RT) for accurate naming and the second was number of naming errors. RT was defined as the time between when participants began viewing the tool stimulus to when they began to name the tool. RT was measured using an in-house program written in MATLAB. The naming of each tool was plotted over time in milliseconds from the output of a voice recorder. The beginning of each tool name was selected on the plots manually as the onset of the vocal response occurred, a method that allowed us to exclude any type of vocalisations that were not the name of the tool (i.e., "umm"). The values were identified on a trial-by-trial basis by the same rater (M.C.K). Naming errors were expressed as a percentage. This was calculated as the total number of trials minus the total number of correct responses, divided by the total number of trials multiplied by 100 [((total number of trials- total number of errors) / the total number of trials * 100]. The means and standard deviations for RT and naming errors are also reported.

A 2 x 2 x 3 analyses of variance (ANOVA) were performed on each dependent variable with Presentation (Prime vs. Target), Prime Format (Picture vs. Real) and Action Condition (DA vs. SA vs. SAME) as within-subject factors. To further evaluate significant main effects and interactions, *t*-tests corrected for multiple comparisons using the Bonferroni method were performed. Significance was established when the corrected *p* value was below .05. All reported *p* values represent corrected values unless specified otherwise. Bayesian ANOVAs were also performed with the same 2 (Presentation) x 2 (Prime Format) x 3 (Action Condition) model as the classical ANOVAs and Bayesian *t*-tests were used to further evaluate any significant main effects or interactions. The default prior settings in JASP were used for these Bayesian tests.

V. Results

Main Experiment: Results

Naming RT

In summary, participants were faster at naming target tools relative to prime tools when the exact same tool was presented twice (SAME condition) compared to all the other conditions. In addition, we observed that the format in which the prime tool was presented (i.e., a picture or real tool) had no influence on participants' naming RT of the target tool. Furthermore, RTs for the target tool in the DA and SA conditions did not differ. The results are shown in Figure 4.5 and Table 4.2 provides descriptive statistics.

The ANOVAs demonstrated a main effect of Action Condition ($F_{(2,30)} = 66.113, p =<.001$, $\eta_p^2 = 0.815$, $BF_{10}>1000$). Pairwise comparisons revealed that naming RT in the SAME condition differed from the other two conditions (all $p<.001$, $BF_{10}>1{,}000$) and all other pairwise comparisons did not differ (all $p > .500$, $BF_{10}=0.140$). There was also a main effect of Presentation ($F_{(1,15)} = 66.725$, $p <.001$, $\eta_p^2 = 0.816$, $BF_{10}>1{,}000$). Pairwise comparisons revealed faster naming RT to targets than primes ($p<.001$, $BF_{10}>1{,}000$). An interaction between Action Condition and Presentation was also found ($F_{(2,30)} = 66.26$, $p <.001$, $\eta_p^2 = 0.815$, $BF_{10}>1{,}000$). This interaction was driven by faster naming RT to the target tool relative to the prime in the SAME condition compared to the other two conditions (all $p<.001$, $BF_{10}>1{,}000$). All other pairwise comparisons did not differ (all $p > .500$, $BF_{10}=0.140$). No statistical differences in RT were found between action conditions for the prime stimuli, regardless of the format of the prime tool (i.e., a real or pictorial format: all $p>.958$, $BF_{10}=1.293$).

There was no main effect of Prime Format ($F_{(1,15)} = 2.765$, $p =0.117$ $\eta_p^2 = 0.156$, $BF_{10}=0.293$), nor was there an interaction between Prime Format and Action Condition ($F_{(2,30)} = 0.333$, $p =0.719$ $\eta_p^2 = 0.022$, $BF_{10}=0.108$) or between Prime Format and Presentation ($F_{(1,15)} = 1.776$, $p =0.202$ $\eta_p^2 = 0.106$, $BF_{10}=0.197$). There was also no three way interaction between Prime Format, Presentation, and Condition ($F_{(2,30)} = 0.021$, $p =0.979$ $\eta_p^2 = 0.001$, $BF_{10}=0.165$).

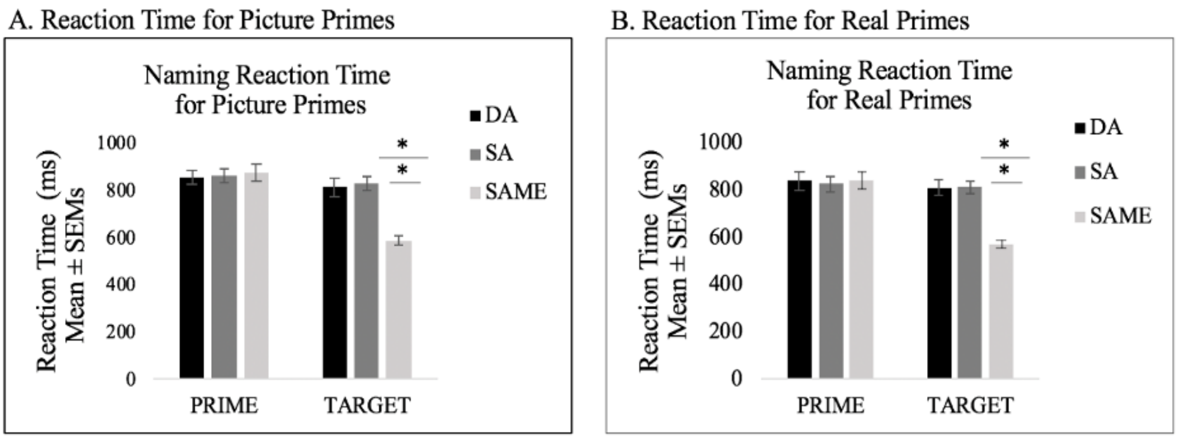


Figure 4.5. Naming reaction time (RT) results. The graphs display the mean ± SEM RT naming scores.

A. Naming RTs for trials in the DA, SA and SAME condition with pictures of tools as the prime tool. B. Naming RTs for trials in the DA, SA and SAME condition with real tools as the prime tool. An interaction between Action Condition, and Presentation was found. Asterisks (*) denotes a significant difference with the SAME condition compared to all the other conditions after correcting for multiple comparisons ($p < 0.01$).

Naming errors

Figure 4.6 shows the mean percentage of naming errors of the prime and target tools while Table 4.2 provides all other descriptive statistics. In brief, we observed that individuals made more errors in naming target tools relative to primes. Furthermore, participants made more naming errors in the DA condition compared to the SAME condition for target tools only.
The ANOVAs demonstrated main effects of Presentation ($F_{(1,15)} = 7.275$, $p = 0.017$, $\eta_p^2 = 0.327$) and Action Condition ($F_{(2,30)} = 3.833$, $p = 0.033$, $\eta_p^2 = 0.204$, $BF_{10} = 3.216$). Pairwise comparisons indicated that there were more naming errors to the target tools overall compared to primes ($p = 0.017$, $BF_{10} = 1.038$) and less errors in the SAME condition compared to the DA condition ($p = 0.011$, $BF_{10} = 4.781$). All other pairwise comparisons did not differ (all $p > 0.1$). An interaction between Presentation and Action Condition was also found ($F_{(2,30)} = 4.157$, $p = 0.025$, $\eta_p^2 = 0.217$). This interaction was driven by more naming errors to the target tools relative to the prime ($p = 0.017$, $BF_{10} = 1.038$), with naming errors in the SAME condition differing to all other conditions (DA vs. SAME: $p = 0.005$, $BF_{10} = 4.781$ and SA vs. SAME: $p = 0.022$, $BF_{10} = 2.792$). All other pairwise comparisons did not differ (all $p > 0.99$). There was no main effect of Prime Format ($F_{(1,15)} = 3.182$, $p = 0.095$ $\eta_p^2 = 0.175$) nor was there an interaction between Prime Format and Action Condition ($F_{(2,30)} = 0.427$, $p = 0.656$ $\eta_p^2 = 0.028$, $BF_{10} = 0.141$) and Prime Format and Presentation ($F_{(1,15)} = 0.082$, $p = 0.779$ $\eta_p^2 = 0.005$, $BF_{10} = 0.259$). There was also no three way interaction found between Prime Format, Presentation, and Condition ($F_{(2,30)} = 1.267$, $p = 0.296$ $\eta_p^2 = 0.078$, $BF_{10} = 0.397$).

Contrary to the outcomes of the classical ANOVA, the Bayesian ANOVA revealed inconclusive support for or against the main effects of Presentation ($BF_{10} = 0.953$) and Prime Format ($BF_{10} = 0.472$) and the interaction between Presentation, and Action Condition ($BF_{10}=2.615$).

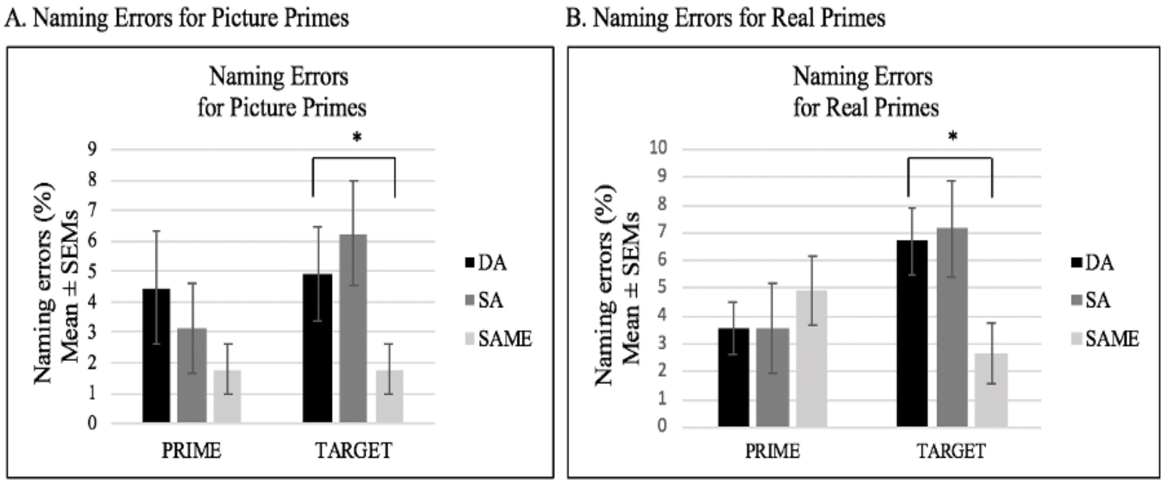


Figure 4.6. Naming error results.The graphs display the mean ± SEM percentage of naming errors.

A. Naming errors for trials in the DA, SA and SAME condition with pictures of tools as the prime tool. B. Naming errors for trials in the DA, SA and SAME condition with real tools as the prime tool. A main effect of Action Condition was found. Asterisks (*) denote a significant difference with the SAME condition compared to the DA condition after correcting for multiple comparisons (*p*=0.011).

VI. Discussion

The present study investigated whether the action representations between tools can facilitate object recognition for the purposes of naming. Specifically, we examined if this effect of facilitation could be influenced by whether the preceding tool was a real tool or a picture of a tool. We aimed to test two competing hypotheses. The first was that if we assumed a more embodied approach to how sensorimotor processes play a role in object processing for the purposes of facilitation in object recognition, then the characteristics of tools would facilitate the naming of the target 3D tool when the prime and target tool shared similar functional actions but are different tools. Furthermore, we should also observe additional influences if the prime was the same format (i.e., a real 3D tool compared to when it was a picture of the same tool). The alternative hypothesis in line with the TVSH, assumed a more hermetical role for the ventral stream whereby the similarity of functional actions between the prime and target tool stimuli would have no influence on tool naming. This meant that we would observe no influence of the characteristics and volumetric cues presented by real tools on tool naming. Our results supported the second hypothesis.

Contrary to our first hypothesis, our results showed that the functional action similarity between different tools did not affect the naming of the target tool relative to the prime. The reason for this could be that understanding how objects are manipulated requires more conceptual processing than what is required for their identification. This suggests that the perceptual processing of the tool's physical properties that enable its identification is dissociable from the processes involved in accessing the knowledge of how that tool is used – as is predicted by the TVSH. This dissociation in processing mechanisms has been demonstrated in neuropsychological studies of some patients with ideomotor apraxia arising from brain damage. Patients with damage to areas within parietal areas surrounding the intraparietal sulcus have shown preservation of their ability to recognise and name objects but have deficits in the recognition of object-related actions such as the knowledge about an object's function (Buxbaum, 2001; Heilman, Rothi, & Valenstein, 1982).

This dissociation has also been demonstrated in neurologically healthy subjects when investigating the role of functional-use gestures in object identification. Bub and his colleagues (Bub et al., 2003) had participants learn to perform different tool-related gestures in response to different colours. Then, in each trial, participants viewed a picture of a tool as well as a colour cue. They performed the colour-cued gesture, and responses were faster when the tool's functional use action was congruent rather than incongruent with that gesture. That is, the objects' functional use properties influenced performance on the gesturing task – but this effect was not demonstrated when participants had to name the objects instead. The authors concluded that the retrieval of functional knowledge about the tool was not present when having to name it, and that the motor representations associated with the objects did not play a role in object identification. Our study, together with Bub et al.'s findings, suggest that processes involved in the functional knowledge of tools are not implicated in object recognition for the purposes of naming. Note that these findings are in line with a recent paper by Saccone, Thomas, and Nicholls (2020), which also showed that performance for tool naming was not influenced by the tools' action-relevant properties.

In addition, patients with damage to areas within parietal areas have also shown their preserved ability to manipulate objects but have differential deficits in the knowledge of their function (Buxbaum, 2001; Goldenberg, 2009; Heilman et al., 1982). This dissociation has also been demonstrated in neurologically healthy subjects when investigating the role of processing motor information for retrieving knowledge about an object's function compared to an object's manipulation. Garcea and Mahon (2012) presented participants with object stimuli that were either in a word or pictorial format. They then examined how quickly participants could name which object out of a pair matched a third object on either manipulation (i.e., the action deployed upon the object; referred to in our study as functional action) or function. They defined function as the purpose and intended goal of using the object (e.g., the goal of cutting a piece of paper can be done with a pair of scissors or a knife). They found that participants were slower at naming matching objects that shared manipulation attributes in word stimuli compared to pictorial stimuli. Conversely, participants were faster at naming responses to matching objects that shared function attributes in word stimuli compared to pictorial stimuli. The authors concluded that the differences in functional compared to manipulation matching with word compared to picture stimuli show that these types of object knowledge are dissociable. Furthermore, this dissociation is highlighted by how the processes involved in retrieving manipulation knowledge about an object is not necessary for retrieving information about an object's function, especially when processing tools in a word format (that provide less representations of action related information than viewing a picture of a tool). Our study, together with Garcea et al.'s findings suggest that processes involved in retrieving knowledge about how an object is manipulated does not aid in object recognition for the purposes of naming. More importantly, these results challenge theories of embodied cognition as they demonstrate that the processing of visual information for retrieving stored sensorimotor knowledge about how a tool is manipulated does not aid in object recognition, specifically for the successful naming of tools. In line with our second hypothesis, our findings instead support the TVSH, which purports that identifying a tool is driven by ventral-stream processes and is not aided by the processing of the action related information of the tool.

We note that these ideas and our findings contrast the study by Helbig et al. (2006) and McNair and Harris (2012). Their findings support theories of embodied cognition by showing that action representations of objects can improve the recognition of other objects that involve similar motor interactions. One thing to note is that the differences in the Helbig et al. (2006) and the current study's findings may be due to differences in measurements and task requirements. For example, the experiment implemented by Helbig et al. (2006) also involved participants naming the prime and target stimuli at the end of each trial. This task required the use of working memory, and therefore the retrieval of the stored motor information of the target tools may have been used as part of a recall strategy to recognise attributes that were similar to the prime tool. Alternatively, we measured participants errors and response times to naming tools in quick succession. We propose that the task demands involved in our study did not require participants to maintain any information in working memory of what they saw as a target to complete the task. Instead, they responded to both the prime and the target as soon as they each appeared. In this view, the differences between our findings and Helbig et al.'s suggest that working memory mechanisms can be a factor that can aid in the perceptual analysis of conceptual (i.e., motor-related) knowledge between tool pairs. Another methodological difference worth considering is that all the tools in our study had identical handles so that they required the same grasp aperture. We did not want participants responses to be influenced by characteristics based on grasping styles rather than their functional actions.

It should also be noted that Helbig et al. had a shorter ISI (167 ms) than the ISI used in our study. We included a longer ISI as this was the length of time required for the experimenter to change over the prime stimuli to the target stimuli, when real tools rather than pictures are used. It could be argued that this duration is too long to induce priming effects; however, a number of studies including those from co-authors Chouinard and Goodale have used an ISI of 2 to 3 seconds and have demonstrated strong behavioural priming and fMRI adaptation (Huettel & McCarthy, 2000; Chouinard & Goodale, 2009; Chouinard & Goodale, 2012; Chouinard, Morrissey, Köhler, & Goodale, 2008; de Groot, Thomassen, & Hudson, 1986). Thus, the longer ISI in our experiment cannot account for the lack of facilitation in the condition where the prime and target tool shared the same functional action but were different tools. We are left to conclude that the differences in the results between studies may have been due to differential task demands.

Aside from the functional action conditions, our participants' naming performance for target tools did not differ according to the 2D or 3D format of the prime. These findings are surprising in the context of other studies that have shown differences in processing real versus pictures of objects. For example, real tools have elicited stronger viewing preferences than pictorial versions of the same objects in 7-9 month old infants (Gerhard et al., 2016). Real tools have produced better recall and recognition performance for real tools than matched colour photos of the same items (Snow et al., 2014) and can elicit differential repetition-related changes in haemodynamic responses (Snow et al., 2011). On the other hand, our findings agree with Squires et al. (2015) who also demonstrated a similar effect in relation to how the realness of a prime tool compared to a picture of a tool provides no difference in performing a grasp-to-use action on a given tool. One consideration is that in their study, participants were merely viewing the prime tool, and the volumetric properties associated with passively viewing the preceding tool was not sufficient to invoke the action representations of the subsequent tool. Our findings suggest that even though the realness of tools must provide depth cues that may influence the way we act upon them, the processing required to identify the tool is not influenced by these characteristics. We propose that the computations required for the retrieval of the semantic representations of a tool for it to be named are not influenced by the format in which the tool is presented. This means that the visual processing of the volumetric cues provided by real tools compared to pictures of tools do not differ in how they contribute to object identification. Our results support the notion that the visual processing of tools for their identification is mediated by ventral stream processes, as the higher-level knowledge about the realness of the tool does not influence how quickly the tool is named.

Given the above, our study challenges theories of embodied cognition that propose that cognitive operations, such as identifying objects, depend on sensorimotor processes. Our results demonstrate that the representation of action related information of tools does not influence naming, regardless of whether subsequently named tools share functional use properties or if they are presented in a real or pictorial format. According to the TVSH (Goodale & Milner, 1992), the findings from this investigation highlight that the perceptual processing involved in naming tools is predominantly driven by ventral stream processes, regardless of the objects' affordances. Needless to say, sensorimotor processes have been shown to be involved in the visual processing of objects for other purposes (Almeida, Mahon, & Caramazza, 2010; Chen et al., 2018).

VII. Tables

Table 2. Pilot study means and standard deviations for controlled factors

Condition																	
		Similarity scores (rating scale between 1 and 5)		Familiarity scores (rating scale between 1 and 5)				Frequency of use in everyday life (rating scale between 1 and 5)				Naming use in everyday language (binary score of 1=correct, 0=incorrect)				Naming frequency in the Subtlex database	
(A) Same function																	
Tool 1	Tool 2			Tool 1		Tool 2		Tool 1		Tool 2		Tool 1		Tool 2		Tool 1	Tool 2
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	F	F
Paint roller	Squeegee	4.95	0.00	4.4	1.07	4.4	0.70	1.9	0.99	2.7	1.06	0.8	0.42	0.5	0.53	293	14
Spatula	Trowel	4.25	1.32	4.9	0.32	4.6	0.52	4.6	0.52	2.6	0.84	0.9	0.32	0.5	0.53	56	349
Hand juicer	Screw driver	4.2	1.45	2.4	1.17	4.5	1.27	1.5	0.71	3	1.05	0.4	0.52	1	0.00	20	128
Knife	Pizza cutter	3.35	1.14	4.5	1.27	4.7	0.67	1.5	0.85	2.9	0.99	1	0.00	1	0.00	2387	59
Cheese slicer	Hand rake	3.15	1.45	3.8	1.23	2.9	1.29	2.1	1.20	1.9	0.57	0.2	0.42	0.5	0.52	6	152

Mixing spoon	Whisk	2.4	1.16	5	0.00	4.9	0.32	4.4	0.84	3.3	0.95	0.9	0.32	1	0.00	388	29
Dust pan brush	Ping pong racket	2.35	1.43	4.9	0.32	4.8	0.42	3.9	1.37	2.6	1.07	0.9	0.43	0.7	0.42	722	191
(B) Different function																	
Knife	Whisk	1.45	0.71	4.5	1.27	4.9	0.32	4.5	0.85	3.3	0.95	1	0.00	1	0.00	2387	29
Hand rake	Spatula	2.75	1.37	2.9	1.29	4.9	0.32	1.9	0.57	4.6	0.52	0.5	0.52	0.9	0.32	152	56
Cheese slicer	Hand juicer	1.3	0.42	3.8	1.23	2.4	1.17	2.1	1.20	1.5	0.71	0.2	0.42	0.4	0.52	6	20
Ping pong racket	Squeegee	1.6	0.42	4.8	0.42	4.4	0.70	2.6	1.07	2.7	1.06	0.9	0.42	0.5	0.53	191	14
Dust pan brush	Paint roller	2.9	1.66	4.9	0.32	4.4	1.07	3.9	1.37	1.9	0.99	0.9	0.43	0.8	0.42	722	293
Pizza cutter	Trowel	2.8	1.10	4.7	0.67	4.6	0.52	2.9	0.99	2.6	0.84	1	0.00	0.5	0.53	59	349
Mixing spoon	Screw driver	1.4	0.42	5	0.00	4.5	1.27	4.4	0.84	3	1.05	0.9	0.32	1	0.00	388	128

Table 3. Reactions times and errors for primes and targets.

Condition	RT (ms)				Naming error (%)			
	Prime		Target		Prime		Target	
	M	SD	M	SD	M	SD	M	SD
(A) Picture Primes								
DA	858.49	120.95	813.43	150.01	4.46	7.32	4.91	6.24
SA	864.25	124.01	828 .55	122.66	3.13	5.81	6.25	6.84
SAME	875.77	141.11	588.60	82.29	1.79	3.19	1.79	3.19
(B) Real Primes								
DA	840.93	156.75	809.84	131.20	3.57	3.69	6.70	4.86
SA	825.86	144.59	813.16	113.37	3.57	6.39	7.14	6.90
SAME	841.41	150.54	572.34	76.22	4.91	5.03	2.68	1.62

Chapter Five

The initiation of actions based on the functional use similarities of tools: A priming study with primes presented as real tools or in a pictorial format[3]

Mutindi C. Kithu, Elizabeth J. Saccone, Sheila G. Crewther, Melvyn A. Goodale, Philippe A. Chouinard

I. Prelude

Study 3 examined how manipulating objects to perform their function is influenced by whether the preceding tool is a 3D real tool compared to a 2D image of a tool. This was achieved by using a priming paradigm in which the functional use actions between tool pairs were either the same or different, and a prime tool that was in either a real or pictorial format followed target tool that was always a real tool. The reaction times, number of correct functional use actions and how quickly the functional use actions towards target tools were measured. I hypothesised that the initiation of functional use actions and speed of movement times toward the target tools would be faster if the functional use actions between tool pairs were the same compared to if they were different. Furthermore, I hypothesised that the similarities in 3D structure and the potential for physical interaction of a prime tool that was real would facilitate the initiation of functional use actions and movement times towards the real target tool more than a prime tool that was in pictorial format.

II. Abstract

Tools are a unique form of manipulable objects as they are associated with a particular way in which we manipulate them to perform their function. However, real 3D tools unlike 2D pictures of tools provide the potential for physical interaction. The question then arises as to whether there may be any differences in how real tools compared to pictures of tools influence how we perform actions towards tools with similar functional use properties. We presented participants with a prime stimulus that was either a picture of a tool, or a real tool, followed by a target stimulus that was always a real tool. Participants were asked to passively view the prime tool, and physically grasp and perform a functional action with the target tool. The functional use action required by the target tool was either the same (i.e., squeegee-paint roller) or different (i.e., knife-whisk) to the

[3]This manuscript is in preparation to submit to Experimental Brain Research.

prime. We found that participants were faster at initiating functional use actions to the target tool when the prime tool was a picture of a tool compared to a real tool. However, there were no differences in response times to initiating functional use actions when the two stimuli differed- regardless of whether the tools' functional actions were the same or different. Furthermore, the movement times in participants' actions were faster when the prime and target tool were the same exemplar compared to when the tools shared the same functional action, although this did not differ with prime format. No differences in participants' errors were found between conditions irrespective of prime format. Taken together, our findings highlight that pictures of tools influence action related responses as much as real tools. Moreover, the computations required to process the similarities in functional use actions between tools are not as effective when having to perceptually analyse tools in succession. The theoretical implications of these results are discussed.

III. Introduction

Humans created 3-dimensional (3D) real tools before 2-dimensional (2D) photographic representations of the same tools were created. As such, humans have evolved to interact within environments that involve real tools as opposed to images. According to the more "classical" theories of embodied cognition, tool use is governed by the body and how it interacts within the laws of the physical world (Grezes & Decety, 2001; Lakoff & Johnson, 1999; Vainio, Symes, Ellis, Tucker, & Ottoboni, 2008). These ideas assume that the physical properties of tools activate sensorimotor processes which contribute to how we apply the abstract knowledge needed to perform a given physical action (Osiurak & Badets, 2017; Osiurak, Jarry, & Le Gall, 2010). One important aspect of how tools are processed is that they are strongly associated with the potential for physical interaction. Gibson (1979) coined this term as "affordances", which is the idea that various physical properties of objects within our environment influence the way we select an action to apply to that particular object (Gibson, 1979). For example, the orientation, shape, size and position of the tool relative to the observer can influence the actions directed at a tool (Chainay et al., 2011; Chen et al., 2018; Cuijpers et al., 2004; Witt et al., 2005). Moreover, the context in which the tool is used also influences the way we select an action to apply to a particular tool (Osiurak & Badets, 2016).

The processing of real tools compared to pictures of tools differ in various aspects, many of which could influence affordance effects. Firstly, real tools provide differential shape and depth cues. For instance, how we perceive the 3D geometrical structure and depth of real tools is caused by how the brain receives information from both our eyes and uses the viewpoint at which this information is being received to extract depth information of the tool (known as binocular disparity; Blake & Wilson, 2011; Makris, Grant, Hadar, & Yarrow, 2013). Conversely, a picture of a tool lacks these depth cues and is therefore a projection on a surface that is perceived as being flat. Secondly, real tools and pictures of tools utilise different spatial frames of reference. For example, a picture of a tool unlike real tools cannot be grasped or manipulated. Though we can imagine using it, the spatial information about different parts of the stimulus is encoded relative to the entire scene (i.e., allocentric frame of reference) as opposed to relative to oneself if close enough to be handled (i.e., egocentric frame of reference Goodale & Haffenden, 1998). Real tools have a 3D geometrical structure. The physical structure of the object relative to one's body dictates the way one configures their hand to accommodate the geometrical properties of an object in real time, and so assumes a more egocentric frame of reference for immediate use (Goodale & Haffenden, 1998). In addition, research has also demonstrated that the differences in the processing of real tools compared to pictures of tools can 1) elicit differential neural activation (Snow et al., 2011), 2) influence the recall and recognition performance of objects (Snow et al., 2014), and 3) influence the recognition performance of objects in patients with visual form agnosia (Chainay & Humphreys, 2001).

Evidence from neuroimaging data has shown that neural networks within parietal, fronto-parietal and temporal regions of the brain are involved in the visual processing of tool information (Binkofski & Buxbaum, 2013; Chao & Martin, 2000; Chouinard & Goodale, 2010; Valyear et al., 2006). More importantly, these areas have been shown to subserve distinct neural mechanisms that involve the successful performance of visually guided actions. For example, the processes involved in object recognition such as using stored information to construct a detailed perceptual representation of objects is mediated by areas in the inferior temporal cortex, which receives projections from the early visual cortex (also known as the ventral stream; Goodale et al., 1991). The processes involved in the long term retrieval of knowledge about how we perform the functional action of a tool is mediated by areas in the inferior parietal cortex (also known as the ventro-dorsal stream; Buxbaum & Kalénine, 2010; Corbetta & Shulman, 2002; de Schotten et al., 2005; Garcea & Buxbaum, 2019), whereas, the processes involved in the online control of actions, such as using the physical structure of an object relative to one's body to reach out and grasp an object, is mediated by areas in the superior parietal cortex, which receives projections from the early visual cortex (also known as the dorso-dorsal stream; Goodale et al., 1994). This distinction between the division of labor within the visual system is supported by various lines of evidence including those from neuroimaging, neuropsychology, neurophysiology and behavioural studies (Binkofski & Buxbaum, 2013; Budisavljevic et al., 2018; Buxbaum, 2001; Milner & Goodale, 2008;

Rizzolatti & Matelli, 2003). Nonetheless, the integration of these streams is essential for the appropriate use of tools.

Note that the perceptual analysis of a picture of a tool still activates the action related representations of what the tool is used for (i.e., how we know what a hammer is used for when we identify a hammer). Therefore, pictures of tools may be more likely processed by ventral and ventro-dorsal stream structures as the online control of actions are not needed to identify the images. In this view, an important aspect of tool processing is the ability to link the stored knowledge about how we manipulate a tool to perform a tool's function. A unique characteristic about tools is that they can share the same grasp and/or functional action with a different tool that is used for different purposes. For example, a paint roller can share the same functional action as a squeegee, yet the paint roller is used for painting and the squeegee is used for cleaning windows. Yet, both these tools still share a similar way in which you would configure your hand to grasp the tool. As a result, these similarities and differences in action related representations between tools reinforce the complex nature of the integration of neural networks required to accomplish the processing of tool related actions, especially in relation to an individual's goals and intentions.

The present study concerns how the processing of functional use attributes of tools in pictures compared to real tools can influence how we grasp a tool with the intention to perform the functional action towards subsequent tools. Behavioural studies using real tool stimuli have demonstrated how grasping objects are strongly associated with various action plans. For example, grasping a tool based on its physical properties (i.e., the handle shape or orientation) may differ from grasping a tool based on intending to use it from the knowledge of its functional action (Frey, 2007; Marangon, Kubiak, & Króliczak, 2016; Valyear et al., 2011). A line of evidence demonstrating this effect is the study conducted by Squires et al. (2015) who used a priming paradigm to investigate how images of tools compared to real tools can facilitate grasping a subsequent tool based on its physical properties compared to grasping a tool based on using it for its functional action. They presented participants with a prime followed by a target tool, in which the prime tool was either the same (i.e., spatula-spatula) or different (i.e., spatula-whisk) photograph or real object to the target tool. This was then followed by a real target tool, with which participants physically grasped either to transport it to a nearby pad (i.e., grasp to move) or to demonstrate its functional use (i.e., grasp to use). The authors found that participants were faster to initiate grasping actions towards the target tools when they had to grasp to move the tool rather than grasp to use it. More importantly they found that both pictures of tools and real tools primed action responses equally. Based on these findings, the authors concluded that priming effects are facilitated by tools that are preceded by pictorial primes, even if there is a lack of physical cues that reflect and afford the physical grasp and actions of real primes.

Squires et al.'s interpretation suggests that grasping a tool to perform its use (i.e., grasp to use) compared to grasping it based on its physical properties (i.e., to move it) requires more planning, and therefore reflects the differences in reaction times to initiating grasping actions. However, one thing to note is that the study by Squires only had pairs of tools that were the same (i.e., spatula-spatula) or different (i.e., spatula-whisk). They did not include tools that afforded the same physical grasp and functional actions but were tools with different defined identities (i.e., squeegee-paint roller). Thus, Squires et al. were not able to answer the question as to whether the mechanisms that contribute to the planning of actions and the processing of functional actions between tools that differ in identity is influenced by whether it is primed by a tool that is in a real or pictorial format. This raises the question that if the corresponding motor plans related to grasping actions can be facilitated by prior exposure to a tool that affords similar actions (i.e., the same tool), then can the functional use properties of tools that activate similar corresponding motor plans but are different tools facilitate how we grasp a tool to perform its functional action? And if so, is this more effective if the preceding tool is a real tool compared to a picture of a tool?. The current study adopted a similar priming paradigm as the one used by Squires et al. (2015) to investigate the differences in how the processing of the functional actions of real tools compared to pictures of tools influence the physical manipulation of real tools. We modelled our design to Squires et al. (2015) in a way that we had the prime tool in either a 2D pictorial format or 3D real format to allow us to determine how earlier encounters of the functional use action properties of tools (i.e., same vs different functional actions) and also real (3D) vs pictorial (2D picture) format can influence manual responses to subsequent tools. We also extended their original design by incorporating more tool pairs that either had the same functional action (SA), a different functional action (DA), or were identical (SAME), and only asked participants to grasp the tool to perform the functional use actions of target tools.

In addition to this, our recently published paper by the current authors (Kithu, Saccone, Crewther, Goodale, & Chouinard, 2021) used a similar priming paradigm and design as the present study in the context of tool naming. Much like the present study, Kithu et al. (2021) incorporated tool pairs that either had the same functional action (SA), a different functional action (DA), or were identical (SAME), and had a prime tool that was in either real or pictorial format. The different experimental task was that participants were asked to name the prime and target tool rather than physically manipulate the real target tool. The study found that priming the functional use attributes between tool pairs did not influence naming responses. Furthermore, this was not influenced by whether the prime tool was a real tool or a picture of a tool. Based on the findings, it was concluded that understanding how objects are manipulated requires more conceptual processing than what is required for their identification. Therefore, the perceptual processing of the tool's physical properties that enable its identification could be dissociable from the processes involved in accessing the knowledge of how that tool is used.

With respect to the present study, we assumed that participants require the knowledge of how each tool is used in order to successfully manipulate them and so hypothesised that the affordances elicited by the prime tools would influence the initiation of functional use actions to the target tool if the tool pairs that were different in identity but shared the same functional action (i.e., SA condition) compared to tools that were different in identity and had a different functional action (i.e., DA condition). Furthermore, the similarities in 3D structure and the potential for physical interaction with a prime tool that is real was expected to facilitate the initiation of functional use actions towards the target tool more than a prime tool that was in pictorial format. Namely, this would be indexed by a decrease in reaction times, movement times and errors. We could then conclude that the faster response times to initiating and performing actions towards tools that share the same functional use attributes, but different defined identities is a consequence of the affordances that real tool may invoke.

IV. Method

Overview

Our experiment employed a priming paradigm where participants were presented with two tools in succession. The first tool (prime) was either a picture of a tool, or a real tool, while the second tool (target) was always a real tool. Participants were asked to view the prime tool, and physically grasp and perform a functional action with the target tool. The pairs consisted of tools that either had the same functional action (SA) or a different functional action (DA). Lastly there was a third condition in which the same tool stimulus was presented as both the prime and target (SAME). The stimulus pairs were previously used, validated and matched along several variables in a naming study published elsewhere (Kithu, Saccone, Crewther, Goodale, & Chouinard, 2021). These variables included familiarity (i.e., how familiar participants were with the use of the tool) and frequency of use in everyday life (i.e., how often the participant reported using the tool). The expected functional actions and lexical labels for the tools in the experiment were also based on the outcomes of this pilot study. In selecting object pairs, we also ensured that functional use similarity between stimuli pairs (i.e., how similar the functional use actions were between two tools) was as different and as similar as possible in the DA and SA conditions, respectively (see Fig. 5.2).

Participants

Twenty-one right-handed participants (16 females, mean age: 25 years, age range: 19-40 years) with reported normal or corrected-to-normal vision participated in the study. Scores from the Edinburgh Handedness Inventory (Oldfield, 1971; scores could range from -100 to +100) indicated that all participants were strongly right-handed (mean score 88, range: 65-100). All participants provided written informed consent and all procedures were approved by the Human Research Ethics Committee of La Trobe University in accordance with the Declaration of Helsinki. Participants were compensated for their time with gift vouchers.

Training

A training session was administered to participants before the main study to ensure that they were familiar with the correct functional use actions and names of each tool used in the study. The experimenter began the training session by reciting the names of each tool from a booklet that had pictures of the tools and their corresponding names printed below it. Thereafter, participants sat in front of a table that had the same real tools laid out in front of them (see Figure 5.1). They were then instructed to name each tool to which the experimenter pointed. This was followed by the experimenter performing the functional use actions associated with each tool. They were then instructed to perform the corresponding actions to each tool to which the experimenter pointed. Each tool had to be named and the functional use action performed correctly at least 3 times before the participant could proceed to the main study. Correct tool names and functional actions were defined and justified by the tools we established in the pilot study mentioned above. The training data revealed that participants performed 92% of correct functional actions of all the tools in their first attempt, 95% in their second attempt and 96% in their third attempt. In addition, participants named all the tools correctly 87% of the time in their first attempt, 95% in their second attempt, and 96% in their third attempt.

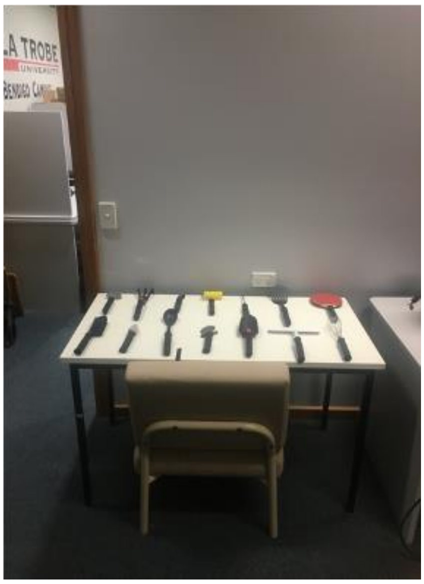


Figure 5.1. Training session set up. Participants sat facing the tools whilst the experimenter pointed at each tool. Thereafter, participant responded by naming and performing the functional action of each tool.

Stimuli

The stimuli were the same as those used in Kithu et al. (2021) and consisted of 14 real tools, and 14 pictures of the same tools. All tools had identical handles so that they required the same grasp aperture (see Figure 4.2). We created the picture stimuli by photographing each individual tool placed on top of the liquid crystal display (LCD) monitor used in the study. The photographs of the tools were then edited using Adobe Photoshop software (Adobe Systems Incorporated, San Jose, CA, USA) and were set onto a grey background and matched the tool size to fit the exact dimensions as the real tools. The presentation order for the prime stimuli was that each tool appeared the same number of times as a 2D picture as much as it did a 3D real tool. For the pairs of tools, the presentation order was counterbalanced such that each tool within a pair appeared as often as the prime as it did the target for each condition (eg., knife-pizza cutter, pizza cutter-knife).

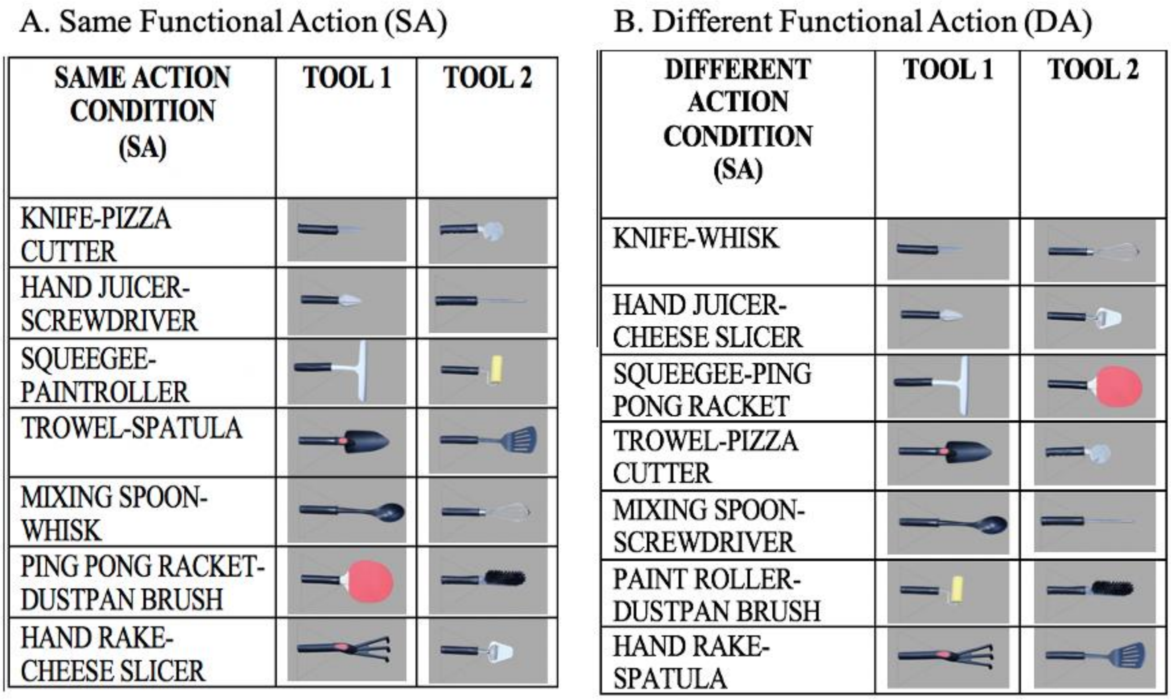


Figure 5.2. The tool stimuli. A. Tools used in the same functional action condition (SA). B. Tools used in the different functional action condition (DA). Tools that were the same exemplar were presented as a pair (SAME). Each tool shown in TOOL 1 was only paired with the tool in TOOL 2. This meant that the tool pairs were never matched with a pair that was not pre-determined as sharing or not sharing a functional use action. Pairing was determined in a previous study (Kithu et al., 2021) and matched between SA and DA conditions along several variables (i.e., familiarity, functional use similarity between stimuli pairs, frequency of use in everyday life and the expected lexical labels for the tools). All tools had identical handles to ensure that the RTs were attributable to the functional action of the tool, and not the grasp.

Participants sat at a table with their head positioned comfortably on a chin rest approximately 40 cm above the table (Fig. 5.3). Their right hand was placed on a button of a Chronos response pad (Psychology Software Tools, Pittsburg, PA, USA) positioned 30 cm to the right of their peripheral view. This device was used to measure the reaction time (RT) to initiate an action. We used E-Prime 3.0 to present the picture stimuli on a 17" Acer LCD monitor screen (Acer Inc., Xizhi, New Taipei, Taiwan) that was positioned horizontally on a turntable apparatus. The monitor had a resolution of 1024 x 768 and the picture stimuli was resized to 2300 x 1300 pixels at 314 dpi. The picture size was approximately 18.75 x 10.56 cm and subtended with visual angles of 15° horizontally and 26° vertically. The real tool stimuli were placed on top of the same LCD monitor.

Participants wore liquid crystal occlusion goggles (PLATO Translucent Technologies Inc., Toronto, Ontario, Canada). The PLATO goggles allowed us to have millisecond precision timing over the visual access to the stimuli. The goggles transitioned from clear ('shutter open') to occluding ('shutter closed') throughout the experiment. Participants also wore Bose QuietComfort QC35 Noise Cancelling Headphones (Bose Corporation, Framingham, MA, USA) that played white noise throughout the experiment. This masked external noise during stimulus changeovers. They also wore an interface microphone that recorded their verbal responses during catch trials.
We used an Olympus Stylus TOUGH TG-6 High- Speed Digital Camera (Olympus Corporation Shinjuku, Tokyo, Japan) to record movement time (MT) and accuracy of functional use actions. The field of view was restricted to the participant's hand. The recordings had a temporal resolution of 420 frames per second and a spatial resolution of 224 x 168 pixels. Adobe Premiere Pro software (Adobe Systems Incorporated, San Jose, CA, USA) was used to analyse the recordings offline.

Figure. 5.3. Experiment set up. Participants sat facing the screen with their head held stationary on a chin rest. Their right hand was placed on a button of a Chronos response pad. The visual occlusion goggles were coded to transition from transparent to occluded during the interstimulus interval (ISI) and inter-trial interval (ITI). The prime and target tools were either displayed on the LCD monitor or placed on top of the monitor. Participants wore noise cancelling headphones that played white noise throughout the experiment that masked external noise during stimulus changeovers. They also wore an interface microphone that recorded their verbal responses during catch trials.

Participants began each trial with their right index finger pressed down on the first button on the Chronos pad. The PLATO goggles were closed to occlude the participants' view of the display monitor. The goggles then opened and the prime tool (a real tool or a picture) was presented for 500 ms while participants passively viewed the stimulus. The googles then closed for 3 to 4 s during the inter-stimulus interval (ISI), and the experimenter replaced the prime tool with the target tool on top of the display monitor. The goggles then re-opened displaying the target tool (which was always a real tool) for 4s during which time participants immediately released the Chronos button and grasped and performed the functional use action of the target tool. Note that before the experiment began, participants were instructed to carry out the tool actions as quickly and as accurately as possible. Immediately after they performed the action, participants placed the tool back on the monitor and placed their finger on the Chronos button again. The goggles then closed when the button was pressed again for the 5s inter-trial interval (ITI) while the experimenter prepared the stimuli for the next trial. Figure 5.4 provides an overview of the trial events. The prime and target tools were positioned in one of 3 different orientations (50°, 90° and 120°) relative to the centre of the monitor and the primes and targets were always in the same orientation for any given pair. Positioning the tools in different orientations discouraged more of the perseveration of repeating the same functional use action towards the tool than if the tool was in the same location on every trial. All tools also had identical handles and similar grasp aperture to ensure that the RTs and MTs were attributable to the functional action of the tool, and not the grasp.

The experiment included 95 trials. Each condition (SA, DA, and SAME) consisted of 27 trials. There were also 14 catch trials, in which participants were instructed to name the prime stimulus they had just seen when a blank screen appeared instead of the target stimulus. We included catch trials to discourage the perseveration of repeating the same functional use action towards the tool in two consecutive trials and to ensure that participants attended to the prime tool.

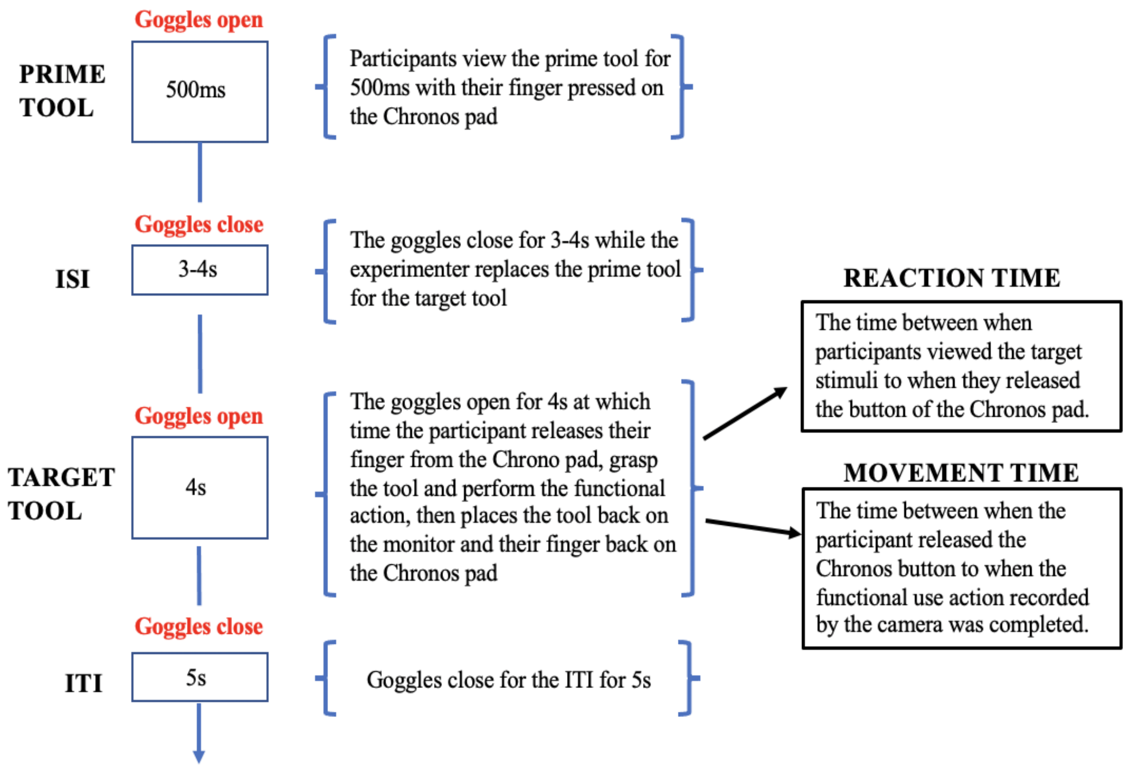


Figure 5.4. Experimental layout and design. The goggles opened for 500 ms to display the prime stimulus, which was either a picture of a tool displayed on the LCD monitor (in the same position as where the real tool would be placed) or a real tool placed on top of the monitor. The participant then passively viewed the prime tool. The goggles closed during the ISI for 3-4 s while the experimenter substituted the prime stimulus with the target tool. The goggles then opened again and displayed the target stimulus (which was always a real tool) with which the participants responded to by grasping and performing the functional action of the tool. The trial was completed by the goggles closing again for an ITI of 5 s.

Statistical analyses

The Statistical Package for Social Sciences (SPSS) version 23 (IBM Corporation; Armonk, NY, USA) and JASP software version 0.8 (University of Amsterdam, Amsterdam, Netherlands) were used to analyse the data.

Three dependent variables were analysed. The first was reaction time (RT) for accurate responses only. This measurement was calculated as the time between when participants viewed the target stimuli to when they released the button of the Chronos pad in milliseconds (ms). The second was MT for accurate responses only. We evaluated MT as the time between when the participant released the Chronos button to when the functional use action recorded by the camera was completed. The experimenter used adobe premiere pro software to code MT by slowing down the speed of the recording, positioning the play head at the desired frame that they wanted to capture, and scaling the frames of the section to fit the position they felt that was the correct start and finish of the functional use action. For the start of the functional use action, the button release was indicated by a light on the Chronos pad. The experimenter coded this by positioning the play head at the section of the frame when the light on the chronos pad illuminated. The same coding was performed for the completion of an action which was defined as the moment the functional action of the tool was completed (e.g., the completion of the first whisk motion if performed more than once). The number of frames between when the participant released the Chronos button to when the functional use action recorded by the camera was then calculated in milliseconds. The third dependent variable was functional use errors expressed as a percentage. The accuracy of functional use actions was evaluated in a binary manner as either 0 for incorrect and 1 for correct. The overall errors were then collected as the percentage of correct responses.

A 2 x 3 analysis of variance (ANOVA) was performed on each dependent variable with Prime Format (Picture vs. Real) and Action Condition (DA vs. SA vs. SAME) as within-subject factors. To further evaluate significant main effects and interactions, *t*-tests corrected for multiple comparisons using the Bonferroni method were performed. Significance was established at an alpha of .05. All reported *p* values represent corrected values unless specified otherwise.
Bayesian ANOVAs were also performed using the same 2 (Prime Format) x 3 (Action Condition) model. We used Bayesian analyses as we were open to a different statistical approach that might yield different results to the more traditional ANOVA. A convergence between both statistical approaches would provide more confidence in the findings, and draw more definite inferences from null results. The Bayes factor we report (BF_{10}) quantified the likelihood that the data support the alternative relative to the null hypothesis as a ratio between the two. We considered a BF_{10} value of 3 or above as substantial evidence in favour of the alternative hypothesis and values of 0.33 or less as substantial evidence in favour of the null hypothesis (Jeffreys, 1998). As per the default specifications for priors used in JASP, the r scales for the Bayesian ANOVA were set to 0.5 and 1.0 for fixed and random effects, respectively. Bayesian *t*-tests using a Cauchy prior set at 0.707 was used to evaluate significant main effects and interactions. The means and standard deviations for RT, MT and functional use errors are also reported.

V. Results

RT

In summary, we observed that RTs to initiating functional use actions to the target tool were faster when the prime tool was a picture of a tool compared to a real tool. However, there were no differences in RTs to initiate functional use actions when the two stimuli differed-regardless of whether the two afforded similar functional use attributes or not. In other words, participants were faster at initiating functional use actions to the target tool when the exact same tool was presented twice (SAME condition) compared to all the other conditions. The results are shown in Figure 5.5 and Table 5.1 provides the descriptive statistics.

The ANOVAs demonstrated a main effect of Action Condition ($F_{(2,40)} = 9.100$, $p = 0.001$ $\eta_p^2 = 0.313$, BF_{10}= 212.141). Pairwise comparisons revealed that RT in the SAME condition was faster than all the other conditions (DA vs. SAME: p=0.005, BF_{10}= 50.681, SA vs. SAME: p=0.009, BF_{10}= 67.737). Pairwise comparisons did not differ between the SA and DA condition (all p > 0.300, BF_{10}= 0.855). There was also a main effect of Prime Format where RTs were faster when the prime was a picture of a tool compared to when it was a real tool ($F_{(1,20)} = 11.642$, $p = 0.003$ $\eta_p^2 = 0.368$, BF_{10}= 12.801). No interaction between Prime Format and Action Condition was found ($F_{(2,40)} = 2.594$, $p = 0.087$ $\eta_p^2 = 0.115$, BF_{10}= 0.519).

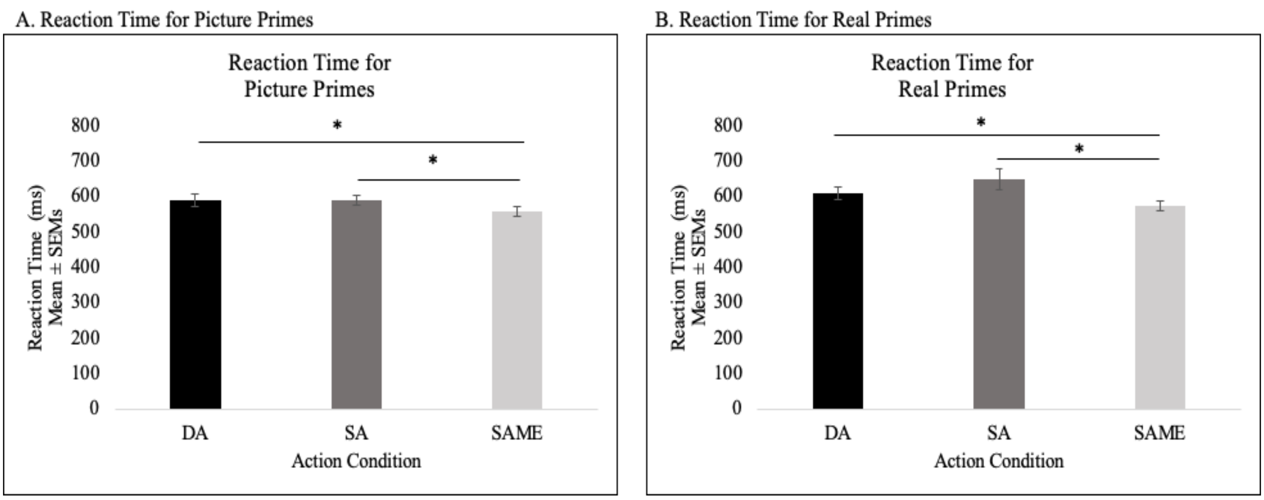


Figure 5.5. Reaction time (RT) results. The graphs display the mean ± SEM RT scores. A. RTs for trials in the DA, SA and SAME condition with pictures of tools as the prime tool. B. RTs for trials in the DA, SA and SAME condition with real tools as the prime tool. A main effect of Action Condition (SAME condition faster than DA and SA) and Prime Format (RTs faster for picture primes that real tool primes) was found. Asterisks (*) denotes a significant difference with the SAME condition compared to all the other conditions after correcting for multiple comparisons (p < 0.05).

MT

Figure 5.6 shows the mean MT scores of the target tools while Table 5.1 provides the descriptive statistics. In summary, we observed that participants were faster at performing the functional actions toward the target tool when the prime and target tool were the same (SAME condition) compared to when the tools shared the same functional action (SA condition). MTs did not differ with prime format (i.e., picture versus real tool).

The ANOVAs demonstrated a main effect of Action Condition ($F_{(2,40)} = 5.477$, $p = 0.008$ $\eta_p^2 = 0.215$, $BF_{10}= 3.156$). Pairwise comparisons revealed that MT in the SAME condition was faster than the SA condition (p=0.022, BF_{10}= 8.380). All other pairwise comparisons did not differ (DA vs. SAME: p= 0.083, BF_{10}= 1.120, DA vs. SA: p>1.00, BF_{10}= 0.218). There was no main effect of Prime Format ($F_{(1,20)} = 0.689$, $p = 0.416$ $\eta_p^2 = 0.033$, BF_{10}= 0.231) nor was there an interaction between Prime Format and Action Condition ($F_{(2,40)} = 1.283$, $p = 0.288$ $\eta_p^2 = 0.060$, BF_{10}= 0.415).

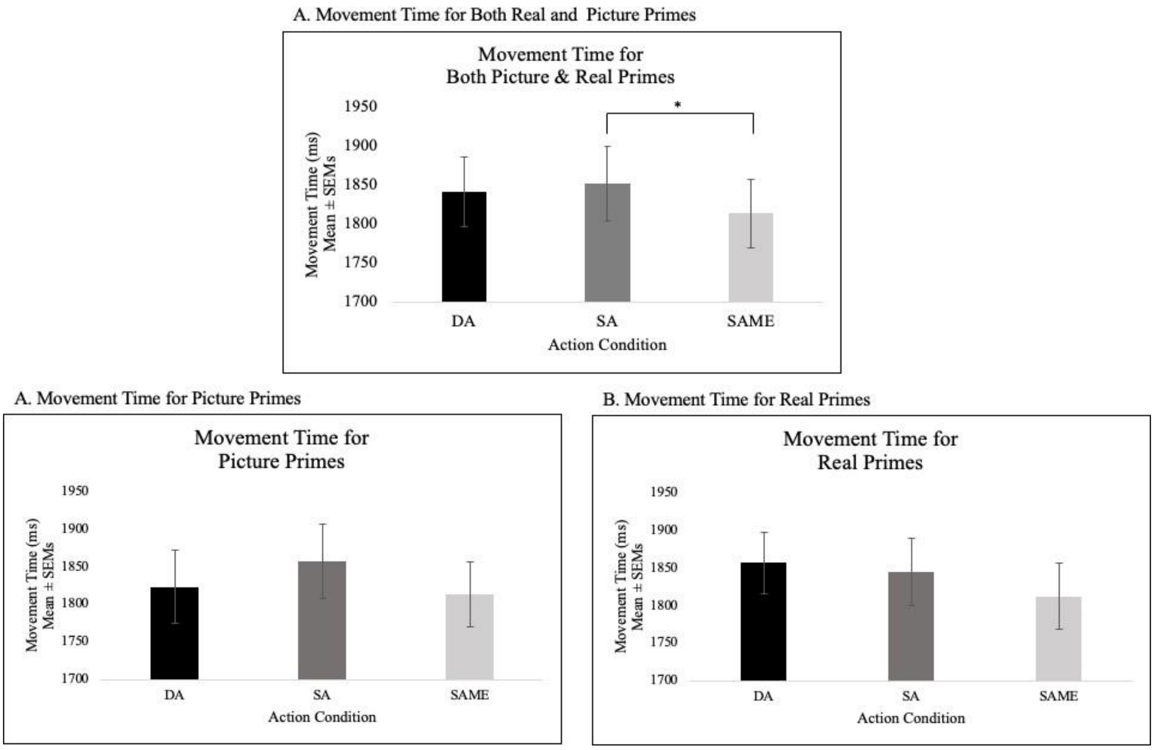


Figure 5.6. Movement time (MT) results. The graphs display the mean ± SEM MT scores. A. MTs for trials in the DA, SA and SAME condition with pictures and real tools as primes pooled together. B. MTs for trials in the DA, SA and SAME condition with pictures of tools as the prime tool. C. MTs for trials in the DA, SA and SAME condition with real tools as the prime tool. A

main effect of Action Condition was found (SAME faster than SA condition). Asterisks (*) denotes a significant difference with the SAME condition compared to the SA condition after correcting for multiple comparisons (p= 0.022).

Functional use errors

Figure 5.7 shows the mean percentage of errors in functional use actions while Table 5.1 provides the descriptive statistics. In summary, there were no differences between conditions on participants' errors in performing functional use actions towards the tools. Furthermore, the format in which the prime tool was presented (i.e., a picture or real tool) had no influence on participants' errors in performing functional use actions. The ANOVAs demonstrated no main effect of Prime Format ($F_{(1,20)} = 2.243$, $p = 0.150$ $\eta_p^2 = 0.101$, BF_{10}= 0.628) and no main effect of Action Condition ($F_{(2,40)} = 2.836$, $p = 0.071$ $\eta_p^2 = 0.124$, BF_{10}= 0.580). There was also no interaction between Prime Format and Action Condition ($F_{(2,40)} = 0.385$, $p = 0.683$, $\eta_p^2 = 0.019$, BF_{10}= 0.174).

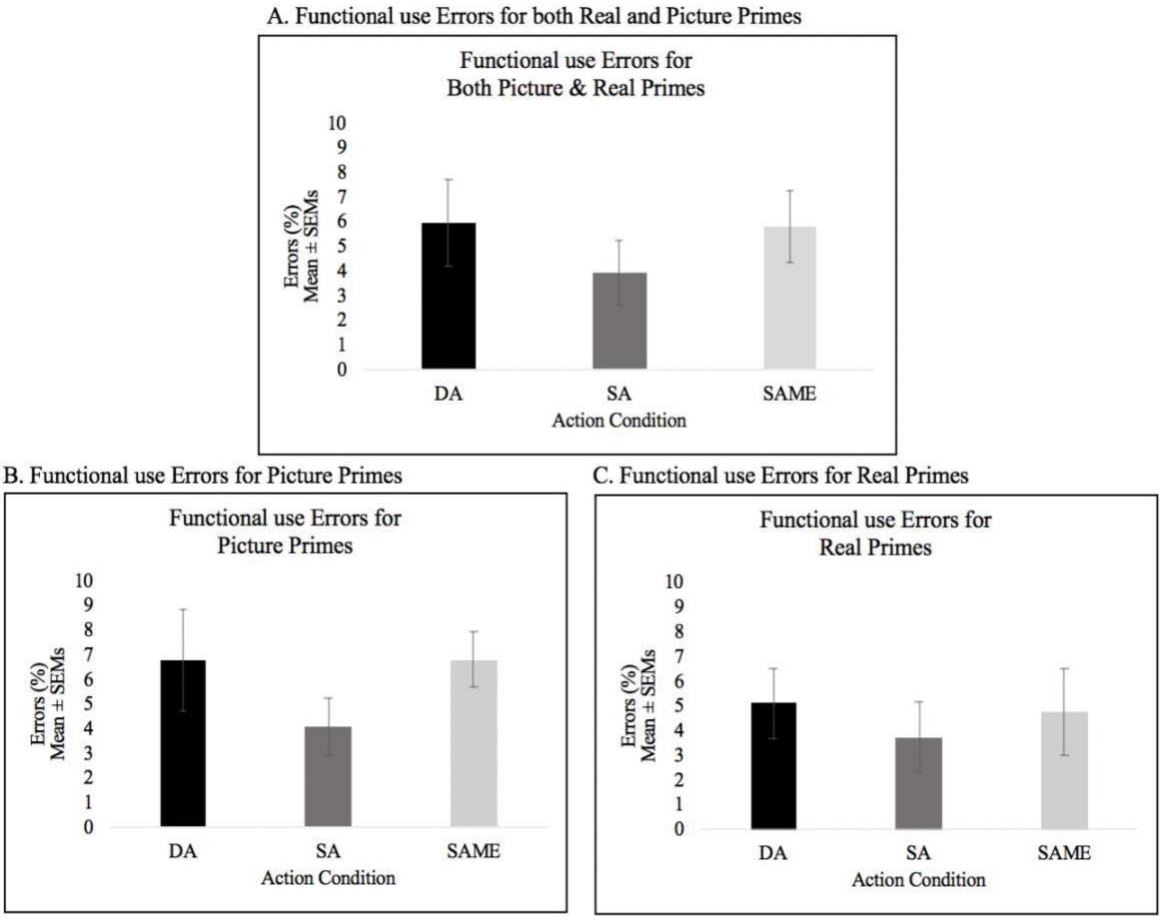


Figure 5.7. Functional use error results. The graphs display the mean ± SEM percentage of functional use errors. A. Functional use errors for trials in the DA, SA and SAME condition with pictures and real tools as primes pooled together. B. Functional use errors for trials in the DA, SA and SAME condition with pictures of tools as the prime tool. C. Functional use errors for trials in the DA, SA and SAME condition with real tools as the prime tool. No differences between Action Conditions and Prime Formats were found.

VI. Discussion

The present study aimed to investigate whether priming the functional use properties between tools can facilitate the actions performed on subsequent tools. Specifically, we examined whether this effect of facilitation would be influenced by whether the preceding tool was a real tool or a picture of a tool. We hypothesised that affordances elicited by the prime tools would influence the initiation of functional use actions to the target tool if the tool pairs that were different but shared the same functional action compared to tools that were different and had a different functional action. Furthermore, the similarities in 3D structure and the potential for physical interaction of a prime tool that was real would facilitate the initiation of functional use actions towards the target tool more than a prime tool that was in pictorial format. Namely, this would be indexed by a decrease in RTs, MTs and errors.

Contrary to our hypotheses, our results showed that there were no differences in RTs to initiate functional use actions when the two stimuli differed - regardless of whether the two afforded similar functional use attributes or not (i.e., SA vs. DA condition). Moreover, we found that there was no interaction between prime format (i.e., picture vs. real tool) and action condition (i.e., SA, DA and SAME). Although we used a similar design to Squires et al. (2015), one important difference is that we incorporated conditions that used pairs of tools that were different but either shared the same functional action or a different functional action. In their case, participants were only presented with pairs of tools that were either the same (spatula-spatula) or different (spatula-whisk). They found reaction time priming in the congruent stimuli, but this was not influenced by whether the prime tool was a picture or a real tool. Our findings demonstrated a similar effect in the SAME condition; however, we observed no differences between the SA and DA condition regardless of whether the prime tool was in a real or pictorial format. This suggests that the affordances elicited by the graspable real tool prime did not influence the processing of functional use attributes between the prime and target tool and therefore had no effect on the initiation of actions toward subsequent tools.

It is perhaps the case that the lack of facilitation we observed is that participants were not actively retrieving the conceptual knowledge of how the prime tools were functionally used by processing it without acting upon it. In this view, participants were identifying each prime tool as it appeared, and therefore perhaps did not perceptually associate the functional use attributes between the prime and target tool. This view is supported by evidence that shows that it takes longer to identify an object based on its more intricate attributes (i.e., a Volvo from any car) than perceptually categorizing it (i.e., as a hammer, flower or car), or by simply detecting its presence (Grill-Spector & Kanwisher, 2005). In this view, it takes longer to consciously retrieve the conceptual knowledge of the more intrinsic properties of objects compared to simply identifying them. Therefore, processing the intrinsic properties such as the functional action between tool pairs without having to consciously retrieve the conceptual knowledge of how they are associated suggests that that there is more processing needed to discriminate the more specific properties of an object than simply identifying it or detecting its presence.

Overall, our findings suggest that the ventral stream is playing a major role in how the prime tools were being processed and supports the TVSH which claims identifying a tool is driven by the ventral stream. This is because participants viewed the prime tools rather than reached out and performed their functional action. As a result, the prime tools were being perceptually processed on the basis of identifying each tool as an individual tool rather than discriminating its functional use actions by just viewing it. This view is also supported by the findings by Kithu et al. (2021) who also demonstrated a similar effect in relation to how understanding how objects are manipulated requires more conceptual processing than what is required for their identification. Therefore, naming the prime tool relative to the target tool was also not influenced by the functional use attributes between tool pairs, or by whether the prime tool was a real tool or a picture of a tool.

Aside from the functional action conditions, surprisingly, participants' RTs to initiating functional use actions to the target tool were faster when the prime tool was a picture of a tool compared to a real tool. However,, we found no evidence that the affordances of the prime tool facilitated the initiation of functional actions performed on the subsequent target tool (i.e., no differences between the SA and DA conditions). The question then arises: why would perceptually processing a picture of a tool enhance a faster response to initiating functional use actions to a subsequent target tool compared to a real tool?

We speculate that the affordances evoked by perceptually processing real tools that are placed within reaching distance of the observer may be more cognitively taxing for the brain, thus yielding a slower response to initiating functional use actions towards the target tools. Unlike a picture of a tool, the 3D structure of the handle of a real tool provides depth and additional shape and form information that affords actions such as grasping. In this view, real tools are richer in visual information, therefore the higher cognitive demands it takes to process the affordances such as the depth, exact location, and size between real tools presented in succession may interfere with the perceptual judgments of the target tool relative to the prime. These ideas are supported by literature that demonstrates the relationship between affordances, and how object features, and attention influences the selection for action (Cisek, 2007; Gomez, Skiba, & Snow, 2018; Humphreys et al., 2013). For example, Gomez et al. (2018) investigated whether motor plans triggered by real graspable objects (i.e., grasping actions) would influence attention and manual responses (i.e., pressing a button) compared to pictures of the same item. Using a flanker task, they presented participants with three spoons that were in either a real or pictorial format, and that were within reaching distance. The target spoon had two identical distractor spoons whose handle orientation was either the same (i.e., congruent) or opposite (i.e., incongruent) from the target spoon. Participants were then asked to respond by making a button- press response to which distractor spoon was either congruent or incongruent to the target spoon (i.e., left or right). The authors found that although there were congruency effects (i.e., a faster response to congruent compared to incongruent stimuli), participants were faster to respond to the targets that were in pictorial format compared to targets that were in real format. In a second experiment, the real objects were placed out of reach or behind a transparent barrier. They then found that the interference effects were the same in real objects and objects in pictorial format. The authors concluded that graspable real objects that are placed within reaching distance offer affordances for physical interaction, and therefore interfere with, and influence attention and manual responses. These results suggest that the affordances evoked by real tools within reaching distance may interfere with the cognitive demands it takes to perform manual responses towards target objects compared to the same items in a pictorial format. With respect to our findings, unlike primes that were in a real format, primes that were in pictorial format may have elicited a faster response as the cognitive demands it would take to identify the tool without the additional shape and form information that affords actions would be less taxing, therefore causing little interference with the initiation of actions towards subsequent tools.

However, one thing to note is that a previous study conducted by the present authors used a similar priming paradigm to examine whether the repeated visual presentation of images of object features such as those related to grasping and their functional can facilitate pantomiming (Kithu et al., 2019). We found that participants were slower at pantomiming the target tool relative to the prime regardless of whether the grasp and function of the tool were the same or different -except when the prime and target tools consisted of identical images of the same exemplar. We concluded that the results we observed may have been attributed to the assumption that images intrinsically do not afford grasp and / or functional use properties in the same way as real objects do. Therefore, participants processing the functional use affordances of tools for the purpose of pantomiming them may be more influenced by a combination of both conceptual knowledge and an object's three-dimensional structure. Alternatively, the present study implemented the use of real tools compared to pictorial stimuli to examine whether the repeated visual presentation of object features such as those related to their functional can facilitate the functional use actions toward a real target tool. However, the findings from the present study contradict the assumptions that we made from the findings in (cite). Although the present study found similar results that there were no differences in response times to initiating functional use actions when the two stimuli differed-regardless of whether the tools' functional actions were the same or different, interestingly, participants were faster at initiating functional use actions to the target tool when the prime tool was a picture of a tool compared to a real tool.

As such, these findings highlight that the format in which a prime tool is presented (i.e., a real or pictorial format) has no influence on priming the processing of the functional use actions between prime and target tools-whether it is for the purposes of pantomiming the target tool or performing its functional use actions. Therefore, the assumption that the lack of facilitation we observed in both studies may be a result of participants identifying each prime tool as it appeared and not actively retrieving the conceptual knowledge of how the prime tools were functionally used and may be a consequence of the task demands in both studies. This highlights the influence of the task demands in each study on how the brain recognises tools, and how this influences how the grasp and/or functional use properties between tool pairs are processed.

On the other hand, some would argue that the grasping actions of the real prime tool were the same as the target tool, therefore there was no conflicting motor plans that would cause an interference in the initiation of actions toward the target tools. We are proposing that the perceptual analysis of the physical structure of real tools relative to one's body may activate differential sensorimotor responses than pictures of tools do. This makes sense when you consider how real tools were created before we could obtain a pictorial representation of the same tool. We are more inclined to want to interact with tools within our environment, and therefore attend more to stimuli that offers the potential for interactive behaviour. Moreover, as mentioned in the methods (see Figure 5.2) all tools had the same handle and therefore had the same grasping aperture across all stimuli to ensure that RT and MT priming would be primarily driven by processes related to the similarities in functional use actions between tool pairs as opposed to grasping. Although there would still be reliable differences in the hand posture when grasping different tools, this would have to depend on participants initial recognition of the tool, and thereafter the selection of a final grasp posture that is appropriate for subsequent movements once the tool is used. Therefore, the function of the tool would influence the details of the grasping posture selected, rather than participants initiation to target tools based on just grasping the tool. Given the above, our study contradicts the study conducted by Squires et al. (2015). Firstly, by adopting a similar methodology of presenting a prime tool that was either a picture or a real tool, our findings contradict the conclusions of the earlier study on how both pictures of tools and real tools primed action responses equally. This contradiction in results may have been caused by a number of factors. Firstly, Squires et.al used photographs of tools, whereas our study used images of tools on an LCD screen. Although some may argue that they both a photograph and an image on a LCD screen may be similar in how they are both perceptually perceived, this difference in how the tools were presented between both studies may have influenced the contradicting findings. As such, future research on the differences of how real-life photographs compared to how images on an LCD screen are processed could be essential in developing our understanding of how this may play a part in how we process 2D objects.

Another factor that may have caused contradicting results is that Squires et.al had conditions where the functional use action between tool pairs were either congruent (exactly the same) or incongruent (different). On the other hand, our study introduced pairs of tools that were different in identity but shared the same functional action. Although this gave us an opportunity to examine if the computations required to process the similarities in functional use actions between tools was effective when having to perceptually analyse different tools in succession, the tool pairs differed between the two studies. Therefore, our study provides an important contribution to our understanding of how the perceptual processing of the format and the functional properties of different tools presented in succession influences how we perform a given action.

Lastly, one thing to note is that Squires et.al measured the grasp to move and grasp to use features of the actions in their study by using motion capturing software. One limitation in our study is that MT was measured by a rater using video analysis software, rather than quantifying the movement kinematics through motion capturing software. As such, the movement characteristics in the present study were less defined, and some would argue that they did not reliably measure MT. With this in mind, further studies, which take these variables into account should use motion capturing software to monitor and measure movements of actions to reliably and accurately define MT. Overall, the current findings add to a growing body of literature on how the processing of functional use attributes of tools in pictures compared to real tools can influence how we grasp a tool with the intention to perform the functional action towards subsequent tools.

VII. Tables

Table 4. Reactions times, movement times and errors for target tools

Condition	RT (ms)		MT (ms)		Error (%)	
	Target		Target		Target	
	M	SD	M	SD	M	SD
(A) Picture Primes						
DA	588.02	75.32	1822.91	222.40	6.80	9.44
SA	588.48	68.92	1857.14	227.84	4.08	5.33
SAME	555.48	62.77	1812.79	197.56	6.80	5.28
(B) Real Primes						
DA	608.54	84.90	1857.17	186.86	5.10	6.44
SA	646.55	138.08	1845.27	205.82	3.74	6.63
SAME	572.75	71.58	1812.40	202.38	4.76	7.93

Chapter Six

General Discussion

I. Summary

The aim of this thesis was to investigate how we process the repeated presentation of action related properties such as those related to the grasp and/or functional use attributes of real tools and pictures of tools, and how this may influence the way in which we pantomime, name and manipulate tools with similar affordances.

The thesis comprised of three studies. Study 1 (Chapter three) examined whether the repeated visual presentation of object features such as those related to grasping and their functional use in pictures of tools can facilitate pantomiming. It was found that initiating the grasp and functional use actions to pictures of tools causes negative priming (i.e., slower response times) to target tools relative to primes regardless of whether their grasp and functional use are the same or different. Study 2 (Chapter four) examined whether the there are differences in how the brain processes the repeated presentation of functional use features between tool pairs that are in real 3D format compared to 2D pictorial format for the purposes of naming. I found that the response times to naming real 3D tools compared to 2D pictures of tools is not facilitated by earlier encounters with different tools affording similar functional use actions. Moreover, the functional action similarity between different tools does not affect the naming responses of the target tool relative to the prime. Lastly, Study 3 (Chapter five) examined whether the there are differences in how the brain processes the repeated presentation of functional use features tool pairs that are in real 3D format compared to 2D pictorial format for the purposes of manipulating the physical use of a subsequent tool. Interestingly, it was found that initiating the functional use action of subsequent real tools are not facilitated by earlier encounters with different tools affording similar functional use actions. Moreover, initiating functional use actions to the target tools are faster when the prime tool is a picture of a tool compared to a real tool.

Taken together, the results in this thesis demonstrate that priming the action related properties between tool pairs that are presented in succession does not facilitate how the tools are either pantomimed, named, or manipulated. These findings also highlight that the visual system processes the successive presentation of visually presented tools in a similar manner, regardless of whether or not the tool pairs share the same affordances, or format (i.e., 2D or 3D). The following chapter explains how the findings from this thesis develops our understanding of how the ventral stream plays an important role in how tools are perceived and processed, and how this may affect the retrieval of functional knowledge between tool pairs within these tool processing outputs.

II. The role of the ventral stream

The hypotheses in this thesis were motivated by evidence from previous studies demonstrating facilitation effects of affordances on object recognition and manual responses to subsequent tools (Bub & Masson, 2006; Bub et al., 2003; Craighero et al., 1996; Helbig et al., 2006; McNair & Harris, 2012; Tucker & Ellis, 2004). However, the results in this thesis reveal that the action related properties that afford actions such as how a tool is grasped and/or functionally used does not offer the same facilitation effects. Furthermore, having real tool stimuli that afford actions does not influence how quickly these action related properties of tools are processed compared to pictures of tools.

Nonetheless, it is important to note that all the results in this thesis support the TVSH in relation to how the ventral stream is a key component in the recognition of tools. The findings within this thesis are consistent with evidence that demonstrates that successfully pantomiming, naming and manipulating tools requires the perceptual recognition of a tool to be invoked prior to the execution of the action. This means that without ventral stream processing mechanisms for the first exposure to a novel tool, an individual will most likely be unable to correctly perform the tool processing outputs outlined in this thesis. The findings from Study 1 support these conclusions as selecting a pantomiming action of a tool is contingent upon prior perceptual analysis of the stimulus which relies heavily on memory and ventral stream processes (Foley, Whitwell, & Goodale, 2015). In Study 2, participants had to name the presented tools, therefore according to the TVSH, this output relies most heavily on ventral stream processing too (Goodale & Milner, 1992). This has also been articulated in Study 3, where in order to perform the functional use action of a tool, it is necessary to extract the tool's identity along with its properties such as its texture and weight, before we retrieve the stored information of how that tool is to be functionally used (Mahon & Caramazza, 2009; Valyear et al., 2011). As such, I propose that the lack of facilitation we observed in how participants processed the grasp and/or functional use properties between the prime and target tools in these tool processing outputs was due to participants identifying the target tool as a different tool. In this view, participants were perceptually analysing the target tool based on its identity, regardless of whether the prime and target tool shared or did not share the same affordances. This makes sense when you consider that the target tool was a different tool to the preceding prime tool.

This view is supported by the differential neural activity that happens in object selective regions within the ventral stream when the identity of an object is changed during fMRI adaptation paradigms (Wiggs & Martin, 1998). For example, Valyear et al. (2006) used an event-related fMRI-adaptation paradigm to investigate the neural activity in the ventral and dorsal stream in response to object identity and object orientation. They presented participants with successive images of real-world graspable objects that were either 1) the same as the first image, 2) a different identity as the first image, 3) a different orientation as the first image, and 4) both different in identity and orientation as the first image. They found that the changes in the identity of objects showed a release from adaptation in areas of the ventral stream but was indifferent to changes in orientation. Moreover, changes in the object's orientation showed a release from adaptation in dorsal stream areas but was indifferent to changes in identity of the object. The authors concluded that the findings support the view that the ventral stream plays an important role in object perception and identification, whereas the dorsal stream plays an important role in the online visuomotor control of object directed actions. These findings among others exploring adaptation effects (Chouinard et al., 2008; Summerfield, Trittschuh, Monti, Mesulam, & Egner, 2008) highlight the sensitivity of object selective areas within the ventral stream in response to adaptation effects when the identity of a stimulus is identical compared to when it is different. This supports the behavioural findings observed in this thesis as the different identity of the target tool relative to the prime made participants identify the target tool as a new tool that differed in identity.

In addition, if these assumptions are correct, then the lack of facilitation we observed in participants processing real tools compared to pictures of tools is a result of the same object-selective areas within the ventral stream of the brain being activated when perceptually processing both real tools and pictures of tools (Freud et al., 2018; Snow et al., 2011). Therefore, even though we cannot cut a slice of cheese with a picture of a knife, we can still identify that a knife is a knife from the learned experience and familiarity with the tool and it's use regardless of whether it is in a real or pictorial format.

III. The retrieval of functional knowledge

First, evidence has shown that the processing of functional use information of tools takes longer than identifying a tool based on its physical properties (Jax & Buxbaum, 2010; Squires et al., 2015; Valyear et al., 2011). So how does this inform us on how identifying a tool based on its physical properties may interfere with the retrieval of the functional use similarities between tool pairs? I propose that activating the sensorimotor information related to a tool's functional use action programs is only accessible to language and awareness when it is needed (Allport, 1987). This means that the activation of stored semantic memory systems related to a tools functional action may not be a fully automatic process and requires more time to consciously access the information related to a tool's functional use action once it is initially identified. In this view, the findings in this thesis demonstrate that actively retrieving the similarities or differences in the functional information of different tools that are presented in succession may take longer than identifying the tools individually. Therefore, the time between the tool presentation may not be long enough for participants to retrieve the functional knowledge of how the grasp and/or functional use actions may be similar or different between tool pairs.

However, the experimental design we used in all the study's included a paradigm that had tools presented in succession with 2-3 seconds between each tool presentation. Although a number of studies have demonstrated strong behavioural priming and fMRI adaptation effects with this duration between tool presentation (Chouinard & Goodale, 2012; Chouinard et al., 2008; de Groot, Thomassen, & Hudson, 1986; Huettel & McCarthy, 2000), this sort of exposure to tools does not happen in real world situations. We have not evolved to interact with tools being visually presented to us two seconds apart. We interact with tools in order to have goal directed intentions in our daily lives. Hence if we wanted to find a hammer from a toolbox in our shed, we would have to look around the shed and identify the tools that are not the hammer and differentiate them from the tool we intend to use or even name. Moreover, the way in which we use an object or tool is based on the context in which we are associating the tools use. Therefore, this influences how we retrieve the conceptual knowledge of how we intend to use the tool for a specific function. For example, when we see a hammer, we translate the perceptual information of the tool to the stored knowledge of the tool's conventional use (i.e., a hammer with a nail) and thereafter activate the appropriate motor outputs in order to use the hammer (i.e., grasping and hammering). However, we can also use a shoe to pound a nail. This highlights that the processes of how we perceive the affordances of tools or objects is not only determined by context we are in, but by the various ways in which we receive information within our environment.

On the other hand, evidence has also shown that identifying a tool based on its physical properties is dissociable from the processes of retrieving the conceptual knowledge of how the tool is manipulated - as predicted by the TVSH (Goodale & Milner, 1992). This has been highlighted in patients with apraxia that show preservation in their ability to recognise objects but have deficits in the recognition of object-related actions such as the knowledge about an object's function (Buxbaum, 2001; Heilman et al., 1982). Furthermore, a similar effect has also been demonstrated when investigating the role of functional-use gestures in object identification (Bub et al., 2003). The findings from Study 2 support this conclusion as the functional knowledge of tools is not implicated in object recognition for the purposes of naming the tool. These results demonstrate that when having to name tools in quick succession, an individual successfully names a tool depending on the tool's visual identification and not by the affordances associated with the tools. As a result, the findings in this thesis have implications for theories of embodied cognition concepts, as such theories propose that object perception is associated with the activation of motor information. However, I found that the perception of tools does not always activate motor information such as the information related to grasp and/or functional use attributes between tool pairs. Thus, my findings argue against embodied cognition theories in that they demonstrate that the processing of visual information for retrieving stored sensorimotor knowledge about how a tool is manipulated does not influence how the tools are visually perceived. Therefore, cognitive processes, such as identifying objects for the purposes of successfully pantomiming, naming or manipulating them are unlikely to depend on the activation of sensorimotor processes.

In contrast, the findings from Study 1 argued that the lack of facilitation we observed in participants associating the grasp and functional use similarities between tool pairs when pantomiming them was because images intrinsically do not afford grasp and functional use properties in the same way as real objects do. Therefore, processing an image would not be expected to afford grasping or functional use actions as there is no way to interact with them physically. However, the results from Studies 2 and 3 further challenge this argument as there were no differences in how participants named images of tools compared to real tools in Study 2. Furthermore, the opposite pattern of results happened in Study 3 where pictures of tools initiated a faster response to manipulating target tools more than real tools that afford action related responses. These findings show us that despite the affordances that real objects may invoke, there are no differences or advantages of real tools compared to pictures of tools in priming the actions performed on a subsequent tool (whether it is the time taken to name or manipulate the tools). In addition, the findings in Study 3 support the contradiction to the ideas proposed by embodied theories of cognition as participants were not actively associating the functional information between the tool pairs regardless of whether the prime tool afforded manual responses. Note that participants had to view a prime tool that was either a real or a picture of a tool, and thereafter perform the functional action of a real target tool. I propose that the lack of facilitation we observed in participants associating the functional use similarities between tool pairs was due to the prime tool being identified based on its physical properties regardless of whether it was in real or pictorial format. As a result of this, participants were not actively associating the functional information between the tool pairs regardless of whether the prime tool afforded manual responses. Once again, these ideas speak against embodied theories as it suggests that the processes involved in identifying tools is dissociable from the processes involved in the active retrieval of the action related information between tool pairs.

IV. Strengths and weaknesses/ Future directions

The differences in how we process the grasp and/or functional use properties of real tools compared to pictures of tools has not been entirely studied within differing tool processing outputs such as how the tools are pantomimed, named, or manipulated. Therefore, exploring these differing tool processing mechanisms expands our knowledge of how the action related properties between tool pairs influences how we communicate and/or manipulate tools with similar affordances. However, the findings from this thesis suggest that the only way to process the functional use properties between pairs of tools that are presented in quick succession is through the active retrieval of the stored knowledge of how the action related properties are shared. These findings have important implications for the experimental tasks that were used to find priming effects within the studies in this thesis. For example, if these experiments were to be replicated, it is most likely that no positive priming effects would be demonstrated as the tasks did not require participants to deliberately access the stored knowledge of how the grasp and/or functional use properties were shared between the prime and target tools. Therefore, the findings in this thesis develops our understanding of how specific task requirements within a study significantly contributes to how the action related properties between tool pairs are processed.

There are various strengths in the methodologies used within the studies in this thesis. First, a particular strength of these studies was using a combination of real and pictorial stimuli. This was an important improvement in the ecological validity of the studies within this thesis as majority of studies within this area of research have employed images of tools as experimental stimuli, yet in the real world, tools are 3- dimensional in structure and therefore provide differential depth information than pictures of tools. As a result, using both pictorial and real tool stimuli provide a more effective and powerful way of drawing inferences about how tool affordances influence different cognitive processes. With this in mind, combining real and pictorial tool stimuli in study 1 would be an interesting avenue for further research. This would allow one to observe whether pantomiming the use of tools are facilitated by earlier encounters with different real tools compared to pictures of tools affording similar grasps and functional use actions. Continued work in this area could also contribute to how pantomiming tool use is used clinically to assess patients that may show signs of apraxia.

Some of the findings reported in this thesis have important implications for other studies using real stimuli to explore certain cognitive processes. For example, study 2 and 3 show us that using real tool stimuli does not offer any differences or advantages in how we process the affordances between tool pairs. As a result, this highlights that the methodology used to test the affordances related to the grasp and/or functional use action of tools is not influenced by the format in which the tools are presented. Therefore, only using pictorial stimuli to explore this area of research may be more affordable and would be easier to include when coding experimental designs. With this in mind, the combination of using both real and pictorial stimuli as in study 2 and 3 does present certain challenges. This information will be useful for other researchers in this field. The first challenge pertained to having to change the stimuli in quick succession. This meant that I had to have an assistant help me rotate the stimuli changes throughout each study. Unfortunately, the only way one would be able to overcome this would be to incorporate a way to rotate the stimuli using a mechanical device. However, this did not have any impact on the consistency in the timings that were made between stimuli presentations. Nonetheless, I controlled for demand characteristics and experimenter bias by having participants wear headphones that played white noise and using shutter goggles to present tool stimuli in study 2 and 3. This meant that participants were not able to know what format the tool stimuli were being presented and were not able to view any tool stimuli unless the goggles were open. Overall, this ensured that participants were not distracted and only paid attention to the stimuli that were presented to them when the goggles were open.

Another strength of the studies in this thesis that is worth noting was the use of a varied selection of tool stimuli that were different in identity, but either shared or did not share the same grasp and/or functional use properties. Note that all the tool stimuli were validated from either a previous study using the same stimuli (i.e., McNair & Harris, 2012 in study 1), or from a pilot study that collected information on how the conditions matched in familiarity, frequency of use, naming use in everyday language and naming frequency in the Subtlex database. This meant that the tool stimuli within each condition were an accurate and valid representation of the factors I was intending to measure. In view of this, most priming studies that have incorporated tools that have different identities but have similar action related properties have had experimental tasks that involve the use of working memory to aid in the perceptual analysis of conceptual (i.e., action-related) knowledge between tool pairs (Helbig et al., 2010; McNair & Harris, 2012). However, as discussed within the studies in this thesis, I did not want participants to maintain any information in working memory of what they saw as a target to complete the task. Therefore, the differences in experimental tasks as well as having a wide range of tool pairs provides more reliable way of answering the questions as to whether the repeated presentation of action related properties of tools may influence how we processes their affordances. In addition to this, the use of a varied selection of tool stimuli that either shared or did not share the same grasp and/or functional use properties shows us the importance of the function of the semantic system in the degree to which sensory and motor systems are involved in processing the action related properties of tools. This can have important implications for assessing patients with neurological disorders such as apraxia or visual form agnosia. Depending on the severity of the disorder, some patients may perform more poorly when recognizing tools, or may make more errors in pantomiming information about how tools are manipulated (Buxbaum, 2001; Cubelli, 2017; Motomura & Yamadori, 1994; Smania, Girardi, Domenicali, Lora, & Aglioti, 2000). As a result, having patients dissociate tools with different identities but that share or do not share the same functional use properties could be a method to clinically assess the damaged or preserved aspects of specific object knowledge in patients with neurological disorders.

Finally, another strength of this thesis that is worth considering is that all the findings in this thesis were analysed by both a classical ANOVA and a Bayesian statistical analyses. Using both these types of statistical analysis has its advantages as the Bayesian analyses provides more confidence in the findings from the more traditional ANOVA, and also allows me to draw more definite inferences from null results. As a result, most significant findings from the ANOVAs in the studies in this thesis were supported by the reported Bayes factors. This meant that we were able to know the likelihood that the data supported the alternative relative to the null hypothesis as a ratio between the two.

Alternatively, like majority of behavioural experiments, weaknesses are inescapable. Firstly, what could be listed as limitation in this thesis is the methodology of how Movement Time in Chapter five was measured. For instance, movement characteristics such as the start and end point of each movement, and the spatial-temporal features of the actions participants performed was not recorded or coded by motion capture software. This may have made the movement times less well defined as some would argue that the raters accuracy in capturing the same endpoint of each movement on the video analysis software would be inconsistent and the spatial accuracy of the spatial-temporal features of the action's participants performed would be less well defined. Although the rater tried to make sure the same endpoint of each movement on the video analysis software was consistently captured, the University lab did not have motion capture software technology. Therefore, those who attempt to replicate this study should consider exploring video analyses software like "DeepLabCut" to quantify movement kinematics and monitor spatiotemporal features of the movement actions.

Another disadvantage of how MT was measured was that it was interpreted by one rater's subjective judgment. The lack of inter-rater reliability between different raters makes it difficult to infer that the correct movement times were the true representations of MT. As a result, it is difficult to draw any conclusions from the MT results as it may have a reduced degree of the validity for the possibility of generalizing the results. As such, adopting a different set of raters to assess the MT results would provide a more reliable evaluation of the results.

Lastly, another limitation in this thesis is that that the pilot study outlined in chapter 3 did not have a quantifiable measure of the constituent functional use movements between tool pairs that had the same functional use action or a different functional use action. In other words, the movements made in each condition (i.e SA and DA conditions) were not validated objectively, rather, the similarity/differences between functional use action between tool pairs was based on a subjective judgment through participants perceiving the tools and making declarative judgements on the actions between tool pairs (i.e., the way in which we manipulate them to perform their function). As a result, the lack of validation through the measurement and comparison of constituent movements may suggest that the stimulus pairs in condition SA and DA may have not been a reliable factor in predicting priming effects or lack thereof. Therefore, comparing both objective and subjective measurers to report the relationship between the similarity or differences in the functional use actions associated with the different pairings of tools would be a better way of validating the null findings in study 3.

V. Conclusions

This thesis has made various contributions to our understanding of how affordances related to the grasp and/or functional use actions between real and pictorial tool pairs are processed within various tool processing outputs. First, the results have highlighted that affordances related to the grasp and/or functional use actions between tool pairs does not facilitate in how tools are pantomimed, named, or manipulated. This is because you have to retrieve the stored conceptual knowledge of the similarities between action related properties between tools in order for priming effects to occur. These findings challenge previous evidence demonstrating that the affordances evoked by object features can facilitate in object recognition and manual responses towards subsequent tools- particularly in the context of the embodied cognition literature. Second, the findings from study 2 and 3 demonstrate that real tools that afford actions do not influence how the action related properties of tools are processed more than pictures of tools. This has made an important contribution to our understanding of how real tools compared to pictures of tools do not provide an advantage in how the action related properties of tools are processed. Third, the findings from this thesis demonstrate that participants do not retrieve the similarities or differences in the functional knowledge between tool pairs when they are presented in succession. Instead, I have proposed that they are identifying each tool as a novel tool and are therefore processing each tool processing output based on the tool that they are identifying, and not associating the grasp and/or functional use actions between tool pairs.

Taken together, this thesis informs theories of the distinction between the visual system when processing visual information for object recognition and the retrieval of the stored sensorimotor knowledge about how a tool is manipulated. Furthermore, the findings in this thesis have important implications for embodied theories of cognition, particularly with regard to how sensorimotor processes play a role in cognitive processing related to the understanding of actions and tools. It is now clear that presenting tools that share the same action-related attributes in succession (i.e., how they are grasped and/or functionally used) does not influence the mechanisms with which we pantomime name or manipulated tools with similar affordances. Moreover, the affordances that are evoked by real tools do not provide any differences or advantages in the way the action related properties between tool pairs are processed. Therefore, the way in which tools are processed is not a by-product of the differing modalities in which humans have been exposed to objects within our environment.

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COLLEGE OF SCIENCE, HEALTH & ENGINEERING

MEMORANDUM

To:	**Philippe Chouinard – Department of Psychology & Counselling**
Student:	**Hayden Peel, Georgina Amos, Rachael Goldsmith**
From:	**Secretariat, SHE College Human Ethics Sub-Committee (SHE CHESC)**
Reference:	**FHEC14/R74 - Ethics application for modification to project - Approved**
Title:	**Vision experiments in typical adults**
Date:	**22 August, 2017**

Thank you for submitting your modification request for ethics approval to the SHE College Human Ethics Sub-Committee (SHE CHESC) for the project referred to above. The CHESC has reviewed and approved the following modification/s which may commence now:

- **Addition of Mutindi Kithu as a student investigator.**
- **Addition of the use of recording videos of the hand and forearm while participants perform hand movements on objects**

Please note that your request has been reviewed by a sub-committee of the UHEC to facilitate a decision before the next Committee meeting. This decision will require ratification by the UHEC and it reserves the right to alter conditions of approval or withdraw approval at that time. However, you may commence prior to ratification and you will be notified if the approval status of your project changes.

The following standard conditions apply to your project:

- **Limit of Approval.** Approval is limited strictly to the research proposal as submitted in your application while taking into account any additional conditions advised by the SHE CHESC.
- **Variation to Project.** Any subsequent variations or modifications you wish to make to your project must be formally notified to the SHE CHESC for approval in advance of these modifications being introduced into the project. This can be done using the appropriate form: *Ethics - Application for Modification to Project* which is available on the Research Services website at http://www.latrobe.edu.au/researchers/starting-your-research/human-ethics. If the SHE CHESC considers that the proposed changes are significant, you may be required to submit a new application form for approval of the revised project.
- **Adverse Events.** If any unforeseen or adverse events occur, including adverse effects on participants, during the course of the project which may affect the ethical acceptability of the project, the Chief Investigator must immediately notify the chesc.she@latrobe.edu.au. Any complaints about the project received by the researchers must also be referred immediately to the SHE CHESC Secretary.
- **Withdrawal of Project.** If you decide to discontinue your research before its planned completion, you must advise the SHE CHESC and clarify the circumstances.
- **Monitoring.** All projects are subject to monitoring at any time by the SHE CHESC.

- **Annual Progress Reports.** If your project continues for more than 12 months, you are required to submit an *Ethics - Progress/Final Report Form* annually, **on or just prior to 12 February**. The form is available on the Research Services website (see above address). Failure to submit a Progress Report will mean approval for this project will lapse.
- **Auditing**. An audit of the project may be conducted by members of the SHE CHESC.
- **Final Report.** A Final Report (see above address) is required within six months of the completion of the project**.**

If you have any queries on the information above or require further clarification please contact me at chesc.she@latrobe.edu.au.

Ms Kate Ferris
Human Ethics Officer
Secretariat – SHE College Human Ethics Sub-Committee
Ethics and Integrity / Research Office
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COLLEGE OF SCIENCE, HEALTH & ENGINEERING

MEMORANDUM

To: Philippe Chouinard – Department of Psychology & Counselling

Student: Hayden Peel, Georgina Amos, Rachael Goldsmith

From: Secretariat, SHE College Human Ethics Sub-Committee (SHE CHESC)

Reference: FHEC14/R74 - Ethics application for modification to project - Approved

Title: Vision experiments in typical adults

Date: 28 March, 2017

Thank you for submitting your modification request for ethics approval to the SHE College Human Ethics Sub-Committee (SHE CHESC) for the project referred to above. The CHESC has reviewed and approved the following modification/s which may commence now:

- **Remove Student investigators - Joshua Sherman, Daniel Wright, Lucy Carolan & Regan Kneller.**
- **Change Georgina Amos from Research Assistant to student investigator.**
- **Addition of new Student investigator - Rachael Goldsmith.**
- **Extension of time to 2 April, 2020.**
- **Change compensation from cash to Coles / Myer vouchers.**
- **Add "lifting" as one of the options participants will do with task stimuli presented in front of them.**
- **Additional study location on Bundoora campus, Biological Science 2 Building, Room 1.02.**
- **Consent forms also be stored in a locked filing cabinet in Biological Science 2 Building, Room 1.02.**
- **Change to recruitment methods to include putting ads in the Bundoora campus and inclusion of social media geared towards members of the entire university community.**
- **Change destruction of all data after 5 years from completion to storing all data in an electronic and completely non-identifiable manner in repository available to the public until perpetuity.**
- **Add a Yes/No check box to the consent form asking participants whether or not they would agree to be contacted in the future to be invited to participate in future experiments, which they will have to sign a new consent form in order to participate**.

Please note that your request has been reviewed by a sub-committee of the UHEC to facilitate a decision before the next Committee meeting. This decision will require ratification by the UHEC and it reserves the right to alter conditions of approval or withdraw approval at that time. However, you may commence prior to ratification and you will be notified if the approval status of your project changes.

The following standard conditions apply to your project:

- **Limit of Approval.** Approval is limited strictly to the research proposal as submitted in your application while taking into account any additional conditions advised by the SHE CHESC.
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- **Auditing**. An audit of the project may be conducted by members of the SHE CHESC.
- **Final Report.** A Final Report (see above address) is required within six months of the completion of the project**.**

If you have any queries on the information above or require further clarification please contact me at chesc.she@latrobe.edu.au.

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