TESTING THE EMBODIED ACCOUNT OF OBJECT REPRESENTATIONS

by

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For the participant who asked me, “What could be more fascinating than the human mind?”

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ABSTRACT

Theories of embodied cognition propose that sensorimotor experiences constrain visual cognitive process. Specifically, these theories posit that object concepts are represented by simulations within modality-specific cortices. These theories make two critical predictions about the role of sensorimotor simulations in representing manipulable versus non-manipulable objects. First, sensorimotor simulations are *functionally* necessary during visual cognitive tasks. That is, in visual processing of objects, simulations are involved in producing successful performance (e.g. object naming). Second, sensorimotor simulations are *coactivated* in response to the visual presentation of objects. That is, we should observe evidence for incidental sensorimotor simulations during the performance of visual cognitive tasks (e.g. orientation judgments). I conducted two studies to test these hypotheses. In the first, I employ a concurrent motor task during an object-naming experiment in an attempt to disrupt sensorimotor simulations. Using this paradigm, I failed to show evidence that concurrent motor activity selectively impairs manipulable object naming; rather, I show that a concurrent motor task affects naming *across* categories of objects. In the second, I investigate behavioural evidence for coactivated sensorimotor simulations in response to the visual presentation of objects. I show a 'motor potentiation effect' for both animals and artifacts, a finding that cannot be explained by coactivation of sensorimotor simulations. In the other studies reported here, I adopt eye-tracking and electrophysiological techniques to investigate ways in which visual attention is biased by artefact and animal stimuli and show covert and overt attentional biases for the handle of manipulable objects. Overall, the results in the present set of studies are more parsimoniously accounted for by a general bias in visual attention that is determined by factors such as experimental task, rather than embodied object representations. I conclude that we must abandon a strong form of the embodiment hypothesis.

LIST OF ABBREVIATIONS AND SYMBOLS USED

RT	Reaction time
ERP	Event related potential
fMRI	functional Magnetic Resonance Imaging
TMS	Transcranial Magnetic Stimulation
CDZ	Convergence-Divergence Zone
FLSD	Fisher's Least Significant Difference
ANOVA	Analysis of Variance
LME	Linear Mixed Effects model
$\acute{\eta}^2_G$	Generalized eta squared
M	Mean
SD	Standard deviation
μV	Microvolts
IA	Interest Area
ms	Milliseconds
MUA	Mass Univariate Analysis
Hz	Hertz
N	Total sample size
DPI	Dots per inch
CRT	Cathode ray tube

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

Since the cognitive revolution of the 1960s, information-processing theories have dominated experimental psychology, providing methods for understanding human cognition and shaping the discipline's ideas about what constitute mental processes. These ideas have their roots in metaphors about computers and the way software is executed in hardware. Whether explicitly or implicitly, most theories in cognitive psychology assume that the brain is an information processing device, receiving and transducing sensory input (like a user inputting information into a computer), transforming it through some relatively specialized algorithmic process (like the programming codes that manipulate that input) and producing a meaningful output (like writing an output to a screen). These ideas are nicely captured by the seminal works by, for instance, Fodor (1983) and Marr (1982). Classic applications of this framework have resulted in accounts of cognitive processing that are largely serial and modular, with different processes specializing in particular types of information and transforming it in particular ways. An important feature of these theories is the notion that the cognitive processes produced by the brain can be understood as algorithms that operate on representations that are 'amodal', independent of the sensorimotor systems that allow us to interact with our environments. Therefore, the cognitive system's representations are symbolic and abstract. This property allows them to be implemented in any medium, including, of course, the very thing that they are inspired by: computers.

Emerging from increasing dissatisfaction with these approaches (due largely to their silence regarding action), theories of embodied cognition are providing a powerful alternative way of understanding the mind and its relationship to brain function. Embodied theories stand in stark contrast to classic informational processing theories of cognition. Though, as will be shown, there is no single unified ‘embodied theory’ of cognition, all of the current proposals assume that *sensory-motor experiences constrain and shape cognitive processes*. In other words, cognition is *derived* from sensory-motor experiences (see Garbarini & Adenzato, 2004). According to this account, cognition is shaped not by amodal representations implemented in the software of the brain, but rather, the types of body that constrain it, the brain that implements it, and the environments we interact with. At their roots, embodied theories reject the notion that cognition is best understood as a computer and better understood as a biological, grounded system constrained by experience.

1.2 THE EMBODIED COGNITION HYPOTHESIS

Much philosophical thought and experimental research has been called ‘embodied’. In a comprehensive survey of the burgeoning field, Shapiro (2011) defines three categories of different embodied hypotheses. The first is what he calls the *replacement hypotheses*. For researchers who endorse this hypothesis mental representations are not needed for cognitive processes, and, consequently, there is no need to model cognition as algorithmic. For instance, robots that have an ‘embodied neural architecture’ can navigate complex environments much more effectively than robots based on traditional information processing architectures (see Brooks, 1991). The second hypothesis described by Shapiro is the *constitution hypothesis*. Here, researchers believe that cognitive systems are actually *made up* of the body and the environment (i.e. the environment is a part of cognitive processing; see e.g. Clark and Chalmers, 1998). For instance, this might be argued when a person uses a grocery list to remember which items to pick up on the way home. Although these two 'embodied' hypotheses are intriguing, and they obviously have consequences for understanding cognitive science in the broader sense, they have had relatively little impact on experimental cognitive psychology and cognitive neuroscience and might be best left to researchers and philosophers concerned with artificial intelligence and the ontology of the concept of *cognition*.

The third category of hypotheses that Shapiro (2011) identifies is what he calls the *conceptualization hypotheses*. According to researchers endorsing this hypothesis, cognitive processes are not only constrained by the body and its modal sensory systems, but simulations and reactivations in these systems are the basis of cognition—identifying objects, thinking and reasoning about people and places, solving emotional problems and planning for the future. According to this view of embodiment, to know that an object lying on the table is a hammer, we must simulate (or reactivate) our experiences with a hammer—visual, auditory, and sensory-motor. Additionally, in the future, when thinking about a hammer, we use similar simulations as the basis of our cognitive operations. Indeed, all of our thoughts about hammers will rely on these modality-specific simulations in some way. By extension (and perhaps this is the most radical consequence of the conceptualization hypothesis) even our abstract thoughts rely on these simulations—thoughts about 'hammering our argument home' or perhaps what it means to 'hammer away at a task'. It is the *conceptualization hypothesis* that has attracted the most attention in experimental cognitive psychology and cognitive neuroscience and underlies the research questions addressed by the present series of studies.

1.2.1 Why Embodied Theories?

Before discussing models and evidence for embodied theories, it is useful to consider why they are appealing. Given the long history and success of information processing theories of cognition, why is an alternative, embodied account necessary? There are at least two advantages to the *conceptualization hypothesis* when compared to an information-processing hypothesis. First, because they are based on our understanding of functional neuroanotomy, embodied theories are neurologically constrained. Cognitive neuroscientific methods (including functional Magnetic Resonance Imaging (fMRI), Event-Related Potentials (ERPs), and single cell recordings have provided evidence that the brain does not implement serial, hierarchical, processes. Further, the concept of a strictly independent module has been challenged by research showing that in many cognitive tasks the entire brain is involved, even in simple visuo-attention tasks (e.g. Gonzalez-Castillo et al., 2012). Many researchers now argue that the brain is best understood as a parallel network (e.g. McClelland & Rumelhart, 1981), one that is amenable to network analyses (see Sporns, 2011) and even dynamic systems theory (e.g. see Shapiro, 2011). Though it is certainly possible for a 'neuroagnostic' information processing theory to be internally consistent, highly predictive, and useful in generating new research questions, the incorporation of functional neuroanatomy into a theory of cognition helps constrain our theories of cognitive processing. It seems that, in the end, this approach will ensure the most neurologically plausible account of human cognition.

The second advantage of the conceptualization hypothesis is that it does not suffer some of the biggest shortfalls of amodal information processing approaches. For instance, it avoids difficult concepts like *top-down processes*, and *central executives*, both of which sit in information processing theories like homunculi mysteriously controlling information flow. Instead, it aims to elucidate information flow during all aspects of cognitive operations at all points in time. Because of this, the conceptualization hypothesis eliminates the redundancy that is within most amodal accounts. That is, amodal theories essentially posit that concepts are duplicated in the brain, represented independently at a sensory level (the features that make up modal processing) and again at a *semantic* level (where they are represented abstractly and can be manipulated by central executives). Embodied theorists argue that the brain did not evolve two different and independent systems for processing *and* representing stimulation from the environment. Finally, and perhaps most importantly, it has been argued that any 'amodal' account of cognition is inherently unfalsifiable, as it equates to a Turing machine which is capable of re-producing any pattern (Barsalou, Simmons et al 2003); that is, there is a *post-hoc* amodal explanation for any cognitive operation. The conceptualization hypothesis makes strong commitments about the role of modality-specific activity in cognitive processes and therefore constrains, *a priori*, the types of predictions one can make. Overall, as we will see, the conceptualization hypothesis does not suffer these shortfalls and instead makes explicit predictions about the flow of information within the brain, what constitutes a representation of a concept, and provides strong predictions about brain activity and behaviour.

Embodied theories are not undisputed (see Caramazza & Mahon, 2003 for an introduction to specific, alternative accounts of conceptual organization; see also Capitani, Laiacona, Mahon, & Caramazza, 2003; Dove, 2011; Mahon & Caramazza, 2008). However, regardless of these theoretical arguments (for the purpose of the present research we do not have to decide which theory is better), there is at least one final advantage of the conceptualization hypothesis, one that I wish to stress in considering the present set of studies. Minimally, the conceptualization hypothesis directs our attention to the role of the modalities in cognition, something that traditional accounts often neglect (Barsalou et al, 2003). A research program aimed at addressing this issue will promise to reveal the contributions of modality-specific processes to a wide variety of cognitive operations, from basic object representations to abstract reasoning, regardless of whether the cognitive system is best construed as an embodied system or as an amodal information-processing device.

1.3 MODELS OF EMBODIMENT; OR, THEORETICAL COMMITMENTS OF THE PRESENT RESEARCH

Though there is no single agreed upon neuropsychological model of embodied cognition there are at least two that provide a strong theoretical foundation[1]. It is from this perspective that the current research program is undertaken. Fundamentally, both of

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[1] Note that nascent ideas about embodiment appear in Allport (1985, p 53), who was one of the first cognitive psychologists to posit "…that the same neural elements are involved in coding the sensory attributes of a (possibly unknown) object presented to eye or hand or ear also make up the elements of the auto-associated activity-patterns that represent familiar object-concepts in "semantic memory"". Further, J.J. Gibson's affordance hypothesis (see Gibson, 1986) is often described as an early form of embodiment. Finally, ideas of embodiment can be traced to James, who suggested that "never is the body felt all alone, but always together with other things," and also his speculations about the role of the body in generating emotional reactions (see James, 1890, Chapter 10).

these architectures share the assumption that Hebbian processes of association (see Hebb's neurophysiological postulate; Hebb, 1949, pg 62) underlie the functional organization of the brain and that the cognitive system that is implemented by it-- that collections of neurons that are active during the experience of a particular event (e.g. the visual and auditory consequences of watching a hammer) become functionally connected (i.e. neural ensembles) and are more likely to be activated together at a later time. (There is now a wide variety of molecular neuroscientific evidence for these types of associative processes, that neural connections are reweighted, reconnected, rewired, and perhaps even regenerated; see Seung, 2012, for a discussion). In these models, it is collections of neural ensembles or cell assemblies that are activated during an experience and are later reactivated during cognitive operations.

The first model has been developed by Antonio Damasio and his colleagues over the last couple of decades (see Meyer & Damasio, 2009). He calls it the *convergence-divergence zone (CDZ) framework* (see Figure 1.1).

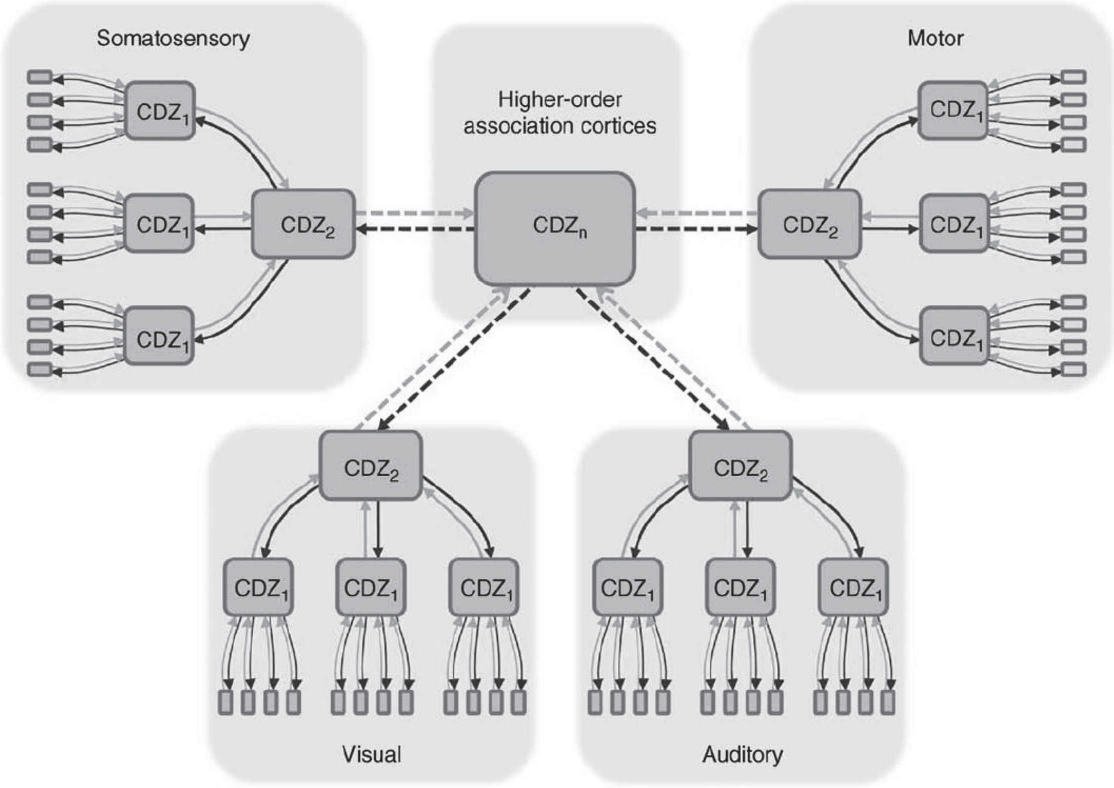

Figure 1.1. A schematic of the convergence-divergence zone (CDZ) framework. Higher-order CDZs can retroactivate simulations in modality specific cortices to support cognitive tasks such as object naming or recognition. Reproduced from Damasio and Meyer (2009) with permission from the publisher.

This theoretical architecture is as follows. First, at its core are neural ensembles that process basic sensory information in the different modalities. For instance, distinct neural ensembles have evolved to detect edges of different orientations in the visual system and different pitches in the auditory system. These are best viewed as *feature maps*, as they quite explicitly map the features of the environment by signalling the presence of various stimulus configurations. These sensory ensembles then converge on other neural networks beyond primary cortices (i.e. the association cortices). Then these networks converge on other secondary, networks, and so on (up and up to what are typically considered the most evolved structures within the anterior cortices, including the pre-frontal cortex and temporal poles). Anatomically, these convergence zones are well-situated to process information that comes from different modalities, and given this pattern of connectivity, convergence zones receive information about the relative timing of activations in different modalities. In this way, the higher order convergence zones hold records of different collections of sensory-motor experiences. According to Damasio, these regions are best thought of as *dispositional ensembles*, as they hold the disposition to reactivate modality specific cortices that were active during experience. However, as pointed out by the author, these zones themselves cannot be said to possess any *knowledge*, but rather they possess simply the *potential* to reactivate components of experience. The key feature of this architecture is that each convergence zone also sends divergent back-projections towards the neural ensembles they receive information from, allowing them to retroactivate different modality-specific ensembles in a simulation of a previous experience. It is not assumed that these retroactivations are complete, nor is it assumed they are conscious (though they could be).

It is argued that these ‘simulations’ form the basis of all cognitive processes, including object perception and recognition. Sensory-motor systems map stimulus-specific sensory information of objects (e.g. the feeling of the hammer’s handle, the sound it makes on wood, the sight of its motion, the shape of its edges) that unfold during interactions with them. These maps are constantly updated as experience unfolds. But by virtue of the functional relationships between sensory and motor regions and association cortices, different suites of experiences are stored as dispositions in higher-level zones, and can be reactivated during tasks of recognition (and presumably naming and categorization). For instance, under certain tasks the visual presentation of a hammer should activate hammer related experiences in other modalities, allowing us to demonstrate knowledge by eventually naming or categorizing the stimulus.

There are a number of important points to make about the CDZ framework as it relates to the present research program. First, this architecture avoids the perennial problem of the grandmother cell (Meyer & Damasio, 2009), a single point in the cognitive system at which all information pertaining to a concept converges (and represents, for instance, the concept of a hammer). This is because, according to this model, a concept as richly experienced as a hammer will involve multiple convergence zones retroactivating multiple aspects of the 'hammer' experience. Therefore, one would not hypothesize that the concept of a hammer could be completely eradicated by lesioning a specific neural site, though the notion of failing to recognize the object through one modality while retaining the ability to recognize it through others, as happens in the case of, for instance, visual agnosics (see Farah, 1990) becomes easily explained. Second, (though this is not explicitly detailed by Damasio himself), this model presents a way 'top-down' processes might be implemented in cognitive tasks, for example, under different task instructions (i.e. different attentional demands). For instance, neural structures implicated in the control of attention (which themselves are convergence zones, for example the anterior cingulate cortex or areas of prefrontal cortex[2]; see Posner & Rothbart, 2007 for neural networks involved in executive attention;

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[2] Though there is no consensus about what constitutes a higher order convergence zone, recent efforts towards this goal are being made by using network analysis to estimate various characteristics of neural networks based on the reciprocal connectivity of different neural hubs or modules—at least in the macaque monkey (see Sporns, 2011). These efforts are revealing that the areas implicated in psychological studies of attention and complex executive tasks are highly reciprocally connected with modality-specific sites. An important point to emphasize is that these regions are not 'executive functional'

see Sporns 2011 for a discussion of neural hubs) can bias processing by inducing changes in the firing potential of neural ensembles within the maps that correspond to the attended feature (e.g. increasing the neural 'gain' of the response of extrastriate visual regions that map object features or extrapersonal space; see Hillyard, Vogel, & Luck, 1998; Yantis & Serences, 2003). Third, and perhaps most importantly, this architecture changes the way cognitive psychologists think about what is typically considered *semantic* memory (as clearly identified by Allport, 1985). That is, in a classic amodal information processing theory, semantics-- the meaning of an object--is stored in some module of the cognitive system and is accessed and retrieved by other cognitive modules depending on the task. In the CDZ framework, semantics is a property that emerges from the dynamic evolution of processes that unfold during a CDZ retroactivation; semantics is not a place, but a process, and complete collections of knowledge are not stored but are re-experienced and demonstrated. More specifically, what is represented in higher order convergence zones is not semantic information about an object *per se*, but rather the instructions to rebuild, dynamically, the aspects of experience. (By analogy, what is represented in a sequence of nucleotides is not eye-colour but the instructions to build an eye with a particular colour.) According to this account of semantics, there is no part of the cognitive system that needs to access an amodal representation of abstract information about hammers. These features of the CDZ underlie much of the reasoning behind the design and interpretation of the data presented in the following series of experiments.

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in the sense of representing decision making processes, but gain their ability to influence information flow through reciprocal connectivity and experience; thus, like 'semantics', 'executive functioning' is procedural (Sporns, 2011).

A second implementation of embodiment extends Damasio's CDZ framework. Barsalou and colleagues have developed what they call *perceptual symbols systems* theory (see Barsalou, Simmons, Barbey, & Wilson, 2003). As in the CDZ framework, concepts are represented through retroactivations of modality-specific information. These retroactivations may be incomplete, and may be unconscious. Importantly, Barsalou is adamant that convergence zones may behave as an amodal region in some circumstances, but that their propensity to reactivate is likely modality-specific and therefore it is not appropriate to think of these zones as 'amodal'. Further, Barsalou extends the CDZ framework by suggesting that processes related to attention help shape the types of sensory-motor information that constitute different concepts. For instance, when viewing a scene, attentional processes prioritize only components of what is experienced, and this increases the chances that those components will become part of the object's representation. In this way, the representation of different stimuli may be 'weighed' towards different types of information in a particular sensory-motor modality. That is, simulations become 'situated' such that the activation of the hammer simulation might not encompass all possible combinations of sensory-motor components, but will depend on the goal and experiences of the observer.

Together, these models serve as a general framework for understanding how the brain represents a concept like a 'hammer'. A number of reviews discuss these models in more detail and highlight a broad range of evidence in favour of an embodied framework, including research on memory, semantics, language, abstract thought, social psychology, and early development (see Meyer and Damasio, 2009; Barsalou, 2008; see also Wilson, 2002). However, despite this overwhelming body of evidence for simulation processes in cognitive tasks, the degree to which the representations of concrete objects are embodied, and the involvement of such embodied representations in tasks such as naming or categorization, remains unclear. The role of sensory-motor systems in representing concrete objects during visual tasks is an important question to address because there are clear differences in modality-specific activity elicited by different objects (see Figure 1.2). Hence, their representation should reflect this, if embodied views of cognition are correct.

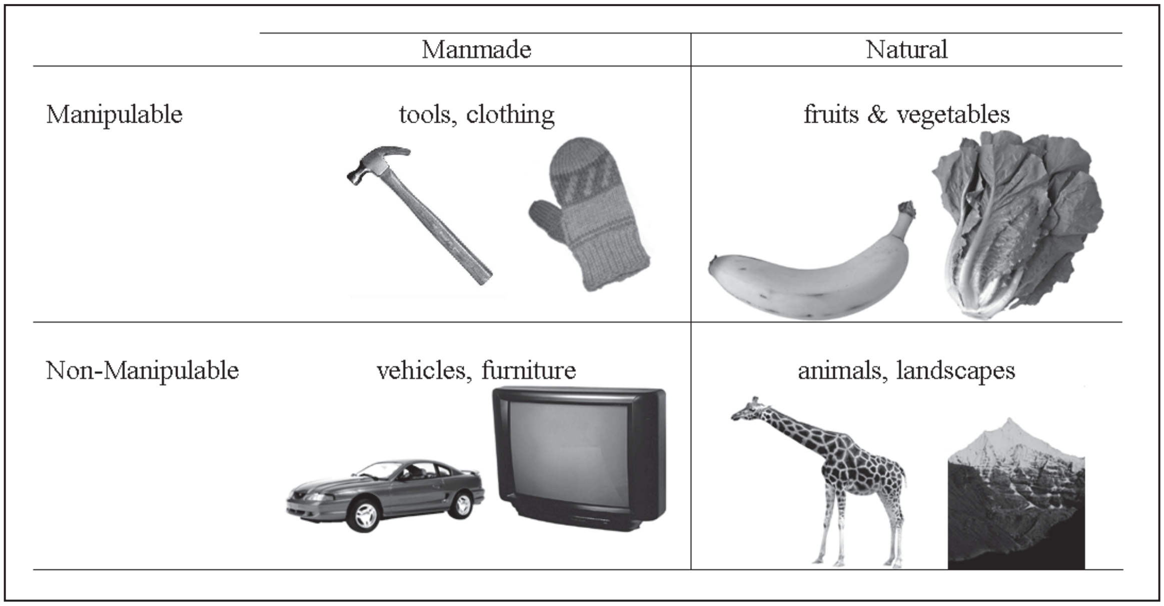

Figure 1.2. Example method of categorisation of types of object-types.

For instance, while visual and auditory processing should occur while processing a giraffe or a hammer (the form and sounds they make), only the hammer will be associated with motor experiences (i.e. grasping or using). In this way, objects can be categorized as either manipulable or non-manipulable (see Salmon, Filliter, & McMullen, 2010). With respect to concrete objects then, the embodied account of object representations makes a number of clear predictions about the brain and behavioural consequences of these different processes in tasks of object processing. For instance, according to this account there should be a clear relationship between visual representations (visual modality-specific activity) and action representations (sensory-motor modality-specific activity) for objects that we can manipulate, but not for non-manipulable objects. Specifically, embodied accounts predict that the visual presentation of manipulable objects should activate motor associations that could facilitate or interfere with action production. Similarly, extending this line of reasoning, motor production should interfere with or facilitate associated visual processing. Neurophysiologically, there should be distinct neural ensembles that integrate information about action and vision. Additionally, we can predict that these relationships become stronger in development, and may become compromised in neuropsychological patients. In the review below, I show that there is general support for these claims. However, as I will highlight, a number of important issues remain unclear. The present research attempts to address these issues.

1.4 EVIDENCE FOR EMBODIED OBJECT REPRESENTATIONS

Evidence bearing on the question of embodied object representations and their involvement in visual tasks comes from a number of sources, including neuroimaging, neuropsychology, developmental psychology, single cell recordings, and of course, behavioural studies of cognition. The most pertinent body of literature to the question of embodied object representations addresses how visual and action representations are related.

1.4.1 Neuroimaging

One of the most obvious predictions of an embodied account of object representations is that viewing manipulable objects should elicit activity in visual *and* motor cortices, while viewing non-manipulable objects should elicit activity in only visual cortices. It is well established that visual information, after reaching the primary visual cortex, is processed in separate 'streams' (see Milner and Goodale, 1995). Information about object shape and colour is processed in the ventral stream, extending from V1 into the inferior temporal lobes, while information about an object's movement, its location in space, and the metrics needed to grasp it are processed dorsally, in the posterior middle temporal gyrus and regions of the anterior inferior parietal lobe. During tasks of visual perception and action these two streams seamlessly interact (see Matheson & McMullen, 2010). Despite this interaction, the notion that there are separate ventral and dorsal cortical streams that process different visual properties is generally taken as evidence that different object features are encoded in distributed neural networks (i.e. form vs. motion or action; see Chao, Haxby, & Martin, 1999). This claim was supported by PET research (Martin, Wiggs, Ungerleider, & Haxby, 1996) showing that, although naming images of animals and tools activated overlapping ventral visual cortical structures, there were category-specific activations in the occipital lobe in response to animals and unique premotor activations in response to tools (manipulable objects). An embodied account of object representation is consistent with his pattern of brain imaging.

Additional research has shown that the visual presentation of a manipulable object activates regions associated with motor activity. For instance, PET studies have shown activation in premotor cortex in response to tools during passive viewing, naming, and describing a tool's actions, findings interpreted as evidence that the premotor cortex partially represents object semantics (e.g. Grafton, Fadiga, Arbib, & Rizzolatti, 1997). fMRI results have revealed fronto-parietal activity during passive viewing of manipulable objects (e.g. Chao & Martin, 2000). Activation in dorsal regions has been reported when participants are instructed to imagine manipulating visually presented objects, including the inferior parietal cortex; importantly, in these imagery conditions activity extends to the prefrontal cortex, the motor cortex (in some cases), and the supplementary motor area (see Grèzes & Decety, 2001). Similar findings have been reported in an upright/inverted judgment task of manipulable objects (Grèzes & Decety, 2002). The degree of ventral and dorsal cortical involvement in representing manipulable objects does depend on task in certain cases, with 'semantic' tasks (e.g. word retrieval, semantic decisions) typically resulting in more activity (Devlin et al. 2002). Overall then, it seems that manipulable objects do elicit motor-related cortical activity while non-manipulable objects do not, a finding consistent with embodied accounts.

Importantly, this interpretation depends on the notion that parietal and/*or* frontal activity constitutes an embodied representation, despite the known differences in their contributions to action planning and execution, respectively (for a review see Kellenbach, Brett, & Patterson, 2003). However, some researchers have made an important distinction that helps clarify the unique contributions of these regions. In one study, Creem-Regehr and Lee (2005) distinguish between actions associated with the structure of the object and actions associated with the function of the object. These authors showed participants 3-D images of objects that afforded a grasp under both a passive viewing condition and an imagined grasping condition. Half of the objects had known functions (e.g. a hair brush) while the other half did not (e.g. an elongated block). In the passive viewing task, tools activated posterior parietal and premotor regions (suggesting that an intention to act is not necessary to activate these regions) and the middle temporal gyrus. A similar result was observed with both tools and non-tool shapes in the imagined movement condition. However, there was some evidence that frontal regions were recruited more for the familiar objects (e.g. hair brush vs. elongated block), suggesting that experience with an object's function constrains the way functional knowledge is represented compared to structural knowledge. This suggests that frontal regions may be more important for functional associations, whereas parietal regions might be more important for planning basic structural grasping.

Together, these results are consistent with the embodied account of object representation and do provide some evidence that manipulable objects elicit motor representations, either those related to the structural properties of objects or their functional properties (I discuss this difference more later). However, an important issue arises from the neuroimaging literature. Specifically, it is unclear whether sensory-motor representations play a *causal* role in cognitive tasks and actually manifest behaviourally; that is, it is unclear whether these representations are necessary to perform cognitive tasks, or that they facilitate them in any way. Indeed, the finding that passive viewing of manipulable objects elicits fronto-parietal activity provides only correlational evidence at best. The apparently automatically-activated neural-networks for action can readily be explained by a passive, Hebbian association; no real consequence for performing a cognitive task is dictated by these findings. That is, their action may be inconsequential in performing the task.

1.4.2 Neuropsychology

It is well documented that lesions to different regions of the cortex can result in category-specific deficits in object recognition. Warrington and Shallice (1984) reported patients who had deficits in identifying animals but relatively intact identification of tools. The reverse pattern has also been shown (e.g. Gonnerman et al., 1997; see also Hills & Caramazza, 1991 for a double dissociation between non-manipulable and other manipulable objects like fruits). Though there is much debate about the interpretation of these results (e.g. see Capitani et al., 2003) this double dissociation suggests that object representations are distributed over modality-specific cortical regions, and hint to the notion that different experiences with manipulable and non-manipulable objects results in modality-specific representations. However, these results do not provide any support for the notion that sensory-motor activity is important for object processing.

Whether sensory-motor activity is important for object processing is addressed by patients with visual apraxia. Apraxia is a multifaceted disorder resulting in impaired motor function (that cannot be attributed to basic movement disorders) after lesions to many different cortical and subcortical regions (see Petreska, Adriani, Blanke, & Billard, 2007 for a detailed review). Though there is no standard taxonomy of apraxic disorders (the review by Petreska et al 2007 characterizes thirty different sub-types), most patients are characterized as either *ideational/conceptual* or *ideomotor/sensory-motor*.

Ideational/conceptual apraxia is typically associated with deficits in the execution of planned action-sequences (e.g. using a hammer to hammer a nail; for instance, see de Renzi & Lucchelli, 1988). These patients have preserved motor abilities (they can pick up a nail and can use a hammer), but may, for instance, execute sequences of actions out of order (e.g. trying to use the hammer before reaching for the nail). Conversely, in ideomotor/sensory-motor apraxia, deficits in the control of the limbs or hands impair the proper manipulation of objects. In one investigation (de Renzi, Faglioni, & Sorgato, 1982), researchers attempted to elicit demonstrations of object use by a) verbal command (e.g. “Pretend to hold a hammer and show me how you would use it”), b) visual presentation (e.g. the object was put on the table and the patient was asked “Show me how you would use it” without actually manipulating the object) or c) tactile presentation, in which the blindfolded subject was given the object and asked to demonstrate its use. Participants typically struggle to appropriately manipulate the objects. In some patients the apraxic deficit was most pronounced for the visual presentation of the object. This suggests that the organization of action was disrupted during the visual presentation of an object specifically, though not disrupted all together. It is tempting to hypothesize that ideational/conceptual apraxia results from a deficit in functional associations that rely on frontal cortices, and that ideomotor/sensory-motor apraxia results from a deficit in instructions for grasping that rely on the parietal lobe, but the neuropsychological literature shows that this is an oversimplification; the anatomical substrates of different apraxic disorders are variable (see Petreska et al 2007).

Importantly, the embodied account of object representations makes a clear prediction about the effects of apraxic disorders on object processing. Specifically, if motor simulations play a role in representing knowledge about an object, then apraxic patients—unable to use intact simulations due to cortical damage—should show deficits in visual cognitive tasks pertaining to manipulable objects. Specifically, apraxia should be associated with some deficits with manipulable objects, either naming, categorizing, object decisions, or the like. However, it is well established that object use and object naming are double dissociated. For instance, Negri et al. (2007), in a large neuropsychological case study, reported four patients who showed deficits in a simple object-naming task though they retained the ability to demonstrate the object's use; conversely, four other patients showed the opposite pattern. This double dissociation is corroborated across studies by other authors. For instance, some studies report intact visual cognitive performance in apraxic patients. Cubelli et al. (2000) report an apraxic patient with intact picture naming and picture word matching (though many of their apraxic patients did indeed show deficits on these tasks). Halsband et al. (2001) report on a small number of patients whose apraxic deficits were clearly manifested by a failure to produce correct pantomimes of tool use; these patients however could still visually identify tools and verbally provide semantic information about tool functions. The other side of this dissociation was clearly provided by Negri et al. (2007), who reported the performance of two patients with semantic dementia, characterized by deficits in semantic tasks including object naming and tests of functional knowledge; however, these patients were able to perform tasks with real common objects. Over all then, it is clear that this neurospsychological dissociation is at odds with a strong from of the embodied object representation; patients *can* perform visual cognitive tasks in the absence of intact motor execution or planning (due to parietal or frontal damage). However, a number of apraxic patients do show deficits in both of these tasks, demonstrating that the deficits may commonly co-occur. This may suggest that these two functions are correlated (see Buxbaum, Kyle, & Menon, 2005 for a similar reasoning with regards to the relationship between action production and action understanding).

A strong association between action and the visual presentation of objects is shown in another group of patients. In a well-cited report, Lhermitte (1983) highlights what he calls ‘utilization behaviour’, in which neuropsychological patients spontaneously act upon objects (i.e. reaching for them, grasping them, and sometimes putting the objects to use) upon the visual presentation of the object. A full description is useful:

> While seated, the patient took a glass, gave it to the examiner and then picked up a jug. He poured water into the glass and, having put down the jug, took the glass from the hand of the examiner and drank the water. Taking a pack of cigarettes, he hesitated a moment, then opened it and drew out a cigarette. He looked puzzled at it, being a nonsmoker. A few seconds later, he held it to the mouth of the examiner who accepted it and taking the lighter which was in the examiner’s hand, near his knees, the patient lit the cigarette. Questioned on this behaviour, he simply said ‘You held out objects to me; I thought I had to use them’. (Lhermitte, 1983, pg 245-246).

The important feature of this type of behavior is that the examiner presenting a visual object does not instruct the patient to act upon it, nor does the patient report intending to act on it. In fact, patients often observe their own behavior with confusion. One patient was shown different pairs of sunglasses during examination and was wearing all three simultaneously by the end of the session. Importantly, in these patients, neurological damage was restricted to the frontal lobes, leading the author to suggest that ‘utilization behaviour’ reflected a lack of inhibition of the automatic activation of motor-behaviours towards objects. In this way, it can be argued that ‘utilization behaviour’ reflects the involuntary nature of motor activation in response to a visual object. Overall then, both apraxia and ‘utilization behaviour’ do suggest a strong link between visual and sensory-motor representations within the brain.

There are a number of other intriguing neurological findings that point to the tight coupling of action and object representations, though they may not address it explicitly. First, in visuospatial neglect, in which patients fail to attend to objects in one side of space, Riddoch et al. (2003) showed that pairs of objects that are related by virtue of action (e.g. wine bottle and corkscrew) were more likely to be reported when they were presented in a compatible way (e.g. corkscrew over wine bottle) compared to an incompatible way (e.g. corkscrew under wine bottle). The authors interpreted this finding as evidence that object-action relations are encoded automatically in vision. Second, embodied theories predict that visual agnosics who show deficits in visually recognizing objects, should have difficulty using perceptual simulations to make semantic decisions about visually similar objects, while decisions about objects that can be differentiated based on motor simulations should remain relatively intact. Using a semantic knowledge questionnaire, Masullo et al. (2012) revealed that is indeed the case. Their visual agnosic patient showed more errors for living things (which are mostly differentiated based on visual features) than artifacts (which can be differentiated based on functional or motor-related features.

Overall, these neuropsychological results suggest a strong relationship between the visual presentation of objects and the activation of action, though some of the most obvious predictions of embodied theories of object representations do not hold (namely, that an intact action system is necessary for visual cognitive tasks). This threatens a strong form of the hypothesis. However, there are a number of possible interpretations of the small body of literature that challenges embodied predictions. First, it is known that substantial alterations to brain function occur after brain damage (i.e. plasticity; e.g. Chollet, et al., 1991). Second, patients might develop behavioural compensation strategies. Third, some models of embodiment (e.g. Barsalou et al., 2003) predict a differential weighting of different modalities in the neurotypical brain. After brain damage (say to motor regions), it is possible that the representations become more heavily weighted to other intact modalities (auditory and visual). Over all then, it is unclear how to interpret the mixed results from neuropsychological case studies.

1.4.3 Neurophysiology

The discovery of mirror neurons in the monkey frontal lobe (i.e. neurons that respond during both the performance and observation of action) has prompted much speculation about the brain's capacity to simulate other people's actions, and it is often argued that mirror neurons are the basis of action understanding (see Rizzolatti & Craighero, 2004). Indeed, the response properties of such neurons appear to validate many assumptions made by embodied theorists and serve as a solid basis of simulation accounts of cognition (see Gallese & Sinigaglia, 2011).

However, the role of mirror neurons in representing object concepts remains unclear. There is a small subclass of visuomotor neurons that are typically called 'canonical neurons' in area F5 of the macaque frontal lobe. Unlike mirror neurons *proper*, these neurons preferentially respond to the presentation of an object or the performance of an action on that object (see Murata, et al 1997). For instance, for some of these neurons, the size of the object affects firing such that those cells that fire during precision grip movements also favour objects that afford precision grips actions; similarly, those that fire during other types of grasping favour larger objects. This suggests that these neurons code complex sequences of movements as they pertain to specific objects (Rizzolatti et al., 1988). This type of neuronal response has been taken as evidence of the automatic activation of motor-representations by the visual presentation of an object and may constitute a neural basis for object affordances (see Garbarini & Adenzato, 2004). Similarly, Ferrari, Rozzi, and Fogassi (2005) have shown a unique class of mirror neuron that prefer responding to the observation of actions that are performed with a tool, what they call 'tool-responding mirror neurons'. These neurons prefer actions that are made with a tool compared to similar goal directed actions without the tool. Though these do not respond to the visual presentation of a tool alone, this result does suggest that such neurons might be representing the action-vision tool relationship for tools. Together, these types of neurons hint towards a simulation of motor actions that occur in response to the visual presentation of objects, and may be a neurophysiological basis of a CDZ convergence zone that can initiate retroactivations across multiple modalities, serving as a basis for manipulable object representations. However, whether these neurons play a role in cognitive tasks remains unknown and, given the lack of language in non-human primates, empirically investigating the role of mirror neurons, canonical neurons, or tool-responding mirror neurons in cognitive tasks remains a challenge.

1.4.5 Development

One prediction of the embodied framework is that differential experience with manipulable and non-manipulable objects will shape embodied representations over time. According to this hypothesis,; as experience with the world accumulates, the reliance on multiple modalities for representation may actually *decrease* as more elaborate and representation begins to form (see Mounoud et al , 2007). Unfortunately, while some lexical research has shown that manipulability is important in conceptual processing throughout development (e.g. Borghi & Caramelli, 2003), and research with real objects shows that children as young as 4 years-old will categorize novel objects based on function over visual similarity (e.g. Kelmer, Nelson, Frankenfeild, Morris, & Blair, 2000), very little developmental research has explored this in visual tasks. An exception is one example, using a picture-matching task, where Kelanine and Bonthoux (2008) have shown that children as young as 5 are able to detect thematic relationships faster for manipulable objects (e.g. screwdriver matches with screw) than for non-manipulable objects (e.g. castle matches with knight) a finding they suggest reflects differential contributions of action experience to concept representation.

Whether or not experience increases or decreases the reliance on sensori-motor representations was explicitly addressed by Mounoud et al. (2007). In their study, young children (5 -11 year) olds were shown short videos of object-pantomimes (e.g. a pantomime of sawing) and subsequently shown images of objects that were congruent/incongruent with the pantomime (e.g. a saw vs. a hammer). They predicted that if action and object representations are tightly coupled in development, then the presentation of a congruent action should prime object categorization. This is indeed what they showed, with priming effects that appeared strongest in early development (i.e.

5 years). According to the authors this suggests that the role of experience in grounding conceptual representations of objects is actually *greater* in early development, when interactions with the world dominate experience; however, later in development, the reliance on these grounded experiences diminishes. Note that this interpretation suggests that there is an increased reliance on amodal processing later in development,[3] a suggestion that is hard to reconcile with some of the other literature reviewed here. Either way, this result shows that action perception can influence object perception as early as 5 years of age.

In general, additional developmental findings further support the notion that motor-based experiences are important in concept formation. In one study (Perraudin & Mounoud, 2009) the authors had children name or categorize target objects (e.g. candle) that were primed with pictures of objects that were related by action (match), category (e.g. lamp) or neither (e.g. hammer). Consistent with the previous result, they showed that priming was observed with action- related primes as early as 5 years of age (and both action- and category-related primes at later ages). This finding further supports the notion of associated action and object representations that appear early in development. However, given the paucity of studies in this area, the exact developmental trajectory of purported embodied object representations remains unknown.

1.4.6 Behaviour

Increasingly, embodied theories are influencing behavioural investigations of visual cognition. It is now well established that the visual presentation of an object can affect both subsequent action and perhaps object recognition. In a preliminary

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[3] As noted by the authors, an alternative account implicates floor effects in the performance of the older children, something that would eliminate any priming effects.

demonstration, Craighero et al. (1996) had participants grasp bars that were oriented 45 degrees from their midline. On some of the trials the bars were preceded by a congruent visual prime (i.e. a bar oriented in the same way) or an incongruent visual prime (i.e. a bar oriented in the opposite way). They showed that responses were faster on congruent trials and interpreted this as evidence that the visual presentation of a graspable object automatically invokes motor behaviours.

This type of result is consistent with a body of research that suggests there is a direct coupling between object perception and action. Rumiati and Humphreys[4] (1998; Experiment 2) have shown that, under speeded conditions, errors in gesturing to a visually presented object that are of a visual nature (e.g. miming the use of a hammer when shown a visually-related razor) are greater than errors of a 'semantic' nature (e.g. miming the use of a hammer when shown a semantically-related saw) suggesting a 'direct-link' between a visual object representation and action. Conversely, they showed that errors are primarily of a semantic nature when gesturing to words. Thus, this direct route to action might suggest a way in which action becomes a part of object representations.

A relationship between the visual processing of objects and action generation has also been shown by Jax and Buxbaum (2010). These authors make the important distinction between structural grasping (e.g. grasping an object to move it to a new location) and functional grasping (i.e. grasping an object to put it to common use). They presented participants with objects that afforded both a structural- and functional-grasps (e.g. a calculator that can be *clenched* when passed to another person vs. *poked* when put

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[4] Note that this study is conducted explicitly under an 'information-processing model' and it makes explicit recourse to 'executive' control.

to use). They showed that movement initiation was slowed when participants were instructed to produce a functional-grasp that differed from the afforded structural grasp. For the authors, this suggested that two forms of motor-representations are activated during the visual presentation of an object and they compete for execution. In this case, the automatic activation of structural-grasps interfered with the execution of the functional-grasp.

The specificity of the sensory-motor activation in response to the visual presentation of objects has been investigated extensively by Masson and colleagues. In one study, Bub, Masson, and Cree (2008) trained participants to produce a specific manual action response (e.g. poke) in response to the colour of a visually presented object (e.g. red). Importantly, the object could afford a structurally compatible/incompatible action (e.g. a grasp towards a computer mouse) and/or a functionally compatible/incompatible action (e.g. a poke action towards a calculator) with the manual action response trained to the colour (so participants were responding to a colour on each trial). They showed that both structural and functional compatibility facilitated manual action responses, suggesting that both of these types of representations were activated in response to objects[5]. Masson et al. (2011) extended this finding by showing that manual action responses to objects are primed with an object whose handle is congruent with the target action (that is, a vertical power grasp after the presentation of a vertical beer mug),

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[5] Interestingly, they found a similar result for words. Similarly, word effects have been shown by others. For instance, Glover, Rosenbaum, Graham and Dixon (2004) showed that grip apertures in response to words implying larger objects (e.g. “apple’) were larger compared to words implying smaller objects (e.g. “grape”). This suggests that word reading automatically activates motor representations and constrains action. This finding is consistent with the embodied interpretation of object representations. However, the literature on word processing is beyond the scope of this Introduction.

suggesting further that the presentation of objects automatically specifies the action the object affords.

However, the extent of this automaticity is controversial. More recently, Bub and Masson (2010) trained participants to either a) reach towards a graspable apparatus with either their left or right hands in response to a colour cue, or b) make simple button-press responses with either the left or right hands. In this study, the reaching movement was primed with either a congruent object (e.g. a beer mug with the handle facing the cued hand) or incongruent object (e.g. a beer mug with the handle facing away from the cued hand). They showed that when participants made reaching and grasping movements, an aligned object facilitated the movement; this effect was not observed for simple key presses. The authors concluded that objects elicit object affordances when participants have the intention to perform a specific motor act, but not a general movement. This raises the possibility that objects do not automatically elicit general motor simulations, but simulations might depend critically on the intention of the observer.

One final demonstration of object-elicited action priming is worth nothing. Tucker and Ellis (2001) reported that pincer-grasps (i.e. grasps made with the index finger and thumb) were executed faster when participants were presented with objects that afforded a pincer-grasp, whereas whole-hand grasps (i.e. grasps made with the palm and fingers) were executed faster for objects affording a whole-hand grasp. Again, this suggests that the type of motor response might be highly specified to the visual object.

This literature suggests that the visual presentation of an object can automatically specify the action it affords. However, there are a number of studies that show that the motor representation activated by a visual object isn't always specific. Indeed, general stimulus-compatibility effects (faster responding with the right hand to right oriented objects and visa versa for the left hand) have been reported by other authors using simple button press responses (e.g. with the index fingers of different hands) rather than with grasping responses. For instance, Tucker and Ellis (1998; see Matheson, White, & McMullen, in preparation; Chapter 3) showed that deciding whether an object was upright or inverted was faster when the handle of an object (e.g. a frying pan) was compatible with the responding hand. Tipper, Paul, and Hayes (2006) showed participants door handles of two different shapes in either a passive state (i.e. horizontally aligned, as though no action was performed on it) or an active state (tilted at a 45 degree angle, as though an action was performed on it, and had them discriminate the handle's shape or simply its colour. They showed that simple button-press responses in making these decisions were faster when the handle was aligned with the responding hand, but only when participants were discriminating the shape of the object; further, this effect was most pronounced in the active state. These results suggest that object affordances activate responses when participants are engaged in a task that requires them to analyze the object's shape but not colour, and implies a general, lateralized, motor potentiation in response to the visual presentation of objects.

Overall, the reviewed body of behavioural research shows relationships between the visual presentation of an object and the performance of actions (potentially very specific actions) that the object affords. In general, these findings are in line with an embodied account of object representation, suggesting a tight coupling between vision and action. The behavioural research suggests that associations between visual and motor representations are automatically invoked by the visual presentation of objects. Further, because the behavioural effects occur in the context of performing cognitive tasks (e.g. deciding whether an object is upright or inverted), this strongly implicates a role of embodied representations in cognitive processing. These stimulus-compatibility effects are predicted by embodied accounts of object representation *a priori*. However, as will be discussed below, though results such as these are often cited as reflecting embodied object representations, just how action representations are a part of the object representations remains unclear. Indeed, there are a number of issues that prevent us from concluding that object representations are embodied based on the current body of behavioural literature.

1.5 CRITICISMS OF EMBODIED OBJECT REPRESENTATIONS

There are largely two main issues in interpreting the above research as evidence for embodied object representations, one methodological and one theoretical. First, methodologically, though widely used in neuroimaging studies, many of the behavioural studies reviewed here have failed to include appropriate control stimuli, for instance, a category of object for which there are no sensory-motor associations. Control stimuli have largely been neglected because most of the designs used in the behavioural research are not amenable to other object categories (e.g. the reaching and grasping tasks of Bub and Masson, 2010). However, some designs, including the stimulus-response compatibility paradigm of Tucker and Ellis (1998) are amenable to this type of comparison. The use of control stimuli is necessary to interpreted motor potentiation responses as evidence of embodied representation.

Second, theoretically, most research has not ruled out simpler, more parsimonious mechanisms that could explain differences in brain or behavioural effects. For example, there has been little effort to describe how different objects are visually explored or what the role of attention is in producing ostensible embodied effects. For instance, one would expect faster responding with a hand that is compatible with an object handle if participants tended to look or attend to this region, all other things being equal. Though finding simple explanations for some of the effects reported in the literature would not eliminate embodied theories it would restrict liberal theoretical interpretations of some of the available data, preventing a premature conclusion that objects representations are embodied.

Though I have spent considerable time explaining the promise and laudable aspects of the conceptualization hypothesis of the theory of embodied cognition, and though a large body of research from neuroimaging, neurophysiology, neuropsychology and behavioural studies is accumulating that is consistent with the notion that object representations are embodied (though certainly not conclusively), this view is not without criticisms (e.g. Dove, 2011). Indeed, many authors maintain that modality-specific activity is insufficient to represent all semantic information (e.g. Shelton & Caramazza, 1999), and there are reports of widespread semantic impairments in the literature that are easily interpreted by amodal accounts (e.g. Hillis, Rapp, Romani, & Caramazza, 1990). Additionally, most of the research reviewed here, claiming to support embodied cognition, is amenable to an amodal account. This raises the important question as to whether an embodied perspective is even necessary. Shapiro (2011) points out succinctly that in some cases it is not clear whether embodied hypotheses and information processing hypotheses are mutually exclusive (indeed, they may not even be asking the same types of questions). For instance, some results might be best explained with embodied theories, while others might be best suited to amodal accounts (one cannot help but be reminded of waves and particles). If these theories are not mutually exclusive, then elucidating object representations from *both* perspectives will provide a more complete understanding of object representations. However, if they are mutually exclusive, and one is ‘better’ than the other, then it is important indeed to determine which one is superior.

Importantly, I am inclined to favour the view that the theories are not mutually exclusive. Most of the research I have reviewed here does not pit modal theories against amodal theories. Indeed, though most cognitive research has adopted amodal perspectives, it does so largely implicitly, out of tradition, and without a large body of evidence explicitly supporting its existence (see Barsalou, et al. 2003). In this thesis, I explicitly approach a number of paradigms from the embodied perspective. This thesis is not about comparing amodal and modal theories. It is about searching for evidence for embodiment (which may or may not be exclusive of amodal accounts). In this specific case, I have chosen paradigms that seem well suited to address some of the basic assumptions of embodied theories, questions that I think are important but have not been resolved. As we will see, the evidence purported to support embodiment is limited when proper control stimuli are used, or might be best explained by simpler attentional effects without any recourse to embodiment (or amodal models, for that matter).

1.6 THE PRESENT RESEARCH

From neuroimaging, neuropsychology, neurophysiology, development and behavioural research, comes evidence for embodied object representations, demonstrated primarily through the relationship between visual and motor processes. The conceptual leap, from an embodied perspective, is that these associations constitute an object’s representation. That is, specifically, embodied theories suggest that motor associations are part of a ‘simulation’ automatically activated during cognitive tasks (see Garboarini & Adenzato, 2004). This is the heart of the question, and the collection of studies reported in this thesis aims to explore this possibility further.

The manuscripts in this thesis are organized into two parts. In Part 1, I empirically test two important and obvious predictions of embodied theories of object representations. The first prediction is that sensory-motor activity plays a *functional role* (i.e. causal) in visual cognition. More specifically, embodied theories posit that sensory-motor activity is *necessary* in the performance of cognitive tasks. In Chapter 2, I test this by attempting to interfere with motor simulations during an object naming task. Counter to the embodied theory I show that naming manipulable and non-manipulable objects is affected similarly by squeezing a sponge. The second prediction is that sensory-motor associations are *coactivated* with visual representations during cognitive tasks (i.e. correlated). In Chapter 3, I investigate evidence that manipulable objects potentiate actions but, unlike previous research, I have included an important control. Here too, the effects of interest are found with both manipulable and non-manipulable objects. Together, my empirical investigations suggest that sensory-motor simulations do not causally play a role in visual cognitive tasks and are perhaps not even coactivated with visual representations, at least in the particular paradigm I have selected.

In Part 2, I explore possible low-level visual and attentional differences between manipulable and non-manipulable objects and provide initial evidence that some embodied effects might be best explained by differences in these process. In Chapter 4, I report a small descriptive study that investigated differences in the way manipulable and non-manipulable objects are visually analyzed using eye-tracking technology. The question was simple: Are there differences in the way we look at manipulable and non-manipulable objects? I show that there are differences, with some evidence that heads of animals are particularly salient, while there is some evidence that both handles and the functional ends of artifacts are salient. Finally, in Chapter 5, I look for neurophysiological evidence that embodied effects might be explained by visual attentional mechanisms, adopting an event-related potential (ERP) paradigm. I provide evidence that handles bias visual attention more than functional ends, and that this bias is associated with superior target detection for targets cued by handles. Over all, the studies reported here do not provide strong support for an embodied account of object representations, but point to low level differences in attentional distribution towards artifacts and animals.

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1.8 APPENDIX: PART I TESTING THE EMBODIED ACCOUNT OF OBJECT REPRESENTATIONS

The embodied cognitive hypothesis of object representations makes two critical predictions about the role of sensorimotor simulations in visual cognitive tasks. First, sensorimotor simulations are *functionally* necessary during visual cognitive tasks. That is, in visual processing of objects, simulations are involved in producing successful performance on visual cognitive tasks (e.g. object naming). Second, sensorimotor simulations are *coactivated* in response to the visual presentation of objects. That is, we should observe evidence for sensorimotor simulations that are elicited during cognitive tasks.

In Part 1, I employ two behavioural paradigms to test these predictions. Behavioural paradigms are particularly well suited to addressing these questions, as behavioural output is one of the strongest measurements we can make to infer a causal role of a purported cognitive mechanism. In Chapter 2, I adopt a paradigm by Witt et al. (2010), who used a concurrent motor task during an object-naming paradigm in an attempt to disrupt sensorimotor simulations. The results of Witt et al. (2010) showed that concurrent motor task affected naming for manipulable artifacts, but not non-manipulable animals. This is one of the strongest pieces of evidence in favour of a functional role of sensorimotor simulations in a cognitive task, as it suggests a functional consequence to disrupting motor simulations (i.e. slower naming). In Chapter 2, I describe two experiments that fail to show evidence that concurrent motor activity selectively impairs artefact naming; rather, I show that a concurrent motor task affects naming *across* categories of object, and the nature of this effect reverses with a simple manipulation of picture-plane orientation. Though the data do not allow me to definitively address the mechanism of this reversal, I strongly favour an interpretation based on a purported difference in attentional salience across the objects, largely determined by the image's relationship to the hand performing the motor task. This result suggests that the differences in naming observed in this task are not due to embodied object representations, but are simply the consequence of an attentional bias for the images.

In Chapter 3, I investigate whether we can observe behavioural evidence for coactivated sensorimotor simulations in response to the visual presentation of objects. To do so, I adopt a paradigm by Tucker and Ellis (1998), who showed that during an object orientation decision task, participants are faster at making a button-press response with the hand that is aligned (compatible) with the handle of the object. An embodied interpretation of this account is that the visual presentation of an object with a handle elicits sensorimotor simulations, and these simulations potentiate a behavioural button press response (what I call motor potentiation). However, I show a similar 'motor potentiation effect' for a set of critical control objects (namely, animals) that cannot be explained by coactivation of sensorimotor simulations. I again interpret these findings as reflective of an asymmetrical bias in visual attention that precipitates faster button pressing to different regions of space occupied by object parts.

Over all then, across two studies, I do not find evidence for embodied object representations. Rather the results are more readily and parsimoniously accounted for by a general bias in visual attention that is determined by factors such as experimental task. I conclude that we must abandon a strong form of the embodiment hypothesis. In Part 2, I adopt eye-tracking and electrophysiological techniques to investigate ways in which visual attention is biased by artefact and animal stimuli.

It is important to note that in the experiments reported here I have restricted my focus to visual paradigms. In doing so, my interpretations are limited to the visual cognitive domain. Additionally, in all studies, the visual stimuli are restricted to manipulable artifacts and animals. Thus, though there are differences in the manipulability of the two categories of objects, there are also differences in a number of other features, the most obvious being their animacy (animate vs. inanimate). However, I argue that this potential confound is justified because we wanted to maximize the likelihood that our manipulable object category is associated with action, and minimize the likelihood that the control category would have sensorimotor associations. Indeed, small animals, or large man-made artifacts, all afford some type of action (e.g. petting a cat or sitting in a car), and therefore are not suitable as a control in this case (also, as discussed in Chapter 6, there is little reason to suspect that this variable underlies any of the reported effects in other chapters). Overall then, the studies reported in Part 1 argue against the strong form of the embodied hypothesis of object representations, assessed from the visual modality, and implicate a more general bias of visual attention.

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CHAPTER 2 TESTING THE EMBODIED ACCOUNT OF OBJECT RECOGNITION: MOTOR ACTIVITY INTERFERES WITH NAMING ARTIFACTS AND ANIMALS

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2.1 Abstract

Mounting evidence from behavioural and neuroimaging research demonstrates that passively viewing images of tools both primes motor responses and activates fronto-parietal networks responsible for programming action. To account for these findings, embodied theories of object representation propose that the same neural networks are involved in encoding and retrieving object knowledge. However, most arguments in favour of this view are based on correlations between viewing manipulable objects and motor activity. In the present study, we investigated whether motor programs play a causal role in the retrieval of object names. Participants performed an object-naming task while squeezing a sponge with either their right or left hand. The objects were either manipulable (e.g. hammer) or natural (e.g. giraffe), and were presented in an orientation that either favoured of did not favour grasping. We hypothesized that, if activation of motor programs is necessary to retrieve object knowledge, then this arbitrary motor act would interfere with naming manipulable artifacts but not non-manipulable animals. In Experiment 1, participants showed slower naming across all objects oriented towards the occupied hand. In Experiment 2, we presented the objects in more 'canonical orientations' again, half of which favoured grasping and half of which did not. In contrast to Experiment 1, participants named all objects more quickly when they were presented towards the occupied hand. Together, these interference/priming effects suggest that objects from both categories are affected by arbitrary motor acts. We suggest that picture-plane orientation may interact with an 'attentional vector' that is elicited by the objects. These effects are not consistent with those predicted by embodied theories of object representation.

Key words: embodied cognition, object recognition, object naming

Testing the embodied account of object recognition:

Motor activity interferes with naming both manipulable and non-manipulable objects

Most studies of human cognition assume that the nervous system transduces sensory information from the environment, represents it for a period of time, manipulates it, and transforms it into an adaptive behavioral response. However, determining the nature of these transformations remains one of the major aims of cognitive psychological research. Historically, theories of cognition have maintained that the brain's representations of the objects, people, and events are symbolic, amodal, and independent of the sensory motor systems that interact with the environment. Such theories dominate the scientific literature in which most models of cognitive processes include—either implicitly or explicitly—symbolic representations. The types of theoretical cognitive constructs arising from this line of thought include different modules of visual processing (e.g. structural encoding, see for example Bruce and Young, 1986) and stores for different types of semantic memory (e.g. Humphreys, Lamote, & Lloyd-Jones, 1995).

Recently, however, theories of embodied cognition have provided an alternative to symbolic theories, proposing instead that the way in which an organism interacts with the environment constrains the cognitive processes that underlie thought and behaviour (Lakoff & Johnson, 1999). Though as of yet there is no standard, unified *theory of embodied cognition,* models of embodied cognition typically reject the notion that amodal symbols underlie thought, proposing instead that simulations of sensory-motor activity (e.g. visual, auditory, and sensory-motor imagery), situated action (e.g. experiences of performing motor acts under different conditions), or bodily states (e.g.

experiences of arousal and other effects of emotional experience), implemented in their respective modal brain systems, underlie complex cognitive process (see Barsalou, 2008 for a review of evidence in favour of embodied theories in perception, action, memory, language, social cognition, problem solving and reasoning, and development). Further, these theories suggest that the representation of the external world is built primarily from the properties that afford action (e.g. object affordances, see Gibson, 1986). One of the key strengths of embodied theories is that they unify research in diverse areas and offer a powerful way of understanding the organization of human perception and action.

Embodied theories of cognition make important predictions about the role of sensory-motor programming in cognitive tasks. Specifically, these theories posit that a) simulations of sensory-motor processing form the basis of object representations and b) these representations underlie our ability to identify objects and reason about them. Thus, embodied theories predict activity in the sensory-motor association cortices even when there is no specific instruction to perform actions on visually presented objects. Chao and Martin (1999) provide evidence that this is the case. In a passive viewing task, functional magnetic resonance imaging (fMRI) revealed activity in the left ventral premotor cortex and the left posterior parietal cortex in response to pictures of tools but not animals. Importantly, this activation was observed in the absence of any specific movement or instruction to imagine movement. This suggests that viewing manipulable objects results in an automatic simulation of the programs used to interact with them. Such a finding is consistent with theories of embodied cognition. Similar findings have been shown by others (e.g. Grafton et al, 1997; Geralch, Law, and Paulson, 2002).

In addition to neuroimaging data, behavioral research provides evidence for shared representations of action production and object perception. For instance, it has been shown that imagining an awkward movement can impair the execution of reaching and grasping towards objects (Ramsey, Cumming, Eastough, & Edwards, 2010), suggesting a role of motor simulation in preparing action towards objects. Further, it is known that naming latencies differ for manipulable and non-manipulable objects (Filliter, McMullen, & Westwood, 2005), suggesting that naming objects depends on whether the object is associated with sensory-motor experiences. A difference in processing manipulable and non-manipulable objects appears as early as 5 years of age (Kalenine & Bonthoux, 2008), providing evidence that sensory-motor experience begins influencing object representations early in development. Finally, the presentation of a manipulable object can 'potentiate' a motor response (i.e. speed it up), even when the identity of the object is incidental to the task (Tucker & Ellis, 1998; 2004), demonstrating that the activation of sensory-motor representations is automatic.

Importantly, the neuroimaging and behavioural evidence reviewed here is *correlational*; it simply suggests that modal representations are automatically activated when viewing manipulable objects and that we can mentally simulate actions. However, it remains unclear whether these simulations play a *functional* role in behaviour, facilitating action execution, object naming, or action understanding. Indeed, co-activation of sensory-motor representations during the visual presentation of manipulable objects may simply reflect associative, Hebbian learning, in which visual representations and sensory-motor representations become associated primarily because we typically act on objects we can see. Critically, theories of embodied theories of cognition propose that sensory-motor representations are not merely correlational (or epiphenomenal), but rather that they play a causal role in cognitive tasks, for instance object identification and action understanding. Because of this critical prediction, assessing the functional role of sensory-motor representations in cognitive tasks remains one of the most important goals of visual cognitive research.

This issue has only recently been addressed. For instance, in an object naming study (Helbig et al, 2006), pictures of manipulable objects were primed with pictures of objects that afforded a congruent grasp (e.g. a frying pan primed by a dust pan) or an incongruent grasp (a frying pan primed by a banjo). It was shown that naming accuracy was higher when the target objects were primed with congruent objects than incongruent objects. This suggests that viewing a manipulable object with a comparable motor association can at the very least *facilitate* object naming. This conjecture is supported by a similar, follow up study (Helbig, Steinwender, Graf, & Kiefer, 2010). In a picture-word matching experiment, participants viewed short video clips of hands performing particular actions (e.g. squeezing), followed by objects that were either congruent with the action prime (e.g. pliers) or incongruent with it (e.g. typewriter). It was shown that matching accuracy was higher when the objects were primed with congruent videos than incongruent videos, suggesting that action observation can prime conceptual processing of objects. Importantly, assuming that action observation activates the observer's motor system, this finding suggests that activating the motor system can prime object identification. Importantly, these results provide initial, though indirect, demonstrations that motor programs play a functional role in the processing and retrieval of conceptual knowledge (i.e. object names).

To test whether sensory-motor representations play a causal functional role in object identification it is necessary to disrupt the simulations that are proposed to underlie object representations and investigate the effects this disruption has on a visual cognitive task. This idea was recently tested by Witt et al. (2010). Participants were shown pictures of tools or animals and had to name them while squeezing a ball. Importantly, the handles of the tools, and the heads of the animals, were either oriented towards or away from the occupied hand. The authors showed that naming times were slower for the tools that were oriented for grasping towards the occupied hand. Naming times did not differ for the animals. These results suggest that pre-occupying the sensory-motor programs responsible for grasping interfered with the ability to name tools. As concluded by the authors, this provides evidence that motor simulation plays a functional role in object naming. To date, this published report provides the first and strongest evidence for motor representations playing a causal functional role in cognitive tasks.

2.2 Experiment 1

Because of the importance of this result, the present study attempted to reproduce Witt et al. (2010)'s findings with the aim of extending the paradigm in a number of ways. First, the participants in Witt et al. (2010) were instructed to squeeze a sponge but were free to hold their hands in any position (most choosing to rest them on the arms of the chair). This introduces variability due to hand position, and—if the hand can be seen--introduces a confound with respect to the location of the hand in the visual field (i.e. when squeezing with the right hand, the hand and sponge are both visible in the right visual field and visa versa). To remove this potential confound in the present experiment, a sponge was mounted above the edge of the table, in front of the computer screen (and therefore in view of the participants), and centered at the participant's midline. This ensured that the position of the participant's hand and the sponge were held constant. Second, Witt et al. (2010) presented participants with profile views of objects at 0 degrees with respect to the horizon. We sought to reduce ambiguity of afforded action by orienting the objects 45 degrees from their initial upright position towards the right or the left (Experiment 1). Subjectively, this increased the sense that each object afforded a left- or a right-hand grasp. Third, Witt et al. (2010) presented the tools with their handles facing the occupied hand, and the animals with their heads facing the occupied hand. In a pilot test, we presented participants (N = 3) with graspable, toy versions of common animals (e.g. horse, chicken). The items were placed on the table in front of the participants and they were instructed simply to pick up the object. In every case, participants grasped the toys by their tail-ends towards the occupied hand (and not their heads). This suggests that presenting animals with their heads towards the occupied hand would reduce the likelihood of activating a motor simulation. To overcome this, we presented the objects with their handles or their tail-ends towards the occupied hands, considering these to be the 'graspable' ends.

We predicted that, if sensory-motor simulations are functionally involved in object identification, then pre-occupying the sensory-motor system by squeezing a ball with a hand should affect the ability to name objects that could be grasped with the occupied hand. This effect should be only be present or at least be strongest with manipulable objects.

2.3 Method

Participants

One hundred twenty-four participants participated in Experiment 1 (N = 61 left-hand squeeze group, N = 49 females, *M* = 23.69, *SD* = 6.64 years old; N = 63 right-hand squeeze group, N = 51 females, *M* = 19.97, *SD* = 2.81 years old). All participants had normal or corrected-to-normal vision and English as a first language. 102 participants were right-handed, 10 were left, and 12 reported being ambidextrous.

Materials

Thirty-seven greyscale photographs of natural objects (i.e. animals) and thirty four photographs of man-made objects (i.e. tools and other human artifacts) were taken from the set developed by Salmon, Filliter and McMullen (2010). Using GIMP 2.0 (GNOME Foundation, Groton, MA) each object was rotated such that the handle (for the man-made objects) or tail-ends (for the natural objects) were oriented towards the right or left at approximately 45 degrees away from alignment with the upright of the object or away the long axis being aligned with the upright. (See Figure 2.1). Sitting at approximately 60 cm from the monitor the stimuli subtended approximately 9.5 degrees of visual angle.

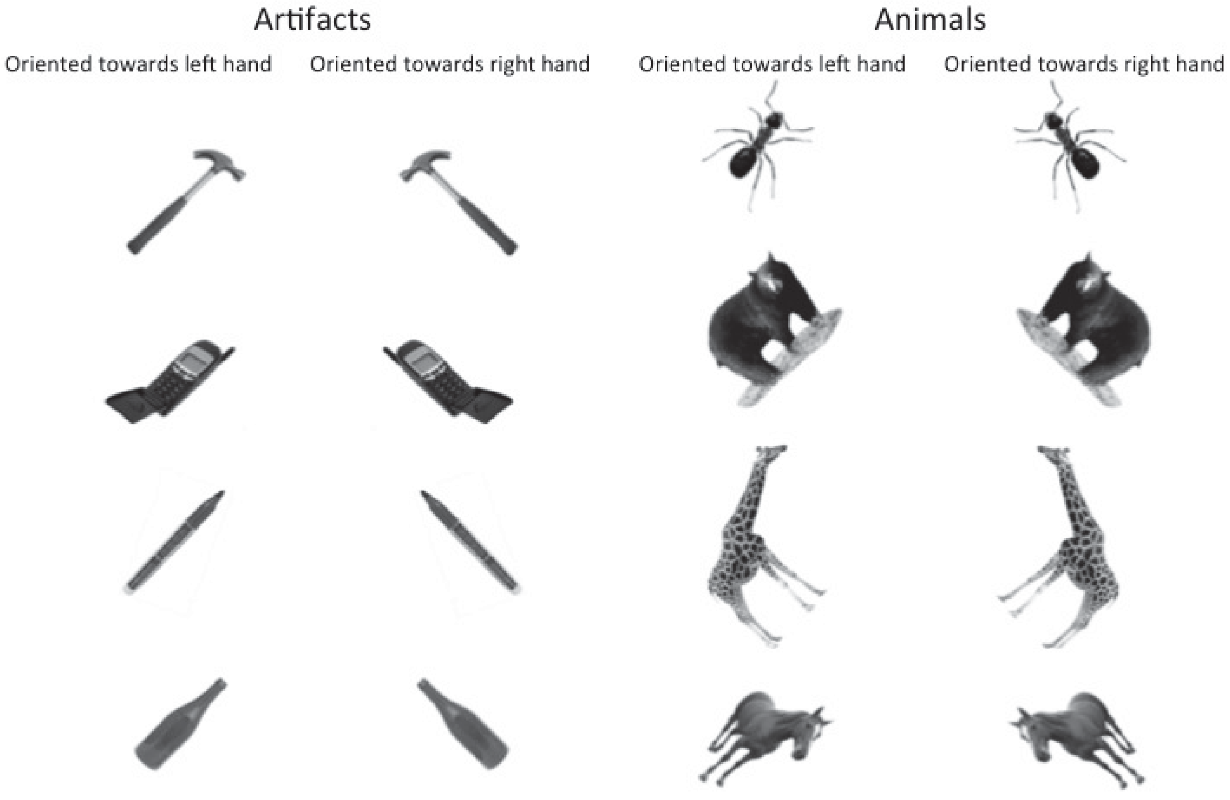

Figure 2.1. Representations of the object images used in the present experiment. Artifacts and animals in both orientations (towards left hand vs. towards right hand) are shown.

Each object in this set is associated with mean ratings of familiarity, age of acquisition, and manipulability according to two different criteria (see Salmon, Filliter, & McMullen, 2010). It was not possible to match the object categories (man-made and natural) on the traits of familiarity and age of acquisition. Importantly, the man-made objects were rated as more manipulable than the natural objects.

Stimuli were presented on a 21in. CRT monitor with a refresh rate of 85 Hz and a screen resolution of 1280 X 1024 at 96 DPI. Presentation was controlled using a

MiniMac (Apple, California) with a Windows (Microsoft, California) partition running DirectRT Experiment software (Empirisoft Corporation, NYC).

A sponge ball approximately 8 cm in diameter was placed at the participant's midline, supported by a metal rod. The center of the ball sat approximately 22 cm above the desk. This ensured that the participants could squeeze the ball comfortably approximately 30 cm from their chest. A Logitech USB microphone (Frequency response: 100 Hz–16 kHz, 8-foot shielded cord with USB connector, USB 1.1) sat centered approximately 15 cm to the left of the metal rod. The microphone was calibrated to trigger a response in DirectRT with the lowest threshold possible.

Procedure

Each participant completed 12 practice trials and 168[6] experimental trials. Presentation order was randomized, with a mandatory self-paced break half way through. On each trial, the word 'squeeze' appeared for 1000 ms. This served as a reminder to the participant to lightly squeeze the sponge-ball with their hand (either right or left, depending on random group assignment). The experimenter visually confirmed that participants were following this instruction. Immediately following this, the image of an object appeared on the screen and participants were instructed to verbally name the objects as quickly and accurately as possible, emphasizing the first sound of each word (this ensured they triggered the microphone with the onset of their vocalization). The image was removed from the screen at voice onset and replaced by the text 'please wait'.

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[6] 7 items from each category were removed from the analysis because they had poorly defined asymmetry with respect to the picture plane. This was largely a consequence of the viewpoint variance of the image set. For instance, one item (i.e. a gun) was excluded because it looked too similar in Experiment 1 and Experiment 2. Further items were deemed too abnormal and often resulted in undesirable behaviour (e.g. laughter to the presentation of dinosaur). Importantly, the final pattern of results does not change.

During this screen the participant was instructed to relax their hand. Further, during this screen the experimenter recorded whether the response was correct (a correct name for the object). Because each image was presented twice (once right oriented, once left oriented), special attention was paid to the response given on the second occasion; if the participant used the same word the trial was marked as correct but if another word was used (e.g. subordinate or superordinate word) it was marked as incorrect (e.g. 'bear' for first presentation, 'black bear' for the second). This ensured that within-subject comparisons between the two presentations were based on the retrieval of the same word (and presumably, this ensured that the participant was accessing the same *concept*). Further, trials were marked as incorrect a) when the participant provided an incorrect name for the object, b) triggered the microphone accidentally (e.g. saying, "um"), c) failed to trigger the microphone, or d) failed to comply with the instructions (e.g. forgot to squeeze). After the experimenter recorded the accuracy of the trial, the next trial began. The entire experiment was completed in approximately 1 hour.

Analysis

Vocal reaction times (RTs) were recorded as the dependent measure. To be included in the analysis, an RT must have a) come from trials in which participants responded correctly and consistently on both presentations of the object, and b) come from trials on which participants complied with instructions (i.e. triggered the microphone with their vocal onset, squeezed at the appropriate time, etc.).

Mean reaction times (RTs)[7] were submitted to three different analyses. First, to explore our full factorial, a 2 (category; animals vs artifacts) X 2 (presentation

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[7] Often, medians are used in the analysis of reaction time data because the mean is heavily influenced by scores in the positively skewed portion of the RT distribution. We have elected to analyze means because

occurrence; first presentation vs. second presentation) X 2 (left/right hand Squeeze Group) X 2 (object orientation; towards right-hand vs. towards left-hand) mixed effects ANOVA was used. Because of the results of this overall, mixed ANOVA, we collapsed data from the between-subjects factor (left/right hand squeeze group) into a 'hand occupancy' variable (towards occupied hand vs. away from occupied hand; see Witt et al. 2010), in which hand occupancy was defined by the compatibility between the squeezing hand and the orientation of the object (e.g. a left hand squeeze with a left-oriented object was compatible; a right hand squeeze with a right oriented object, etc.). The analysis then became a 2 (category; animals vs. artifacts) X 2 (hand occupancy; towards occupied hand vs. away from occupied hand) X 2 (presentation occurrence; first presentation vs. second presentation) repeated-measures Analysis of Variance (ANOVA). All ANOVAs were conducted using the *ez()* package (*v*. 4.1-1, Lawrence, 2012) as it is implemented in *R* statistical computing software (*v*. 2.15.1, R Core Team, Vienna, Austria).

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medians tend to overestimate the true population mean (Miller, 1998). Further, we have not performed outlier rejection on the RT distributions for a number of reasons. First, Ratcliff (1993) has pointed out that reaction-time outliers are typically the result of processes that researchers are not interested in, including fast guesses, the participant's inattention, or guesses based on a failure to reach a decision. Because the researcher decided whether to include an RT in the analysis (by manually flagging correct trials) we are confident that RTs in the final analysis are not the result of such occurrences (i.e. throughout the experiment the experimenter ensured the subject remained on-task). Further, Ratcliff (1993) has shown that the type of cut-off used can often drastically change the pattern of significance in the Analysis of Variance (ANOVA; see Figure 6, pp. 518), and because of this, such decisions about which cutoffs to use should be made before data collection. Because we have a) have not made these *a priori* decisions, and b) have no practical reason to assume these types of outliers in the current data, we have analyzed raw RTs. Additionally, raw RTs were analyzed in Witt et al. (2010), and doing the same here allows us to more readily compare our results and theirs.

2.4 Results

Overall ANOVA. The omnibus ANOVA[8] showed a significant effect of presentation occurrence, F (1, 122) = 772.4 $p < .001$, $\acute{\eta}^2_G = .268$, demonstrating that people were faster naming the objects on their second presentation ($M = 806.84$, $SD = 93.97$) than their first ($M = 971.94$, $SD = 123.96$). There were no other main effects, ps > .05. There were three interactions. First, the interaction between the hand-squeeze group and object orientation was significant, F (1, 122) = 4.32, $p = .004$, $\acute{\eta}^2_G = .001$. This interaction arose because the effect of the left-right orientation of the objects was in opposite directions for the two different groups; in the right-hand squeeze group, RTs were slower for right-oriented objects ($M = 897.77$, $SD = 95.02$) than left-oriented objects ($M = 889.44$, $SD = 95.23$), and for the left-hand squeeze group, RTs were slower for left-oriented objects ($M = 891.01$, $SD = 125.39$) than right oriented objects ($M = 879.61$, $SD = 114.59$). There was a significant object category X presentation occurrence interaction, F (1, 122) = 8.17, $p = .005$, $\acute{\eta}^2_G = .002$, due to a bigger effect of presentation occurrence on artifacts (difference = 178.27) than on animals (difference = 151.71). Finally, there was a significant three-way interaction between hand squeeze group, object orientation, and presentation occurrence, F (1, 122) = 7.53, $p = .007$, $\acute{\eta}^2_G = .005$. Inspection of Figure 2.2 shows that this appears to arise because of larger effects of object orientation during the first presentation than during the second. This was explored further in subsequent analysis.

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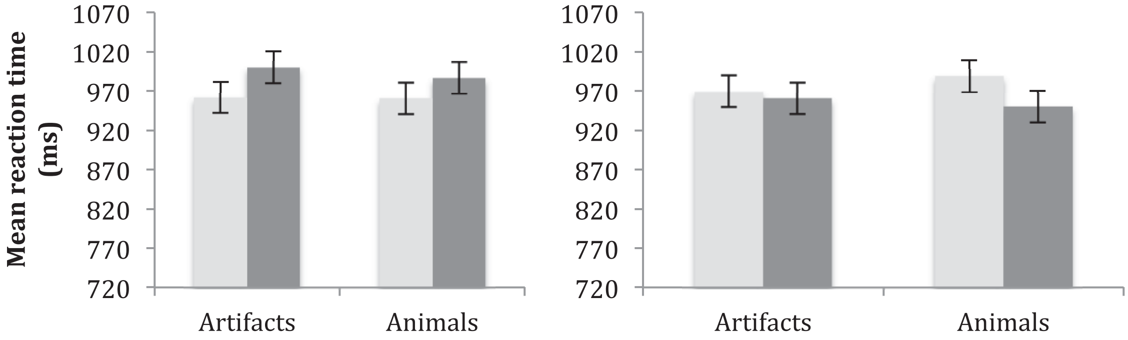
[8] For a measure of effect size we present the generalized eta squared. Unlike the partial eta squared, which is dependent on the number of factors in an experiment, the generalized measure is designed to reduce the influence of the number of factors, giving values that are easily comparable across experiments while retaining the conventional interpretations of small, medium, and large effects (see Olejnik & Algina 2003).

Right-hand squeeze group **Left-hand squeeze group**

First presentation



Second presentation

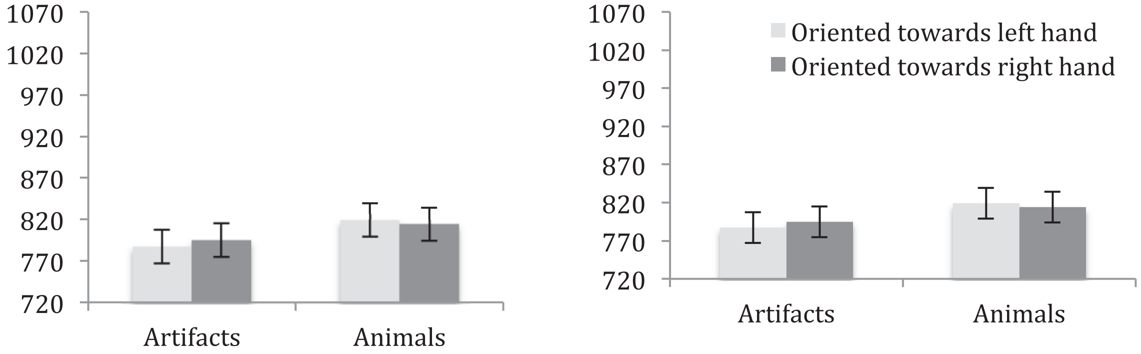


Figure 2.2. Results of full factorial ANOVA. Mean reaction time (RT) as a function of object category and object orientation for each squeeze group and presentation occurrence. Error bars represent Fisher's Least Significant Difference.

Collapsed ANOVA. Given the absence of a main effect for the squeeze group but the expected interaction with hand-squeeze group and object orientation, we decided to increase our statistical power by collapsing across between-subject group (left-hand squeeze and right-hand squeeze) into a hand occupancy variable (towards occupied hand vs. away from occupied hand). As in the previous analysis, there was a significant main effect of presentation occurrence (whether the recorded RT occurred during the first or the second presentation of the object), F (1, 123) = 772.95 $p < .001$, $\acute{\eta}^{2}_{G}$ = .268, showing that objects in general were named more quickly when presented the second time. Further, this analysis showed the two-way interaction between object category and presentation occurrence, F (1,123) = 8.06, p = .005, $\acute{\eta}^{2}_{G}$ = .267, suggesting a larger effect of presentation occurrence for artifacts than animals. Most importantly, there was a main effect of hand occupancy, F (1,123) = 4.12, p = .044, $\acute{\eta}^{2}_{G}$ = .001, and a two-way interaction between presentation occurrence and hand occupancy, F (1,123) = 8.22, p = .005, $\acute{\eta}^{2}_{G}$ = .005. This main effect and interaction appear to be the result of slower naming for objects in both categories when the handles/tail-ends were oriented towards the occupied hand, and this interference effect is particularly apparent on the first presentation. This is clear upon inspection of Figure 2.3, in which we have plotted mean RT for each presentation. Importantly, object category (artifacts vs. animals) did not interact with any other factor, suggesting that the interference seen during the first presentation occurred across both categories of object. Indeed, Fisher's Least Significant difference calculated for this comparison (FLSD = 18.89) shows that hand occupancy significantly affects RTs on only the first presentation.

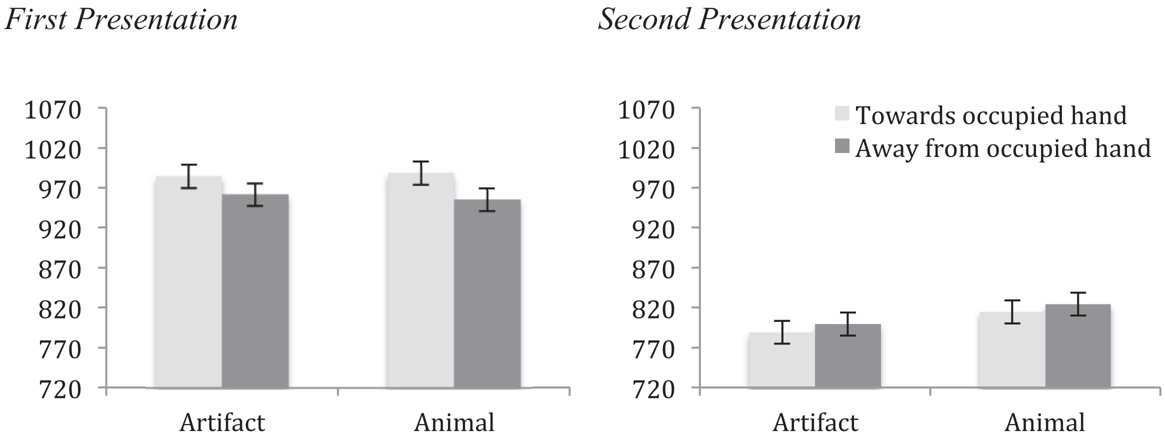


Figure 2.3. Effect of Object Category as a function of Hand Occupancy based on response times from Experiment 1. Error bars represent Fisher's Least Significant Difference.

2.5 Discussion

In Experiment 1, we predicted that occupying the motor system should interfere with naming artifacts that afforded a compatible grasp. This hypothesis was based on the results of Witt et al. (2010) who showed that preoccupying the sensory motor system by squeezing a ball interferes with naming objects that are graspable. However, unlike Witt et al. (2010), who showed that squeezing a sponge impaired tool naming but not animal naming, we have shown that squeezing a sponge can impair naming both artifacts and animals. This result challenges the notion that motor simulations play a causal role in naming artifacts.

According to embodied theories of cognition, modality-specific simulations play a causal role in representing and cogitating about objects in the world. Because of our different sensory motor experiences with different objects (i.e. manually manipulating artifacts but not zoo animals), it is hypothesized that motor simulations will play a disproportionate role in representing artifacts. However, we have shown that squeezing a sponge with either hand can actually interfere with naming both artifacts and animals that are presented such the tails and handles are oriented towards the occupied hand. This finding is perplexing, and we discuss possibilities in the General Discussion.

However, before ruling out the motor simulation account of the interference effect that we report here (and because we have not replicated Witt et al., 2010), it is important to make sure we have not artificially induced the effects in Experiment 1. Indeed, we sought to enhance the likelihood that the visual presentation of our objects *could* generate motor simulations (if they exist) to all objects in the present experiment by rotating them 45 degrees with the handles and tails towards the occupied hand. We also ensured that participants could view their hand in relation to the object. By presenting the objects in this way we may have altered the way participants implicitly categorized the natural objects, enhancing the likelihood that they appear manipulable (e.g. they may have appeared as toys). This suggestion is plausible for a number of reasons. First, the receptive fields of visuomotor neurons of the frontal lobe track the location of the hand (see Rizzolatti et al 1997), suggesting that the visual presence of the hand in peri-personal space will activate neurons that program action. In our study, participants could see their hand clearly during the presentation of the object. This may have served to activate neural systems that code for hand-object interactions for all the objects in the experiment. Second, the perceived size of an object affects processing in ventral visual areas. For instance, activity in the parahippocampal place area is altered in response to the visual presentation of a house when it appears to fit in the palm of the hand relative to when it does not (Cate et al., 2011). In our experiment, all of the objects were of a manipulable size on the computer screen and viewed in context with the participant's hand. Further, recent research shows that the presence of a hand can affect cognitive tasks. Borghi, Flumini, Natraj, & Wheaton, (2012) had participants judge whether two objects were related functionally (i.e. scissors-paper) or spatially (scissors-stapler). Sometimes the objects were presented along with the image of a hand (in different configurations). For our purposes, they showed that decisions slowed when hands were present in the visual field. Overall, then, the presence of the participant's own hand may have affected how they made decisions about the relationship between the visual stimuli.

Importantly, embodied theories of cognition propose sensory-motor representations that should depend largely on experience; though we have assumed that our participants had no sensory-motor experience with the animals used in the present experiment, we cannot make the same assumption when it comes to manipulable objects such as toy animals. The importance of experience in shaping embodied representations is provided by Kiefer et al. (2007). In their experiment, participants were trained to identify two different classes of novel objects, differentiating them based on visual cues or performing action pantomimes. Only the participants that performed action pantomimes during training showed early event-related potential (ERP) activity during name- or category-verification tests that were localized to fronto-central areas (in the pre-motor cortex). Finally, it is known that relatively specialized neural regions (e.g. the parahippocampal place area for places) do respond to toy-representations of the specialized class of object (e.g. toy lego; see Epstien et al, 1999). Together, these results may suggest that any early experience with toys, combined with the presentation of animals on a computer screen, may have activated sensory-motor representations of the animals used in the present experiment. Both of these issues are explored in Experiment 2 with a simple manipulation.

An additional result of Experiment 1 is worth noting. Importantly, it is clear that our interference effects are present more strongly on the first presentation of the object compared to the second presentation in which performance was faster and equal. We suggest that the data from the second presentation likely reflect ceiling effects, in that participants were faster at responding to all images a second time (i.e. visual priming or a simple practice effect).

2.6 Experiment 2

One interpretation of the results of Experiment 1 is that sensory-motor simulations are used to represent artifacts and animals when they appear manipulable, as is the case when they are perceived as toys. Importantly, there are a number of features of Experiment 1 that may have biased the visual system to interpret all of the objects as manipulable. One possible feature of our experiment that might have encouraged the visual system to interpret all objects as manipulable is the object's picture-plane orientation. In Experiment 1, we presented the objects in 'non-canonical' orientations, rotated 45 degrees towards the occupied hand. In such non-canonical orientations, participants might have been more likely to perceive the objects as manipulable toys. Indeed, the goal of presenting objects in this way was to enhance the likelihood of inducing motor simulations (with the artifacts in particular).

In Experiment 2 we investigated whether the object's picture-plane orientation affects the way our objects were categorized by presenting them in more 'canonical orientations'. Specifically, we presented the manipulable objects along the horizontal midline, with the handles or graspable part of the object facing the left/right; similarly, the natural objects were presented in more canonical orientations (i.e. upright and along the horizontal midline) with the tail-ends facing the left/right. This presentation better approximates Witt et al. (2010)'s methods. If the results in Experiment 1 are due to perceiving the animals as manipulable, rotating them in this way should reduce this perception by reducing their afforded graspability. Our predictions were the same as Experiment 1: If sensory-motor simulations are used in the retrieval of manipulable object names, we should observe an interference effect with artifacts but not animals. If however, other sources are responsible for the effects in Experiment 1, then naming both categories of objects should again be influenced by the squeezing manipulation.

2.7 Method

Participants

92 participants participated in Experiment 2 (N = 45 left-hand squeeze group, N = 32 females, *M* = 21.06, *SD* = 5.9 years old; N = 47 right-hand squeeze group, N = 39 females, *M* = 19.73, *SD* = 2.52 years old). All participants had normal or corrected-to-normal vision and English as a first language. 85 participants were right-handed, 2 were left, and 5 reported being ambidextrous.

Materials

Materials were identical to those used in Experiment 1, although they were now oriented at 0 degrees vertically, ensuring that the items (particularly the animals) were presented in a more 'canonical' orientation. Objects without a canonical orientation were presented with the long axis parallel to the horizontal meridian.

Procedure

Procedure was identical to Experiment 1.

Data Analysis

Analysis was identical to Experiment 1.

2.8 Results

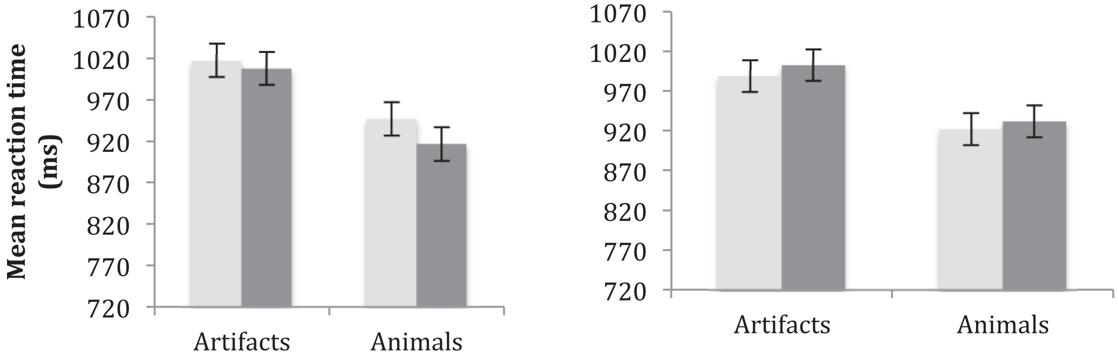
Overall ANOVA. Mean RTs were submitted to a 2 (object category; animals vs. artifacts) X 2 (orientation; left vs. right) X 2 (presentation occurrence; first vs. second) X 2 (Left/right-hand squeeze group) mixed ANOVA. As in Experiment 1, there was a significant effect of presentation occurrence, $F\ (1, 90) = 747.34$ $p = < .001$, $\acute{\eta}^{2}_{G} = .246$, with faster responding on the second presentation ($M = 795.77$, $SD = 114.66$) than the first ($M = 966.72$, $SD = 147.17$). There was also a main effect of object category, $F\ (1, 90) = 42$, $p = < .001$, $\acute{\eta}^{2}_{G} = .026$, this time (unlike in Experiment 1) due to faster naming of animals ($M = 856.81$, $SD = 139.81$) than artifacts ($M = 905.67$, $SD = 126.92$). Further, there was a significant Category X Presentation Occurrence interaction, $F\ (1, 90) = 33.83$ $p = < .001$, $\acute{\eta}^{2}_{G} = .008$. An inspection of figure 4 shows that this effect is due to a larger category effect on the first presentation (difference = 75.09) than on the second (difference = 22.64).

Importantly, there was an interaction between hand-squeeze group and object orientation, $F\ (1, 90) = 6.25$ $p = .001$, $\acute{\eta}^{2}_{G} = .001$, though it is the opposite pattern of that shown in Experiment 1. Specifically, in the right hand squeeze group there were *faster* reaction times for right oriented objects ($M = 880.45$, $SD = 113.80$) than left oriented objects ($M = 983.28$, $SD = 120.85$), whereas in the left-hand squeeze group RTs were *faster* for left oriented objects ($M = 870.62$, $SD = 139.86$) than the right ($M = 880.12$, SD

= 147.20). This shows that hand squeezing does affect naming. We explored this further in the subsequent, collapsed analysis. See Figure 2.4.

Right-hand squeeze group **Left-hand squeeze group**

First presentation



Second presentation

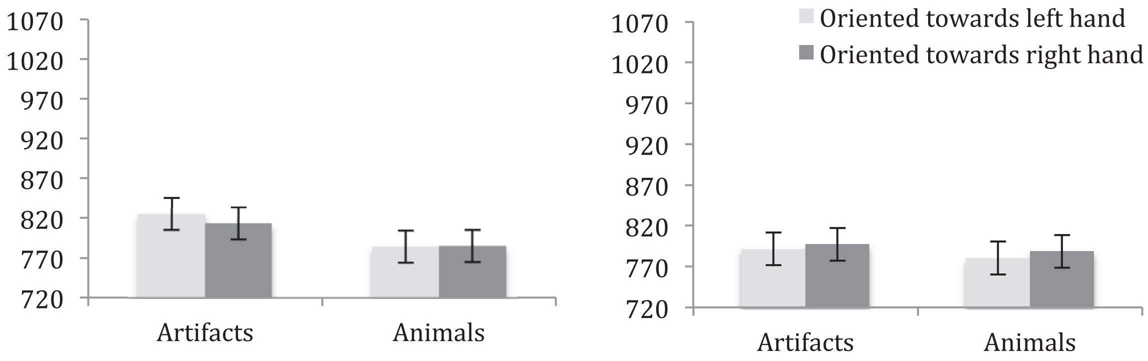


Figure 2.4. Effect of Object Category (mean RTs) as a function of Orientation in Experiment 2 for both the right- and left-hand squeeze groups during the first and second presentation. Error bars represent Fisher's Least Significant Difference

Collapsed ANOVA. Mean reaction times (RTs) were submitted to a 2 (object category; artifacts vs. animals) X 2 (hand occupancy; towards occupied hand vs. away from occupied hand) X 2 (presentation occurrence; first presentation vs. second presentation) Analysis of Variance (ANOVA). As in the previous analysis, there was a significant main effect of presentation occurrence, *F* (1, 91) = 730.36 *p* = < .001, $\acute{\eta}^{2}_{G}$ = .247, demonstrating that objects presented for a second time were named more quickly. There was a main effect of object category, $F\ (1, 91) = 42.5$, $p < .001$, $\acute{\eta}^2_G = .026$, showing that artifacts were named more slowly than animals. There was also a two-way interaction between object category and presentation occurrence, $F\ (1, 91) = 33.13$, $p < .001$, $\acute{\eta}^2_G = .007$, suggesting that the category difference is larger from the first than the second presentation.

Importantly, there was a significant main effect of hand occupancy, $F\ (1, 91) = 6.90$, $p = .01$, $\acute{\eta}^2_G = .002$, suggesting that overall, naming was *faster* when the handle/tail-ends were presented towards the occupied hand. As in Experiment 1, there was no interaction between hand occupancy and object category, suggesting that this priming effect is present for both categories of object. Also, unlike Experiment 1, the Occupancy X Presentation Occurrence interaction did not reach significance, p > .05. See Figure 2.5.

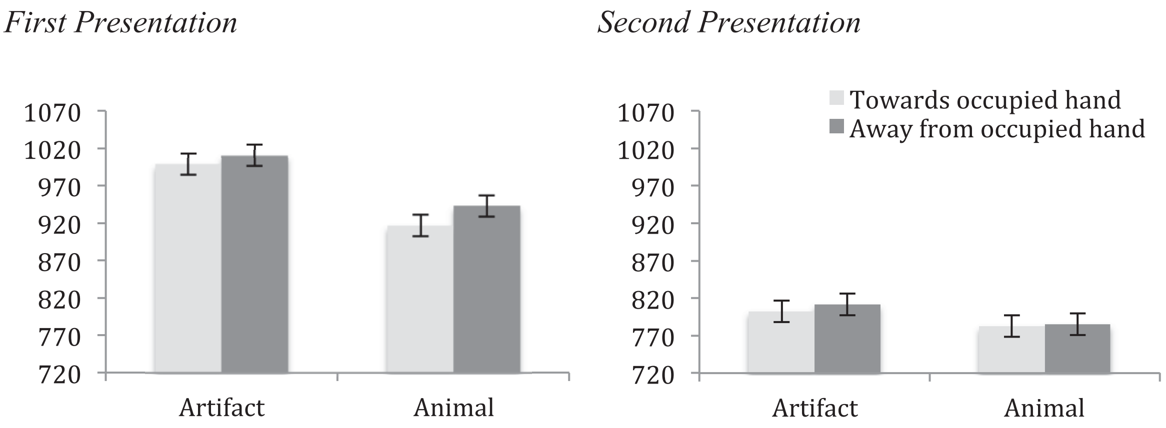


Figure 2.5. Mean RTs as a function of object category and hand occupancy. Error bars represent Fisher's Least Significant Difference.

2.9 Discussion

The results of Experiment 2 were the opposite to those of Experiment 1; specifically, participants were *faster* (rather than slower) to name objects when the handle/tail-ends were oriented towards the occupied hand. These results suggest that squeezing a ball (a motor activity) while naming objects that are oriented optimally for grasping affects naming times differently, depending on picture plane orientation. The results of Experiment 2 do not support the embodied object representations.

Surprisingly, compared to Experiment 1, Experiment 2 shows that having participants squeeze a sponge can actually *facilitate* (as opposed to interfere with) naming objects from both categories. In Experiment 1, we presented objects in 'non canonical' 45 deg orientations that optimized graspability and conjectured that this may have altered the way in which participants implicitly categorized the objects, perhaps biasing them to categorize the natural objects as manipulable (i.e. like toys). The objects in Experiment 2 were presented in more 'canonical' orientations, which should have minimized the perception that the natural objects were graspable. We found that the more canonical orientations actually resulted in facilitated naming (when the object was oriented away from the occupied hand) in Experiment 2. Importantly, this does not replicate Witt et al. (2010) who showed an interference effect on RT. In the current study, we have shown that the direction of this effect is sensitive to subtle manipulations of the picture plane orientation of the objects-to-be-named. We discuss possible mechanisms of this effect in the General Discussion.

Importantly, one particular result from Experiment 2 confirms that picture-plane orientation did change the way objects were named. First, in Experiment 1, there were no overall category differences in naming. However, Experiment 2 revealed faster naming of animals than artifacts. This likely occurred because animals have a strong canonical upright orientation and when they were presented in this orientation they do not have to be rotated before naming (e.g. McMullen & Jolicoeur, 1990). In contrast, when they were presented at 45 degrees away from upright in Experiment 1, they need to be rotated by that amount prior to naming. This effect was not so apparent for artifacts across the two experiments because many of them did not have a canonical orientation and so were named equally quickly in the two experiments. We suggest that presenting the natural objects in more 'canonical' orientations resulted in the faster naming of these objects in Experiment 2[9]. We explore the consequences of this difference on naming, and the possible ways this interacts with hand squeezing, in the general discussion.

2.10 General Discussion

In two experiments we have tested the functional role of sensory-motor simulations in object naming by having participants squeeze a sponge while naming manmade, manipulable objects (artifacts) and natural objects (animals). In accordance with embodied accounts of object representations (e.g. Helbig et al; 2010; Witt et al., 2010), we hypothesized that, if sensory-motor simulations play a role in retrieving conceptual information about manipulable objects (i.e. the object's name), then having participants engage sensory-motor programs prior to and during the presentation of manipulable objects should affect naming; however, naming animals should not be affected. Contrary to these predictions, the results of Experiments 1 and 2 clearly indicate

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[9] We thank Raymond Klein for suggesting this interpretation.

that squeezing a sponge can either facilitate or interfere with naming *across object categories*.

Importantly these results do not support the predictions of embodied cognition (e.g. Witt et al., 2010, Helbig et al., 2010), which posits that sensory-motor simulations are important for the retrieval of conceptual information but should only be used in the retrieval of concepts for which we have sensory-motor experience (see Barsalou, 2008). It was assumed that most participants had little sensory-motor experience with natural objects as normally they are too large, dangerous, and rare and if they did have such experience (e.g. perhaps from growing up on a farm), that it would not involve grasping actions, since these animals could not be picked up. Here, we showed that a) occupying the sensory-motor system affects naming across categories of objects, and b) that that effect of hand occupation is dependent on the effects of naming due to picture-plane orientation[10].

If sensory-motor simulations, reflective of embodied object representations, are not involved in object naming in the present task, what could explain the present pattern of results? Though the present experiments do not allow us to draw firm conclusions we can speculate about the underlying cause of the interference/facilitation reversal. There are at least two possibilities.

First, it is important to note that there are well-documented effects of picture plane orientation on object naming within the naming literature, such that orienting an object away from 0 degrees in the picture plane delays naming latency (e.g. McMullen &

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[10] See Appendix for a further analysis on objects that have definitive canonical orientations (mono-oriented) and those that do not (polyoriented). These analyses removed oddly oriented items like the ‘ant’ and the ‘bottle’. The pattern of results did not change.

Jolicoeur, 1990). These effects are related to a large literature on mental rotation (*cf.* Shepard & Metzler, 1971). Indeed, we argue that the effect of picture-plane orientation is present in our two experiments. Specifically, we showed an effect of object category in Experiment 2 but not in Experiment 1, in that naming latency was faster for animals than artifacts in Experiment 2 (but there was no category difference in Experiment 1). We suggested that this is likely because the objects were presented in more ‘canonical’ orientations in Experiment 2, eliminating the need for mental rotation in Experiment 2 compared to Experiment 1, especially for the animals. This might suggest that squeezing *does* affect naming, but in a non-specific way at the level of mental rotation (i.e. an interaction between squeezing and the need to mentally rotate the image).

Indeed, neuroimaging has shown that the superior parietal cortex is involved in mental rotation of objects (e.g. Parsons, 2003; for transcranial magnetic stimulation results see Harris & Miniussi, 2003), and other imaging studies have implicated a broad collection of fronto-parietal regions (e.g. Milivojevic, Hamm, & Corballis, 2008; see meta-analysis by Zacks, 2008). In the current experiments we attempted to disrupt processing in fronto-parietal regions with a concurrent motor task. Further, it is known that concurrent motor tasks can affect mental rotation performance. Specifically, using Sheppard-style mental rotation tasks, Wexler, Kosslyn, and Berthoz (1998) established that performing a motor act congruent with the direction of mental rotation facilitates performance while performing a motor act that is incongruent with a motor act can interfere with it (a similar result was reported by Wohlschläger & Wohlschläger, 1998). Our results could imply that some form of mental rotation interacted with hand occupancy. Importantly, this interpretation suggests that mental rotation processes were employed across all objects in the present study. However, this interpretation is problematic. The notion that mental rotation was used with our images regardless of object category stands in contrast to research that shows picture plane inversion has particularly robust effects in objects with canonical orientations but not ‘poly oriented’ objects. For instance, Leek (1998) showed that picture-word matching of polyoriented objects (i.e. objects without an obvious canonical orientation) suffered less from picture-plane orientation than canonical objects. Thus, it seems likely mental rotation was not applied similarly to the animals and artifacts used in the present study. Future research should adopt a neurocognitive index of mental rotation (e.g. an event-related potential component recorded at posterior parietal sites at about 430 ms; e.g. Yoshido, Inoue, & Suzuki, 2000; see review by Heil, 2002) to explore how hand squeezing interacts with picture plane inversion.

A second possible cause of the facilitation/interference reversal is consistent with interpretations of the effects reported in the next chapter, and is the one we favour for the present data. We argue that the present results reflect a general attentional phenomenon. Previous research in our lab suggests that animals and artifacts attract attention asymmetrically, and this asymmetry depends on task (see Matheson, White, & McMullen, in preparation; see Chapter 3). In the current study, the task remained the same in both experiments (i.e. object naming). However, we argue that *picture plane orientation determined the attentional asymmetry of the objects with respect to the occupied hand*. That is, we argue that our objects biased attention in asymmetrical ways, and the nature of this directional asymmetry depended on the picture-plan orientation of the object and its relationship to the occupied hand. For this explanation we will argue that attentional asymmetry is represented by a vector that points in one direction, though it can be flexibly applied to objects (i.e. imagine an attentional arrow that is drawn over the objects). For instance, in some circumstances, the attentional vector points in one direction (e.g. towards the head or functional end) and in other cases it points in another direction (e.g. towards the tail or handle). Extending this idea, we speculate that changes in this attentional vector can account for the interference/facilitation reversal we observed here[11].

In Experiment 1, objects were oriented at 45-degree angles such that the tail-end of animals or the handles of artifacts were oriented towards or away from the occupied hand. In this experiment, one could argue that there was an attentional asymmetry for all objects such that the handles or the tail-ends were more 'salient' than the heads or the functional ends, simply by virtue of their physical proximity towards the hand (a relationship made more explicit by the fact that the objects were rotated at 45 degree angles). Indeed, this was something we attempted to make explicit. Thus, in Experiment 1, we argue that the attentional vector 'points' towards the tail-end or handle-end of the objects. In this case then, we observe slower naming (i.e. interference) when the vector points towards the hand. Conversely, in Experiment 2, we attempted to change the way objects were categorized by rotating them in the picture plane. In this experiment, we wanted to obscure the relationship between the tail-end /handle and the occupied hand; that is, we wanted participants to avoid categorizing the objects as manipulable,

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[11] Note that this idea is very similar to general 'saliency maps' (see and Kotch & Ullman, 1985), or 'attentional gradients' (Eimer, 1997) that is often discussed in the literature on attention. In our experiments, we prefer the use of the term 'attentional vector' because it strongly implies that the attentional bias is a *directional* asymmetry that is tied to the left/right orientation of the objects rather than simply a bias to different regions of objects. In this way, though we are simply describing an attentional bias, the use of the concept 'vector' has advantages.

particularly the animals. If we were successful, this simple manipulation might have completely reversed the attentional vector of the objects. Specifically, and most importantly for our argument, in Experiment 2, in which there was no obvious relationship between the handle/tail-end and the occupied hand and objects were presented in more canonical orientations (at least for the animals) we can speculate that the attentional vector now favoured the functional ends and heads of the objects (as in this experiment objects were presented at more 'canonical orientations'). Eye movement data from our lab (Matheson & McMullen, in preparation; see Chapter 4), using a different set of objects, show that participants do have a strong tendency to fixate the heads and functional ends of animals and artifacts when presented in more canonical orientations. Thus, we argue that the direction of the attentional vector results in interference in Experiment 1 and facilitation in Experiment 2, and is a consequence of the picture-plane orientation of the object and its relationship to the occupied hand. Future research can investigate the existence of attentional vectors and how the experimental task determines its direction.

Regardless of the ways in which attentional biases and picture-plane orientation interact, the present set of experiments does not support embodied theories of object representations. We should note that our present results are consistent with findings from a recent working memory study. In five experiments, Pecher (2012) investigated a similar hypothesis to ours, namely that interfering with motor simulations should affect working memory processes related to manipulable objects but non non-manipulable objects (Pecher's hypothesis pertained to working memory rather than naming). Pecher had participants engage in a concurrent motor task (i.e. a complicated hand and finger movement sequence) during working memory tasks for pictures and words denoting manipulable and non-manipulable objects. She showed that the concurrent motor task affected working memory for both manipulable and non-manipulable objects, a finding that she too argues is inconsistent with embodied accounts of object representations. The author speculates that a non-specific effect might underlie her results, such as interference at the level of the visiospatial sketchpad (in Baddeley's working memory model, Baddeley & Hitch, 1974), but this interference occurred for all type of objects in the study, manipulable and non-manipulable. This study and ours provide evidence from two different motor interference tasks in two different visual cognitive domains (i.e. naming and working memory) that motor simulations do not play a functional role in object representations. This challenges a strong form of the embodied hypothesis.

There are two caveats we wish to address. First, we acknowledge that our use of the terms 'facilitation' and 'reversal' are rather arbitrary. We mean to suggest simply hand occupancy influences naming in opposite ways across our two experiments (with faster naming when objects are oriented towards the occupied hand than away from the occupied hand in Experiment 1, and the reversed pattern in Experiment 2). Without a baseline (i.e. naming times for the two experiments with no hand occupancy) it is not possible to determine whether these effects reflect facilitation or interference. Indeed, in certain conditions, there may be no difference between squeezing and a no-squeeze condition. Future research should explore this possibility. Second, our vocal reaction times are generally faster than those reported by Witt et al. (2010)[12], a finding that might suggest the naming processes we have measured in the present study differ from those

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[12] We thank Dr. Susanne Ferber for this insight.

measured by those authors. However, because our design had participants squeeze a centrally mounted sponge, this ensured that their hands were in view at all times. It is likely that the attentional biases induced by hands (reported earlier) could have induced this general, over all advantage. Future research can explore this possibility.

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2.12 Appendix A

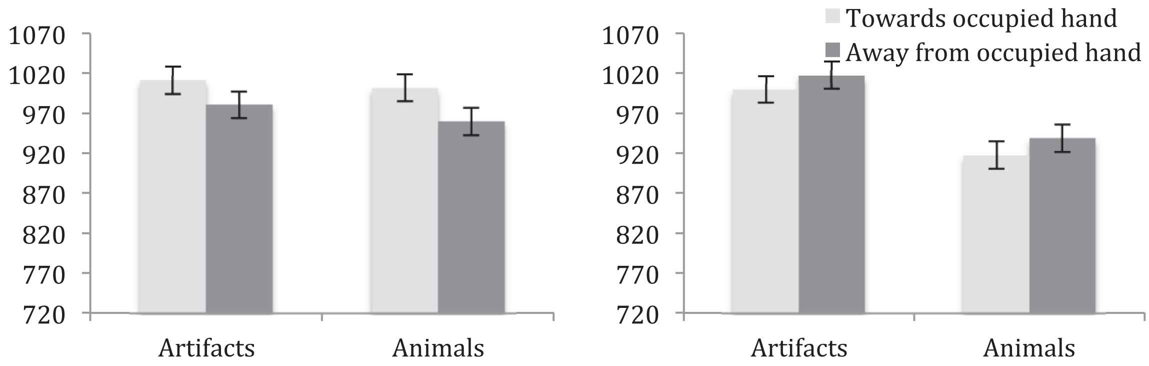
Upon close examination of the stimulus set it was determined that a small number of items in the manipulable artifact condition had canonical orientations (e.g. bottle), while a small number of animals had non-canonical orientations. We decided to remove these items, further trimming the data set, and running an additional analysis. On this set then, we are confident that all of the animals have a canonical orientation, and all of the artifacts are clearly without a canonical orientation. For the artifacts, six out of thirty-four items were removed (bottle, baby bottle, baby powder, frying pan, salt shaker, umbrella), and seven of the thirty-six animals were removed (bee, beetle, butterfly, dragonfly, frog, spider, and ant). Further, data from Experiment 1 and 2 were collapsed, allowing us to directly investigate the effect of the picture-plane orientation across experiments.

Mean RTs were submitted to a 2 (object category) X 2 (hand occupancy) X 2 (presentation occurrence) X 2 (Experiment) mixed ANOVA. There was a significant main-effect of Object Category, *F* (1, 214) = 11.19, *p* = < .001, $\acute{\eta}^2_{G}$ = .005, due to faster responding to the animals overall (*M* = 884.17, *SD* = 135.59) than the artifacts (*M* = 904.75, *SD* = 117.49). As in the previous analyses, there was a main effect of Presentation Position, *F* (1, 214) = 124.21, *p* = < .001, $\acute{\eta}^2_{G}$ = .238, due to faster naming of objects on the second exposure (*M* = 809.41, SD = 105.42) than the first (*M* = 979.51, SD = 138.31). There was a significant Object Category X Experiment interaction, *F* (1, 214) = 20.06 *p* = < .001, $\acute{\eta}^2_{G}$ = .008. As we described in the General Discussion, this effect was due to a category effect in Experiment 2 that was not present in Experiment 1. Specifically, animals were named more quickly (*M* = 857.61, *SD* = 144.25) than artifacts (*M* = 910.19, *SD* = 128.35) in Experiment 2, but there was no difference in naming latencies for animals or artifacts in Experiment 1 (*M* = 903.87, *SD* = 125.78; *M* = 900.72, *SD* = 109.09, respectively). This effect was due to the fact that animals have a canonical orientation and the artifacts do not. Additionally, as would be expected given the separate analyses of Experiments 1 and 2, there was an Experiment X Hand Occupancy interaction, *F* (1, 214) = 10.84, *p* = .002, $\acute{\eta}^{2}_{G}$ = .002, due to the interference effects of hand occupancy in Experiment 1 and the facilitation effects of hand occupancy in Experiment 2. Also, there was an Object Category X Presentation Position interaction, *F* (1, 214) = 34.23, *p* = < .001, $\acute{\eta}^{2}_{G}$ = .006. This was due to a larger effect of presentation position on artifact naming times than animal naming times. Specifically, artifacts named on the second exposure (*M* =808.33, *SD* = 105.31) had much shorter latencies than on the first exposure (*M* = 1001.16, *SD* = 145.31); conversely, in animals, this difference between first (*M* = 810.49, *SD* = 121.63) and second exposure (*M* =957.85, SD = 160.17) was smaller. Finally, as would be expected from the separate analyses, there was a three-way interaction between Experiment X Hand Occupancy X Presentation Position, *F* (1, 214) = 6.84, *p* = < .01, $\acute{\eta}^{2}_{G}$ = .002. This was mainly driven by the floor effects on second exposure naming in Experiment 1. See Figure 2-A1.

Figure 2-A2 plots the significant Object Category X Experiment interaction. Mean reaction times are shown as a function of object category and experiment. This plot clearly shows that this effect is driven by overall speeding of naming of animals in the second experiment, whereas the general naming times of artifacts are largely the same across both experiments. This finding strongly implicates general mental rotation effects across the two experiments and points to one possible way in which hand squeezing and mental rotation might interact.

Experiment 1 **Experiment 2**

First presentation



Second presentation

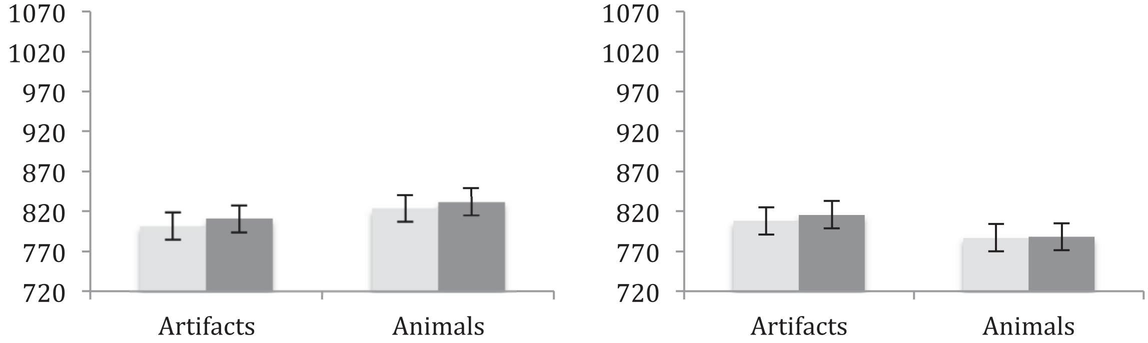


Figure 2-A1. Mean naming reaction time (ms) as a function of object category and hand occupancy. Error bars represent estimated Fisher's Least Significant Difference.

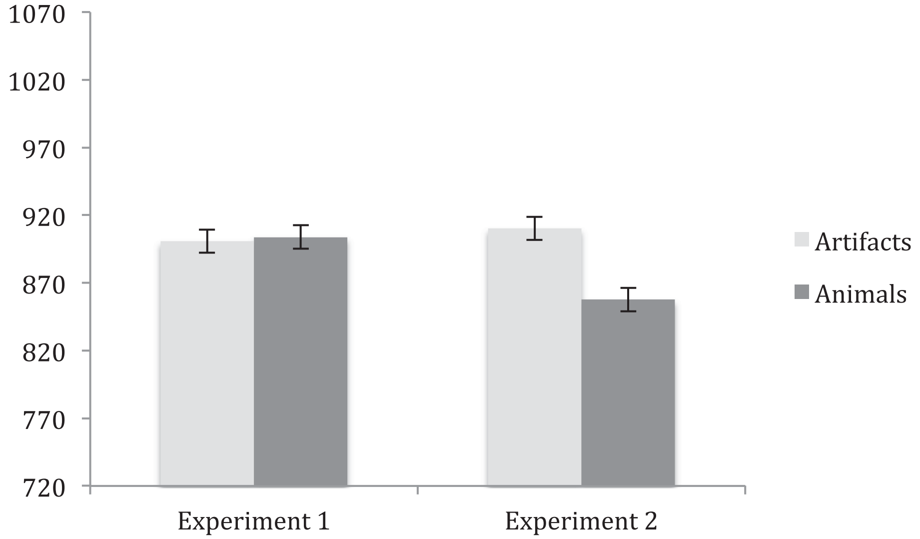


Figure 2-A2. Mean reaction times (RTs) as a function of experiment and object category. Error bars represent Fisher's Least Significant Difference.

CHAPTER 3 A TEST OF THE EMBODIED SIMULATION ACCOUNT OF OBJECT PERCEPTION: POTENTIATION OF RESPONSES TO ARTIFACTS AND ANIMALS

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3.1 Abstract

Embodied theories of object representation predict a tight association between sensorimotor processes and visual processing of manipulable objects. Previous research has shown that object handles can ‘potentiate’ a manual response (i.e. button press) to a congruent location. This potentiation effect is taken as evidence that objects automatically evoke sensorimotor simulations in response to the visual presentation of manipulable objects. In the present series of experiments we investigated a critical prediction of embodied object representations that potentiation effects should be observed with manipulable artifacts but not non-manipulable animals. In four experiments we show that a) potentiation effects are observed with both animals and artifacts, b) potentiation effects depend on the absolute size of the objects and c) potentiation effects with artifacts depend on the task. We conclude that potentiation effects do not provide evidence for embodied object representations but are suggestive of a more general stimulus-response compatibility effect that may depend on the distribution of attention to different object features and their corresponding location in space.

Key words: stimulus-response compatibility, attentional bias, motor potentiation, embodied simulation, object perception

A test of the embodied simulation theory of object perception: Potentiation of responses to artifacts and animals.

Classical information-processing theories of cognition suggest that cognitive processing is executed by hierarchically organized, amodal, cognitive modules (see Wilson, 2002). Recently, theories of embodied cognition (e.g. Barsalou, 2008)[13] have challenged this view, positing instead that higher-order cognition is supported by (or sometimes equates to simulations of) modality-specific (i.e. sensory-motor) processes within the brain. These theories draw upon research of ‘canonical mirror’ neurons, a class of neurons that respond similarly to both the observation of object-directed actions and to the visual presentation of the same objects (e.g. Murata et al. 1997; see Rizzolatti & Craighero, 2004, for a review), and suggest that information processing is constrained by simulations of sensory-motor activity. More specifically, embodied theories predict that the visual processing of objects requires partially (and mostly non-consciously) simulating the somatosensory properties and motoric actions that would normally accompany an interaction with that object. For instance, in an embodied view, the visual processing of a hammer elicits both visual processes and covert simulation of other, non-visual, sensory-motor experiences of a hammer and that these simulations are used for cognitive tasks such as identification or object categorization. As such, embodied theories predict greater involvement of sensory-motor representations in processing manipulable

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[13] Currently, there is no unified theory of embodied cognition, and many accounts have been provided. For instance, see Wilson (2002) for a general overview of the issues associated with embodied cognition; see the perceptual symbols theory of Barsalou et al. (2003) for his account of grounding cognition (2008); and see Lakoff & Johnson (1999) for a general theoretical framework. A similar approach has been described in the literature on common-coding (e.g Prinz, 1997) and regarding semantic representation (Allport, 1985). Finally, Shapiro (2011) has identified at least three distinct aspects of the embodied cognition hypothesis; in the present experiment, we are specifically referring to the ‘conceptualization’ hypothesis.

artifacts compared to natural objects. In humans, some functional magnetic resonance imaging (fMRI) studies have supported this notion, demonstrating activity in sensory-motor association cortices, including left ventral premotor cortex and the left posterior parietal cortex, during viewing of manipulable objects compared to non-manipulable objects (Chao and Martin, 1999; Creem-Regehr & Lee, 2004; Grafton et al, 1997; Gerlach, Law, and Paulson, 2002; Kellenbach, Brett, & Patterson, 2003). Importantly, these regions are involved in object directed actions (see Jeannerod, Arbib, Rizzolatti, & Sakata, 1995, for a review). In the absence of an instruction to execute an action, activity elicited in these regions by visually presented artifacts may indeed reflect 'simulations' of the type posited by embodied theories.

Critically, embodied theories of cognition predict an associations between sensory-motor simulations and visual object representations in cognitive tasks (e.g. Gallese and Sinigaglia, 2011). Recent research has adopted behavioural paradigms with the goal of demonstrating relationships between action and perception. For instance, Helbig et al. (2006) have shown that object naming is more accurate when graspable objects are primed by pictures of objects that afford a similar grasp (e.g. a frying pan primed by a dust pan, both of which would be grasped with the whole hand) compared to a dissimilar grasp (e.g. a frying pan primed by a banjo). These results suggest that the visual presentation of manipulable objects facilitates the identification of objects that afford similar motoric actions. Similar priming effects are observed on object naming by videos of congruent actions (e.g. a video of a hand performing a squeezing action primes the naming of objects like 'pliers' but not 'typewriter'; see Helbig et al., 2010). Finally, pantomimes (i.e. the execution of an object-based action with an imagined object), can also prime object identification and categorization in children as young as five years old (Mounoud et al., 2007). Importantly, these findings assume that motor simulations are elicited by the observation of a manipulable artifact or a hand-action that corresponds to use(s) of that object, and this simulation facilitates processing of the primed graspable object. Recently, this assumption was tested by Witt et al. (2010), who had participants engage in a motor activity during an object-naming task. The authors reasoned that if motor simulations are important for cognitive processing of manipulable artifacts, then occupying the motor system should interfere with these simulations and impair naming of manipulable artifacts but not non-manipulable objects (i.e, animals). This is exactly what they report. Together, these results provide initial support for the idea that motor programs play a role in the processing and retrieval of conceptual knowledge.

Another paradigm for investigating the relationship between perception and action comes from studies of 'action potentiation[14]'. In such tasks, the presentation of a manipulable object facilitates a motor response with the hand that is aligned with the object's handle. Within the literature on embodied object representation, one of the most widely cited experiments comes from Tucker and Ellis (1998; e.g. see Barsalou, 2008; Witt et al., 2011; Mounoud et al., 2012). In this study, participants were shown images of manipulable objects that were either upright or inverted. The participants were instructed to indicate with a left- or right-handed keyboard response whether the objects were upright or inverted. Incidentally, objects were presented with their handles pointing

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[14] This effect has also been referred to as the orientation effect (see Vainio, Ellis, & Tucker, 2007), the visuo-motor priming effect (Craighero et al. 1996) or simply the correspondence or compatibility effect (see Phillips & Ward, 2002). However, the original task manipulated two orientation variables (left vs. right and upright vs. inverted orientations) and therefore we use the more descriptive and less ambiguous term 'potentiation effect' to avoid confusion.

towards the left or the right hand. The authors showed that, when the response was made with the right hand, participants were faster to judge the orientation of objects that afforded a right-hand grasp; the same was true for the left-hand responses and objects that afforded a left-hand grasp. Thus, when the handle of the object was ‘compatible’ with the response hand, performance was better than when it was incompatible. The authors suggested that these findings reflect an automatic activation of the affordances of objects; specifically, the visual presentation of a manipulable artifact results in covert simulations of an afforded action and these simulations potentiate a manual response (i.e. key press).

The existence of a potentiation effect has important implications for embodied theories of cognition as it suggests that sensory-motor simulations are automatically elicited in response to the visual presentation of manipulable artifacts, an interpretation that is consistent with fMRI results (e.g. Chao and Martin, 2000). Thus, from an embodied perspective, this automatic activation could form a part of a larger, distributed, modality-specific representation. The importance of a potentiation effect to theories of embodied cognition necessitates further investigations of this phenomenon to determine its reliability and to ensure that it does not arise solely from paradigm-specific attributes. Importantly, consistent patterns of results have been reported using paradigms similar to that originally used by Tucker and Ellis (1998). For instance, Tucker and Ellis (2004) have shown that the presentation of precision grip objects (e.g. clothes peg) potentiates responses requiring precision grasps (e.g. grasping with fingers), while the presentation of power grasp objects (e.g. wine bottle, grasping with the whole hand) potentiates power grasps (e.g. grasping with the whole hand).

However, despite this evidence, more recent studies have provided only limited support for the embodied interpretation of the potentiation effect (see Viano, Tucker, Ellis, 2008), or have challenged it completely (see Phillips & Ward, 2002). For instance, in a paradigm similar to Tucker and Ellis's (1998), Anderson, Tamagishi, and Karavia (2002) presented participants with schematic pictures of scissors or clocks while they made orientation judgments. The authors observed the potentiation effect when the response hand was compatible with the location of the scissor's handles *and* the clock's hands. If the potentiation effect is due to sensory-motor simulations we would not expect to observe facilitation of responses when viewing clock hands because they do not afford actions. The authors interpreted this finding as indicative of an attentional bias towards different features of asymmetrical objects, an interpretation that is not ruled out by Tucker and Ellis's (1998) original study. Similarly, Phillips and Ward (2002) have shown that potentiation of responses depends on whether the left/right location of the object's handle corresponds to the *side* of the response (i.e. response location/handle location compatibility), rather than to the specific effector executing the response (hand/handle compatibility). Specifically, the authors demonstrated potentiation effects with limbs in the same spatial location as the object's handle, including foot responses. This result cannot be interpreted as action potentiation caused by the object's afforded action, as we do not use our feet to pick up objects. Vaino, Ellis, and Tucker (2007; Exp 2) have shown that attention to irrelevant features (i.e. having participants attend to a target dot that changes colour during the trial, rather than attending to the object) eliminates the potentiation effect, questioning the effect's automaticity and implicating a role of early attentional or visual processes. Additionally the authors showed that potentiation can occur when the required responses change from left/right hands to the index and middle fingers of a single hand, a finding that is more suggestive of an 'abstract response code' similar to the type posited for the Simon effect[15] than motor simulations (see Simon, 1969; Kornblum, Hasbroucq, & Osman, 1990). This finding has been reported by at least one other group (Cho & Proctor, 2010) and led the authors to conclude that the potentiation effect is likely the result of the handle coding the particular region of space relative to the rest of the object and facilitating responses to that region rather than motor potentiation in response to the object's handle, *per se*.

One other study provides strong evidence against the embodied interpretation of the potentiation effect. Using an electric torch (i.e. flashlight) as a stimulus, Pellicano et al. (2010) replicated the potentiation effect in response to the handle when participants made orientation judgments (upright vs. inverted) but the exact opposite effect was found when participants made colour judgments (red vs. blue). The authors interpreted this finding as evidence for distinct effects that depend on task; a motor-affordance effect in the orientation task, and a Simon-like effect in the colour task. We argue that these results are more suggestive of a general stimulus-response compatibility effect, one that depends on the goals of the observer (as discussed later; see Bub & Masson, 2010 for a similar argument). The findings of different potentiation effects in the colour discrimination task shows at the very least that facilitated motor responses to object handles might not reflect embodied object representations.

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[15] Critically, potentiation effects are thought to differ from Simon effects as potentiation effects are dependent on left-right object orientation, and perhaps follow a different time course (see Phillips and Ward, 2002).

Overall then, the results of the studies of action potentiation are mixed, with some studies providing support for embodied accounts of object processing and others suggesting a more general stimulus-response compatibility effect. Importantly, whether a more general stimulus-response explanation better accounts for the current literature remains unclear for a number or reasons. Most critically, with the exception of Anderson et al. (2002), the studies of action potentiation reviewed here have failed to include an appropriate control stimulus condition that would not be expected to elicit motor simulations. The inclusion of a category of objects that are asymmetrical yet non-manipulable would allow us to further test the specificity of the potentiation effect. Thus, if the potentiation effect depends on object affordances, then we should observe it with manipulable artifacts but not animals (see Witt et al., 2010, for similar reasoning). If, on the other hand, it depends on a location-specific code for some object feature, as previous results suggest (Cho & Proctor, 2002; Phillips & Ward, 2002), we should expect to see it with both types of objects, albeit relative to some potentially unknown feature of the objects. Handles seem to be the feature with artifacts but it is unclear what feature might be potentiated in animals.

Additionally, previous studies (e.g. Anderson et al.; Cho & Proctor, 2010; Phillips and Ward; 2002) have used a limited number of impoverished, schematic, stimuli. With the use of only a few stimuli it is difficult to ascertain whether differences are due to object category (i.e. manipulable artifacts) *per se* or some other low-level stimulus feature of the particular images used (for instance, salient features derived from low-level visual contrast). Thus, it is unclear whether the use of a single stimulus might have biased visual or attentional processing over the course of the experiments reported by these authors.

It is also known that different experimental tasks can modify the extent of sensory-motor activity elicited by manipulable artifacts. This was clearly shown by Gerlach, Law, and Paulson (2002), who observed greater activity in the left premotor cortex in an object categorization task (e.g. deciding if an object is 'natural' or 'man-made') than an object decision task (i.e. deciding if an object is 'real' or 'non-real'). This suggests that motor simulations might be used for some aspects of cognitive processing (categorization) but not others (identification). Thus far, research investigating the potentiation effect has either required accessing long-term visual object representations (upright vs. inverted judgments, e.g. Tucker and Ellis, 1998) or has directed attention away from object category by having participants make judgments about task-irrelevant features (which can eliminate the potentiation effect; e.g., the dot colour task in Viano, Tucker, and Ellis, 2008). Thus, a direct comparison of the potentiation effect under different task instructions in necessary. Any change in the direction of the potentiation effect across task would challenge the embodied interpretation (e.g. Pellicano et al, 2010).

In the present series of experiments we addressed these three issues by attempting to replicate Tucker and Ellis (1998). Additionally, we included an animal category as a control to determine if potentiation effects were specific to manipulable objects. We also used a large, visually complex stimulus set to expand the generalizability of any findings. If the potentiation effect observed in Tucker and Ellis (1998) is due to covert motor simulations, then the incidental left/right orientation of manipulable artifacts, but not animals, should lead to action potentiation. In Experiment 1, we failed to replicate Tucker and Ellis (1998), in that we did not show a potentiation effect. In Experiment 2, we tested whether this failure was due to size differences between our stimuli and theirs. Here, we tested whether the absolute size of a stimulus (i.e. the size of the image on the screen) influenced the potentiation effect. The results of this study replicated those of Tucker and Ellis (1998), showing a potentiation effect for manipulable artifacts. However, there was also a potentiation effect for the animals (with head/response hand compatibility resulting in faster responses) challenging the embodied interpretation. In Experiment 3, we investigated whether this effect of action potentiation elicited by animals was due to the implied size of the animals. We found that the implied size did not change the effect. Finally, in Experiment 4, we demonstrated a reversed potentiation effect ('action inhibition') for the artifacts in a categorization task. Overall these results suggest that action potentiation effects reflect basic stimulus-response compatibility effects that arise from task demands, rather than automatic covert motor simulations that are part of an embodied object representation. These effects fail to support the hypothesis of embodied object representations.

3.2 General Methods

Overview

For this series of experiments, we adopted the paradigm used by Tucker and Ellis (1998) to investigate action potentiation effects in response to artifacts and animals. We adopted the procedure of Tucker and Ellis (1998, Experiment 1) in as much detail as possible, selecting the same object stimuli as they reported using. Our stimuli were presented on a computer screen and participants made responses via key presses on a standard keyboard.

Participants

Participants were recruited from the Dalhousie University Psychology Department or surrounding community. All participants had normal or corrected-to-normal vision, reported no visuo-motor deficits, and spoke English as a first language by self-report. Most participants reported being right handed.

Materials

In all experiments, 20 greyscale photographs of natural objects (i.e. animals) and 20 photographs of man-made objects (i.e. tools and other manipulable human artifacts) were obtained from various photographic databases available online (see Table 1 for a list of the object stimuli). Animals were used as a control stimulus category because they are non-manipulable and, like our manipulable artifacts, when shown in profile, they have a high degree of left/right asymmetry. Each object was presented on a white background in approximate profile view. Each image was presented four times: upright, facing left; upright, facing right; inverted, facing left; and inverted, facing right. The raw images of the two categories were equated on average area and average pixel luminance using graphics software (GNU Image Manipulation Program, v2.6).

In Experiment 1, the stimuli subtended approximately 12.6 visual degrees in width and 11.4 in height at a viewing distance of 45 cm. In all other experiments, the object stimuli subtended approximately 36 degrees of visual angle in width and 27.4 in height at a viewing distance of 45 cm. Additionally, in Experiment 3, four images of hands were used as primes: large, left hand; large, right hand; small, left hand; small, right hand. The small hand prime subtended approximately 7.6 degrees of visual angle in width and 5.1 in height, while the large hand prime subtended 36 visual degrees in width and 20.2 degrees in height.

Stimuli were presented on a 21in. CRT monitor with a refresh rate of 85 Hz and a screen resolution of 1280 X 1024 at 96 DPI. Presentation was controlled using a MiniMac (Apple, California) with a Windows (Microsoft, California) partition running DirectRT Experiment software (Empirisoft Corporation, NYC).

Table 3.1. List of individual object stimuli used in experiments. Numbers correspond to unique instances of objects.

Artifacts		**Animals**	
Axe 1	Kettle 2	Bear1	Giraffe 1
Coffeepot 1	Knife 1	Bear 2	Giraffe 2
Coffeepot 2	Knife 2	Cheetah 1	Horse 1
Coffeepot 3	Mug 1	Cheetah 2	Horse 2
Frying pan 1	Mug 2	Deer 1	Lion 1
Frying pan 2	Pitcher 1	Elephant 1	Lion 2
Handsaw 1	Pitcher 2	Elephant 2	Seagull 1
Handsaw 2	Watering can 1	Elephant 3	Sheep 1
Iron 1	Saucepan 1	Fox 1	Zebra 1
Kettle 1	Saucepan 2	Fox 2	Zebra 2

Procedure

The procedure of each experiment was similar. After a short practice session (using objects not included in the experimental set) participants completed the experimental task. On each trial, a brief fixation appeared for 1000 ms, followed by an object image (Experiments 1, 2, 4) or a prime stimulus for 250 ms followed by an object image (Experiment 3). In all experiments, the object image stayed on the screen until the participant responded. In Experiments 1-3, participants were instructed to indicate via key-press whether the objects were upright or inverted. Though this decision was obvious for our animal stimuli (as they have a canonical orientation), it was not always so for some manipulable artifacts (e.g. saw). For manipulable artifacts, participants were told to define orientation with respect to the object's use (i.e. the same instruction was given as in Tucker & Ellis, 1998). In Experiment 4, participants were instructed to indicate the object category (animal vs. artifact) via key-press. Participants were told to respond by hitting the 'z' key on the keyboard or the '3' on the number pad of the keyboard with their left and right index finger, respectively (with random key-category assignment across participants). At this distance, the participant's hands were spaced 35 cm apart. Breaks in participation were administered every 40 trials.

Analysis

Accuracy and the natural log of reaction time (logRT) from correct trials were dependent measures. Raw RTs less than 200 ms were excluded as anticipatory responses, and raw RTs greater than 4000 ms were excluded as attentional lapses. We used logRT to better meet the assumptions of normality for our statistical models and to better characterize condition differences (see Ratcliff, 1993; Whelan, 2008). In all analyses 'compatibility' was defined for manipulable artifacts as response hand/object handle compatibility and for the animals as response hand/animal tail compatibility. Tails were deemed to be the end of animals that would most likely be grasped if they were picked up. To reach this definition, we performed a small pilot task (N = 3) in which we presented participants with toy models of animals (e.g. horse) in different orientations and asked them to pick them up (same as pilot reported in Chapter 2). Intuitively, in all cases, participants picked up the animals by their long axis, with the animal heads extending away from the hand. This shows that, behaviourally, the tail-ends are treated consistently like graspable ends.

Two types of statistical analyses were used to provide a more complete description of the data. First, we submitted aggregated data to a series of repeated-measures Analyses of Variance (ANOVAs) to allow for traditional hypothesis testing of the differences between means (of accuracy proportion and logRT), as it is implemented with the *aov()* function and the *ez()* package (*v.* 4.1-1, Lawrence, 2012) in R (*v.* 12.2; R Core Team, 2012). This analysis facilitates comparison of our results with those of previous research of the potentiation effect, including the ANOVAs used by Tucker and Ellis (1998).

Secondly, logRT measures were analyzed using linear mixed-effects modelling as it is implemented by the *lmer()* function of the *lme4* library in R (Bates, Maechler & Bolker, 2012). Although linear mixed-effects modelling is a relatively new advancement in statistical modelling, this approach has been used by a number of authors in the analysis of continuous data (see Baayen, 2008), and offers a number of advantages over the more traditional repeated-measures ANOVA. First, it accounts for the non-independence of repeated-measures while avoiding the computations of by-item and by-subjects regressions. Second, it models both fixed effects parameters (those corresponding to the controlled manipulated variables in the experiment, including the category of object and its orientation—compatible vs. incompatible) and random effects (the effects of a variable that are randomly chosen from a larger population such as the experimental stimuli used or the participants sampled). Modelling random effects allows the analysis to better meet the assumption of uncorrelated randomly distributed residuals, an assumption that is typically violated in analyses of repeated measures RT data. Further, modelling random effects allows for greater generalization of the results beyond the participants and items used in the experiment (Baayen, 2008). This is an important advantage of the current study over previous research that has used single stimuli (e.g. Anderson et al., 2002); in these cases, there is no confidence that the effects will extend to other stimulus sets. By accounting for variability due to items we are able to derive a more precise estimate of the effects within and between our two object categories (see Baayen, 2008 discussion comparing LME with quasi-F comparisons in item and subject analyses). Third, linear mixed effects models account for non-sphericity and missing data points, which is often an issue when analyzing only a subset of RTs (i.e. from correct trials only), without the use of common corrections (e.g. using the Greenhouse-Geisser or Huynh-Feldt corrections). Lastly, mixed models do not aggregate the data, meaning that each data point is used in building the statistical model, increasing its power.

In the ANOVA analyses, we first performed outlier rejection on a by-subject basis by excluding logRTs that were more than 2.5 standard deviations from subject means. In our linear, mixed-effects analyses, initial model fitting was conducted using a number of fixed effects predictors, including the compatibility of the stimulus’s orientation with the response hand (functional end/head compatible vs. handle/tail compatible) and the category of the object (artifact vs. animal). By-subject random adjustments to the intercept were included in the model. After fitting the initial model, we removed outliers from the data (on a by-subject basis, excluding data more than 2.5 standard deviations from the subject mean). We proceeded to identify the optimal mixed-effects model for logRT measures using an iterative procedure that first fit the most complex model and compared the fit of progressively simpler models using a log-likelihood ratio test (see Tremblay, 2011). With this procedure, interaction terms and other factors that do not explain significant amounts of variance are removed, resulting in a model with the fewest number of parameters that accounts for the most variance. Variance explained by factors in the model was tested using *F* tests for main effects and interactions (using upper bound and lower bound *df* to determine *p* values). The R package *LMERConvenienceFunctions()* was used for forward-fitting random effects and calculating *p* values (*v*. 1.6.7; Tremblay & Ransijn, 2011). (See Appendix A for a more detailed description of the model fitting procedure.)

3.3 Experiment 1

In Experiment 1, we attempted to replicate Tucker and Ellis (1998) and extend their findings with the inclusion of a control object-set category (i.e. animals). If the potentiation effect previously reported is due to covert simulation of afforded actions we should observe the fastest RTs when the location of an artifact's handle is compatible with the responding hand (i.e. when the object's handle affords action by the response hand, regardless of whether the object is upright or inverted); conversely, there should be no compatibility effect with the animal stimuli (i.e the incidental tail-end direction of the animal should not matter for response time). Because we did not expect participants to have difficulty with the task, we anticipated high accuracy in all conditions and therefore our main hypotheses were based on the pattern of RTs.

Method

Twenty-six participants completed Experiment 1 (5 males, mean age = 22.5 years, 22 right-handed). In this experiment, the task was to decide if the objects were oriented ‘upright’ or ‘inverted’ and to indicate this decision by pressing a corresponding key (either the ‘z’ or the ‘m’, randomly assigned across participants).

Results and Discussion

We calculated the accuracy (proportion correct) and mean log reaction time (RT) within each condition, and submitted these to separate 2 (category; animals vs. artifacts) X 2 (compatibility; compatible vs, incompatible) repeated-measures ANOVAs. (See Figure 3.1.)

Accuracy. For the proportion correct, there was a significant effect of object category, F (1, 25) = 10.73, $p < .001$, $\eta^2_G = .07$, due to better performance on the animals ($M = .96$, $SD = .037$) than the artifacts ($M = .93$, $SD = .063$) [16]. No other effects were significant, $p > .05$.

logRT. In line with the accuracy effects, the ANOVA revealed a significant effect of object category, F (1, 25) = 191.4, $p < .001$, $\eta^2_G = .11$, due to faster responses to the animals ($M = 564.34$, $SD = 81.57$) than the artifacts ($M = 635.57$, $SD = 89.84$). No other effects were significant, $p > .05$.

Linear mixed model of RT. We performed LME modelling on the natural logarithm of reaction times. Our initial model included category and compatibility as fixed-effects factors and by-subjects random intercepts. The optimal model included only an effect of

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[16] Note, the effect size we report is the generalized eta squared, a measure of effect size designed to reduce the influence of the number of factors in an experiment, giving values that are easily comparable across experiments (see Olejnik & Algina 2003).

object category and no interaction terms, as well as by-subject random intercepts (i.e. a by-subject adjustment to the mean), and by-item random intercepts (i.e. a by-item adjustment to the mean). The results of the model are shown in Table 3.2. Overall, the mean RTs in response to animals were faster than to artifacts. (difference = .102 in natural log units).

Table 3.2. ANOVA table of significant factors in the LME model of RT data.

Coefficient	*df*	*SumSq*	*MeanSq*	*F*	*upper.den.df*	*upper.p.val.*	*lower.den.df*	*lower.p.val.*
Category	1	2.53	2.53	62.76	3825	< .001	3639	0

Experiment 1 failed to replicate Tucker and Ellis (1998; Experiment 1). We did not show a potentiation effect. Interestingly, participants were faster at making upright/inverted judgments about animals than artifacts. This finding is consistent with research showing larger decrements in recognition performance with inversion for objects with ‘canonical’ orientations compared to objects without canonical orientations; because animals are typically seen in their upright position but artifacts are often seen in many orientations, our results support the conjecture that it is easier to detect orientation differences with canonical animals than with non-canonical artifacts (c.f. McMullen & Jolicoeur, 1990).

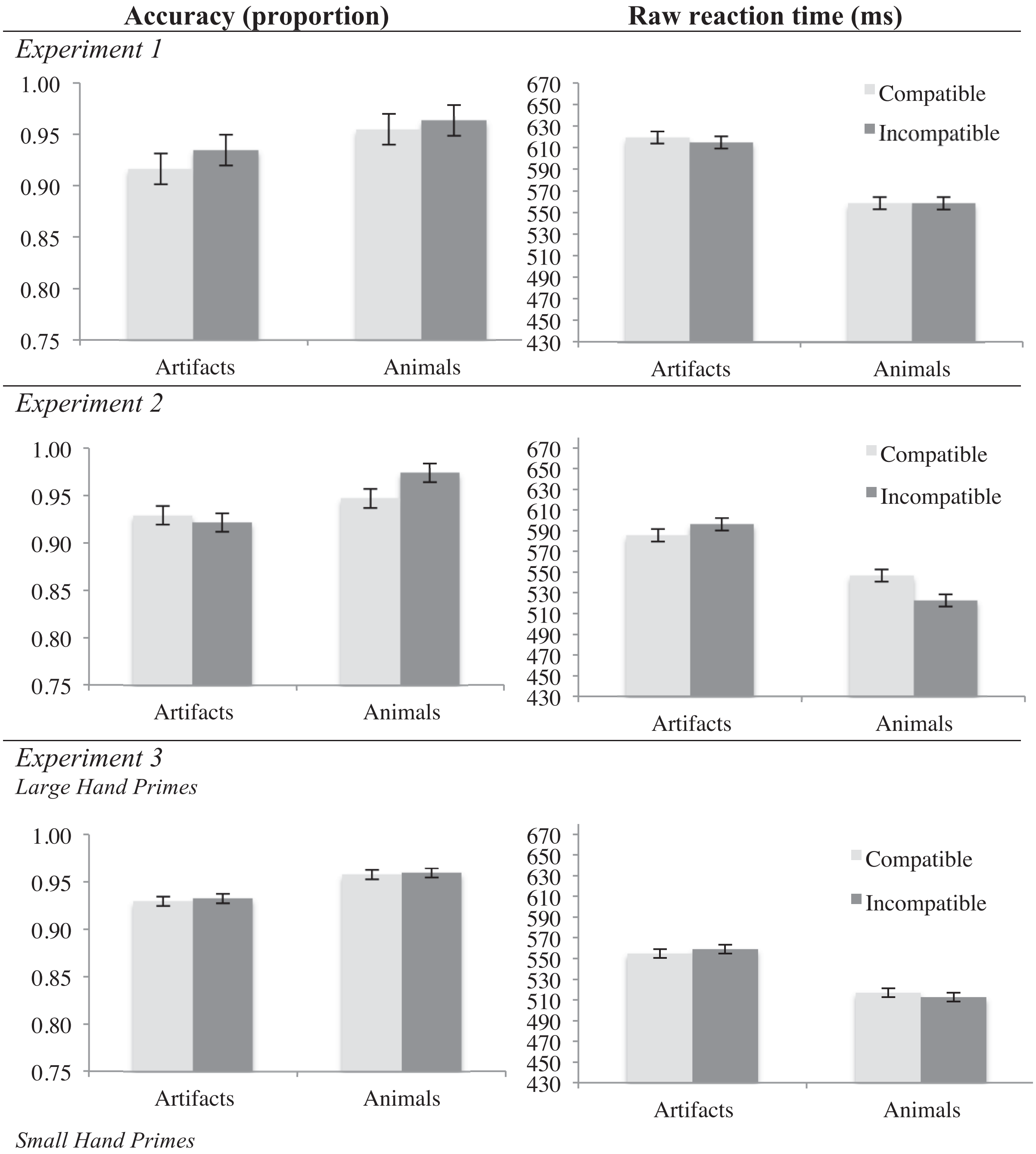
The failure of experiment 1 to elicit a potentiation effect may be due to a number of factors. We attempted to replicate the methods of Tucker and Ellis (1998) in as much detail as possible (including presenting the same types of objects). One critical difference between their study and ours is that we presented our stimuli at a smaller visual angle (scaled to present at about 12 degrees vs. up to 18 degrees). The potentiation effect is purported to result from object affordance properties; failing to demonstrate a potentiation effect with smaller stimuli raises the question of whether the absolute size of the objects is important for eliciting this effect. Other visuo-motor priming studies tend to use larger stimuli, presented at or near (e.g. 90% of) ‘actual size’ (e.g. Tucker and Ellis, 2004). Additionally, it has been reported that ventral visual regions (in the lateral occipital cortex) respond more robustly to objects that appear to be closer to the viewer (Cate, Goodale, and Köhler, 2011). Though we are not measuring neural responses to our object categories, these findings suggest that stimulus size may affect the processing of affordances. We explore this possibility in Experiment 2, again attempting to replicate Tucker and Ellis (1998; Experiment 1) but using larger stimuli.

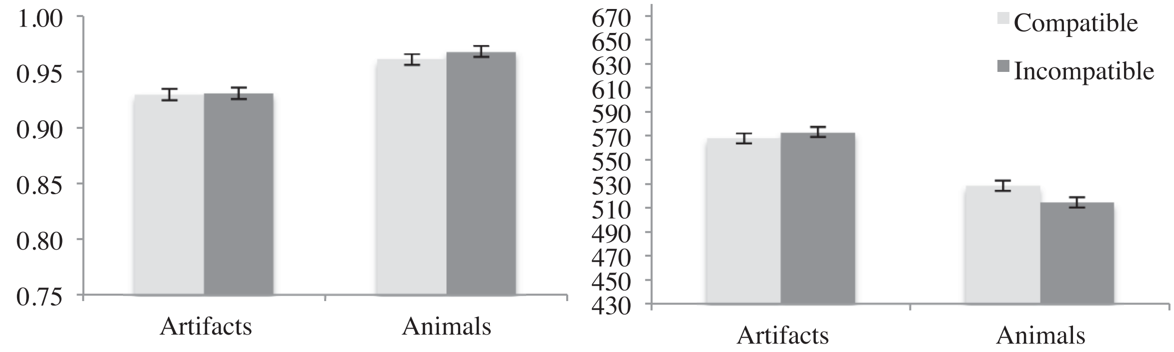
3.4 Experiment 2

In Experiment 2, we again attempt to replicate and extend Tucker and Ellis (1998), except we presented the stimuli at a larger visual angle that was more consistent with the one they used, reasoning that the absolute magnitude of the retinal image might be important for the effect. Again, we predicted that we would see fastest RTs when the location of the object’s handle was congruent with the responding hand; if the Tucker and Ellis (1998) motor potentiation effect is due to covert simulation of afforded action, then there should be no compatibility effect with the animal stimuli. A potentiation effect in response to animal stimuli would suggest that the effect arises from a more general stimulus-response compatibility induced by task structure, not from covert simulation of action.

Method

24 participants completed experiment 2 (4 males, mean age = 23.7 years, 21 right-handed). The task was to decide if the objects were oriented 'upright' or 'inverted' and to press a corresponding key (either the 'z' or the 'm', randomly assigned across participants).





Experiment 4

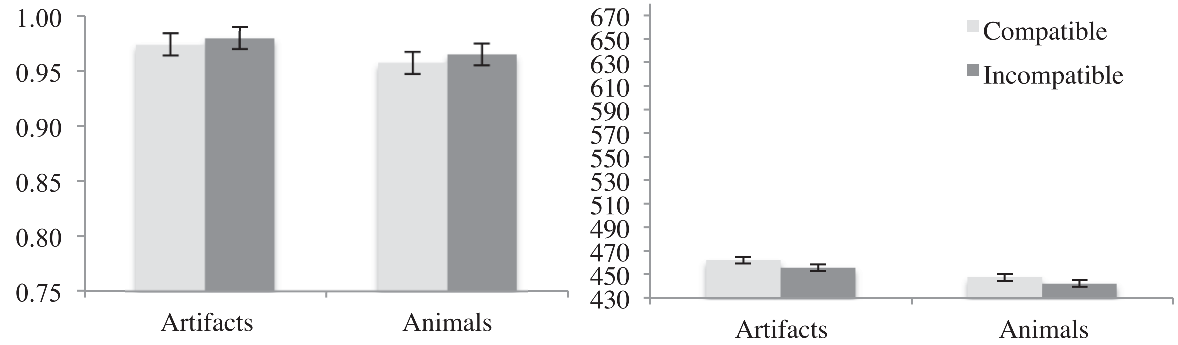


Figure 3.1. Mean accuracy and reaction time (RT) as a function of object category and compatibility. Error bars represent Fisher's Least Significant Difference.

Results and Discussion

We calculated the accuracy (proportion correct) and mean log reaction time (logRT) within each condition, and submitted these to a 2 (category) X 2 (compatibility) repeated-measures ANOVA.

Accuracy. As in Experiment 1, for the proportion correct, there was a significant effect of object category, *F* (1, 23) = 9.23, *p* = .006, η^2_G = .10, due to better performance for animal trials (*M* = .96, *SD* = .031) than for artifacts (*M* = .93, *SD* = .06). More importantly, there was a significant interaction between category and compatibility, *F* (1, 23) = 6.19, *p* = .02, η^2_G = .03. See Figure 3.1 for the effect. This interaction indicated that the compatibility effect was different for animals compared to artifacts. For artifacts, accuracy was slightly higher on compatible trials (*M* = .93, *SD* = .08) than incompatible trials (*M* = .92, *SD* = .06). The difference was in the opposite direction for the animals, with highest performance on the incompatible trials (*M* = .97, *SD* = .03) than the compatible trials (*M* = .95, *SD* = .04).

logRT. Consistent with the accuracy results, ANOVA on the log RTs revealed a significant effect of category, *F* (1, 23) = 88.42, $p < .001$, $\eta^2_G = .08$, due to faster responses to animals (*M* = 534.53, *SD* = 84.67) than to artifacts (*M* = 590.64, *SD* = 100.81). Additionally, there was a significant Category X Compatibility interaction, *F* (1, 23) = 16.59, $p < .001$, $\eta^2_G = .008$, indicating that the compatibility effect was different for the animals and the artifacts. For animals, responses were faster on incompatible trials (*M* = 522.79, *SD* = 78.79) than compatible trials (*M* = 546.73, *SD* = 94.05). For artifacts, the opposite pattern was shown, with faster responses on compatible trials (*M* = 585.49, *SD* = 101.33) than incompatible trials (*M* = 596.14, *SD* = 102.55). (Fisher's Least Significant Difference showed that the compatibility effect for the animals was significant though it was not in the artifacts. However, an *a priori* directional paired samples *t*-test in artifacts was significant, $p = .033$; see Figure 3.1).

Linear mixed model of RT. We performed LME modelling on the natural logarithm of reaction times. Our initial model included category and compatibility as fixed effects factors, as well as by-subjects random intercepts. The optimal model included the category and compatibility factors, and the interaction between category and compatibility. The model also included by-subject random intercepts (i.e. a by subject adjustment to the mean) and by-item random intercepts. Additionally, there was a by-subject adjustment to the slope for the category effect, allowing us to model variance in the size of the category effect for each subject. The results of the model are shown in Table 3.3. Overall, the mean RTs in response to animals was faster than the response to artifacts (difference score = .084 in natural log units). The Category X Compatibility interaction was due to faster responses on compatible trials relative to incompatible trials for artifacts (difference score = .019), while the opposite pattern was observed for animals (difference = -.037).

Table 3.3 ANOVA table on significant factors in LME model of RT data.

Coefficient	*df*	*SumSq*	*MeanSq*	*F*	*upper.den.df*	*upper.p.val.*	*lower.den.df*	*lower.p.val.*
Category	1	1.98	1.98	57.25	3532	0	3300	0
Compatibility	1	0.08	0.08	2.36	3532	0.12	3300	0.12
Category X Compatibility	1	0.68	0.68	19.74	3532	0	3300	0

We have successfully replicated Tucker and Ellis's (1998; Experiment 1) potentiation effect for manipulable artifacts in Experiment 2 by using larger stimuli. This strongly suggests that the size of the stimulus has consequences for the potentiation effect and indicates that object stimuli that are similar in size to actual objects are more likely to produce the effect. However, contrary to the predictions of an embodied simulation interpretation of the potentiation effect we also observed a (reversed)[17] potentiation effect with our animal stimuli. Theories of embodied cognition predict that the incidental horizontal orientation of an animal stimulus should not lead to sensory-motor

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[17] We recognize that the direction of the potentiation effect depends on our definition of 'compatibility'; therefore, in this way the effect's direction is arbitrary. For simplicity, we retain our definition throughout this report and discuss the consequences in the General Discussion. Importantly, whether we consider the potentiation effect as 'reversed' or not has no consequences for the main conclusion we draw here.

stimulations based on action affordances, and therefore should not affect responses with either hand. The finding of a reversed potentiation effect strongly suggests that potentiation in both object categories is not due to covert motor simulations.

The present finding is consistent with Anderson, Tamagishi, and Karavia (2002) who showed potentiation effects with non-manipulable objects such as clocks (i.e. faster responding with response hand/clock hand compatibility). The authors interpreted their results as a consequence of attentional bias towards salient features of the asymmetrical objects (e.g. the hands of the clock pointed to one side). Extending their reasoning, we suggest that differential attentional bias to salient regions of objects could explain our results, provided that object handles and animal heads are salient to the visual system. There is some evidence that this is the case, at least for animals.

Indeed, in two different studies, Kovic, Plunkett & Westermann (2009a; 2009b) used eye-tracking technology to monitor participant eye movements while they engaged in different tasks with different categories of objects. A principle finding was that there was a strong tendency for participants to fixate the heads of the animals. Though eye movements are only a proxy of covert attention, if a similar propensity existed in our subjects during the upright/inverted task we would expect results like ours, a finding that would support the conclusion of Anderson et al. (2002). Additionally, it is known that animals are rapidly and automatically categorized, at least in visual scenes (e.g. Kirchner & Thorpe, 2006). If this rapid bias is related to detecting animal heads this could partly explain the potentiation effect reported here. Thus, it appears that attention to different regions of objects results in a stimulus-response compatibility effect that is more general (similar to the Simon effect; Simon, 1969) and not dependent on motor simulations elicited by object affordances. Further, this suggests that changing the salience of different object regions by manipulating task demands could attenuate the potentiation effect. We explore this possibility later.

Before pursuing the idea that task can change the distribution of attention it is important to address one other potential explanation of the results of Experiment 2. Our experiment is the first to compare potentiation effects between artifacts (which have visual affordances) and animals (which have few or none). However, in our experiment the images were all presented at the same size on a computer screen. We have shown that absolute size of stimuli will determine whether we observe a potentiation effect, and given the role of apparent size in determining cortical activity in the ventral stream (Cate et al., 2011), this raises the possibility that we observed a potentiation effect because the animals in our experiment were perceived as manipulable. According to this argument, potentiation effects would be expected for animals because graspable-objects (e.g. toys) would arguably activate sensory-motor simulations. (Of course, to explain the reversed potentiation effect in our study, this argument would suggest we have defined compatibility incorrectly in the animals, and that participants are inclined to pick the animal stimuli up by their heads and not their tail-ends as our pilot study suggested). We address this possibility in Experiment 3.

3.5 Experiment 3

In Experiment 3 we attempted to replicate experiment 2, again presenting the stimulus set at a larger visual angle, though we have also included a manipulation of implied size. The results of experiment 2 raised the question as to whether the animals were perceived as manipulable objects (e.g. toys). Here, we investigate this issue by using a manipulation intended to influence the implied size of each object. In this way, we tried to bias our participants to interpret our objects as either a) graspable, or b) not graspable. To do this, we manipulated the implied size of the objects by priming them with small or large images of a hand in a reaching position. The hand primes suggested either large, ungraspable objects (i.e. hand primes that were too small in relation to the object to support grasping the object) or small, graspable objects (i.e. hand primes that were large enough to be compatible with grasping the object).

There were a number of predictions. For animals, if the potentiation effect of Experiment 2 was due to the perception that animals were graspable, then we should replicate our potentiation effect with animal stimuli, but only when they are primed with a large hand prime (suggestive of grasping); conversely, with a small hand prime, the animals should be processed as non-graspable and therefore we should eliminate the potentiation effect. Similarly, with the artifacts, the potentiation effect should only be observed with the large hand prime (supporting grasping) but not with the small prime; however, object affordances in artifacts may be elicited regardless of implied size, and therefore potentiation effects might be seen regardless of hand prime. Finally, a replication of the result of Experiment 2 in which there was no effect of the size of hand primes would suggest that the potentiation effect in animals is not influenced by the implied manipulability of the object. This latter finding would challenge the notion that the animals were perceived as graspable in Experiment 2 and further suggest that the potentiation effect is the result of a more general task-induced stimulus-response association.

Method

Thirty-three participants completed Experiment 3 (9 males, mean age = 21.33 years, 27 right-handed). As in previous experiments, the task was to decide if the objects were oriented 'upright' or 'inverted' and to press a corresponding key (either the 'z' or the 'm', randomly assigned across participants). Participants were instructed to not respond to the hand primes (which were always upright).

Results and Discussion

We calculated the accuracy (proportion correct) and mean log reaction time (logRT) within each condition, and submitted these to a 2 (category) X 2 (compatibility) X 2 (hand prime size) repeated-measures ANOVA.

Accuracy. For the proportion correct, there was a significant effect of object category, F (1, 32) = 24.4, $p < .001$, $\eta^2_G = .06$, due to better performance on animal trials ($M = .96$, $SD = .04$) than artifact trials ($M = .93$, $SD = .06$). There were no other significant effects, $p > .05$.

logRT. ANOVA revealed a significant effect of category, F (1, 32) = 218.39, $p < .001$, $\eta^2_G = .07$. Participants responded faster to animals ($M = 517.80$, $SD = 75.32$) than to artifacts ($M = 563.50$, $SD = 80.59$). Additionally, there was a significant effect of hand prime size, F (1, 32) = 17.19, $p < .001$, $\eta^2_G = .004$; responses were faster to images presented after the large hand prime ($M = 535.32$, $SD = 77.02$) than the small hand prime ($M = 544.69$, $SD = 78.62$). Again, there was a significant Category X Compatibility interaction, F (1, 32) = 11.32, $p = .002$, $\eta^2_G = .002$, indicating that the compatibility effect was different for animals and artifacts, replicating the pattern of Experiment 2. For animals, responses were faster on incompatible trials ($M = 513.39$, $SD = 78.23$) than compatible trials (*M* = 522.44, *SD* = 73.62). In the artifacts, the opposite pattern was shown, with fastest responding on the compatible trials (*M* = 561.11, *SD* = 78.48) than the incompatible trials (*M* = 565.89, *SD* = 83.86). (Fisher's Least Significant Difference tests showed that, while the compatibility effect for the animals was significant, it did not quite reach significance in the artifacts despite the hypothesized direction; see Figure 3.1.)

Linear mixed model of RT. We performed LME modelling on the natural logarithm of reaction times. Our initial model included category, compatibility, and hand prime as fixed effects, as well as by-subject random intercepts. The optimal model included the category, compatibility and hand prime factors, as well as a two-way interaction between category and compatibility. The model also included by-subject random intercepts (i.e. a by subject adjustment to the mean), and a by-item random intercepts. Consistent with the results of the ANOVA, the interaction was driven by different compatibility effects for the animals (different score = -.018) and the artifacts (difference score = .008). Importantly, this pattern replicates the pattern of Experiment 2. See Table 3.4.

Table 3.4. ANOVA table on significant factors in LME model of RT data.

Coefficient	*df*	*SumSq*	*MeanSq*	*F*	*upper.den.df*	*upper.p.val.*	*lower.den.df*	*lower.p.val.*
Category	1	2.76	2.78	75.56	9656	0	9463	0
Compatibility	1	0.06	0.06	1.76	9656	0.18	9463	0.18
Prime	1	1.16	1.16	31.59	9656	0	9463	0
Category X Compatibility	1	0.39	0.49	10.59	9656	< .01	9463	< .01

There are a number of key results of Experiment 3. First, we replicate the finding of faster responding to animals than artifacts. Again, this is consistent with previous research on canonical objects. Further, the large hand prime appeared to speed responses compared to the small hand prime. The interpretation of this result is theoretically ambiguous, especially without the appropriate experimental control. For example, it is unclear whether this effect results from hand size *per se*, or some low level feature of the stimulus (e.g. that the larger hand prime covers a greater area on the screen). If this were the case, the larger hand prime could prime attentional processing to a larger area of the stimulus display, facilitating upright/inverted judgments. Without another prime object (or prime non-object pattern) of varying size it is not possible to assess this. Future research could explore this possibility.

The most important result of Experiment 3 was the Category X Compatibility interaction and the absence of a higher order interaction with hand prime size. This suggests that hand prime did not alter the compatibility effect in either the animals or the artifacts. One caveat to this interpretation is that participants were told not to respond to the hand primes, thus it is possible primes were not processed and our implied size manipulation failed. We argue that the main effect of hand prime argues against this and indicates that the prime was processed by our participants. In addition to the lack of an interaction with hand prime size, we found that the Category X Compatibility interaction followed the same pattern as in Experiment 2. Though, the *post hoc* t-test on the artifacts did not quite reach conventional significance (though the pattern was the same), we argue that a finding of a compatibility effect for animals regardless of hand prime size provides evidence against the notion that animals were perceived as manipulable objects.

Overall, experiments 1-3 suggest that the salience of different object regions leads to a general stimulus-compatibility effect rather than reflecting covert motor simulations that make up an embodied object representation.

3.6 Experiment 4

The results of Experiment 3 replicate the pattern of results of Experiment 2, and further suggest that potentiation effects may not result from motor simulations. This implies that some other characteristic of the task promotes the potentiation effect. In Experiment 4, we investigated whether task influences the potentiation effect by changing the participant's goal, having them perform an explicit categorization task rather than an inverted/upright task. Although colour discrimination has been previously used (e.g. Pellicano et al, 2010, had participants discriminate the colour of a graspable object and showed a reversal of the potentiation effect) as a control task, we favour the use of a categorization task for three reasons.

First, the participant's decision remains binary and they are still required to explicitly process the object (unlike previous manipulations of task in which participants were instructed to attend to other, incidental feature of the task; e.g., the dot discrimination of Viano, Ellis, and Tucker, 2007, which eliminated the potentiation effect), and this allows us to compare decisions across the two tasks. Further, unlike the task used by Viano, Ellis, and Tucker, (2007) (in which the researchers had participants respond to the colour change of a dot rather than to a property of the object), a categorization task maintains the participants' attention to the objects, and therefore allows us to draw conclusions based on the qualities of the potentiation effect and not simply its presence/absence in different tasks. Second, and more importantly, categorization relies on different neural processes than identification. We argue that in an upright/inverted decision task, participants must identify the object (i.e. it is necessary to know what the item is before deciding if it is inverted) whereas in a categorization task participants must identify objects at the superordinate level. Previous fMRI research has shown that frontoparietal networks involved in processing manipulable objects are more strongly activated in categorization than identification tasks (Gerlach, Law, and Paulson, 2002). Thus, we hypothesize that the potentiation effect for artifacts may be more *robust* when a categorization task is employed, as this process should invoke fronto-parietal systems implicated in action generation. Finally, changing the nature of the task while keeping the stimuli and response demands constant alone allows us to keep all other aspects of the experimental design constant (stimuli, timing parameters). Under these conditions, any change in the pattern of results would suggest that the potentiation effect is affected by task demands such as changes in processing features of objects or attentional biases.

Method

Thirty participants completed Experiment 4 (4 males, mean age = 19.77 years, 27 right-handed). In this experiment, participants were instructed to indicate whether each stimulus belonged in the category ‘animals or ‘artifacts’ by pressing a corresponding key (either the ‘z’ or the ‘m’, randomly assigned across participants).

Results and Discussion

We calculated the mean accuracy (proportion correct) and mean log reaction time (logRT) within each condition, and submitted these to a 2 (category) X 2 (compatibility) repeated-measures ANOVA.

Accuracy. For the proportion correct, there was a significant effect of object category, *F* (1, 29) = 6.47, *p* = .002, η^2_G = .057. Unlike in the previous orientation decision experiments, this effect was due to better performance for artifacts (*M* = .98, *SD* = .02) than for animals (*M* = .96, *SD* = .04). There were no other significant effects, *p* > .05.

logRT. ANOVA revealed a significant effect of category, *F* (1, 29) = 17.51, *p* < .001, η^2_G = .026. As in the previous experiments, participants responded faster to animals (*M* = 444.77, *SD* = 46.86) than to artifacts (*M* = 458.77, *SD* = 47.94). Together with the accuracy data, this might suggest a speed/accuracy trade-off in the present task, with participants taking longer to categorize artifacts with higher accuracy. Unlike Experiments 1-3, there was a significant main effect of compatibility, *F* (1, 29) = 12.08, *p* =.002, η^2_G = .005, due to faster responding on incompatible trials (*M* = 448.91, *SD* = 47.91) than on compatible trials (*M* = 454.763, *SD* = 45.39). The Compatibility X Category interaction was not significant, *p* > .05.

Linear mixed model of RT. We performed LME modelling on the natural logarithm of reaction times. Our initial model included category and compatibility as fixed effects factors, as well as by-subjects random intercepts. The optimal model included the category and compatibility factors with no interaction term. This model also included by-subject random intercepts and a by-subject slopes and intercepts for category. The results of the model are shown in Table 3.5. The effect of compatibility was due to faster responding on incompatible than compatible trials (difference score = .016 in natural log units).

Table 3.5. ANOVA table on significant factors in LME model of RT data.

Coefficient	*df*	*SumSq*	*MeanSq*	*F*	*upper.den.df*	*upper.p.val.*	*lower.den.df*	*lower.p.val.*
Category	1	0.46	0.46	19.42	4535	0	4445	0
Compatibility	1	0.28	0.28	11.96	4535	< .001	4445	< .001

Overall, the results of Experiment 4 provide converging evidence that simulation of motor programs does not underlie the 'potentiation effect', and further implicate a more general stimulus-response compatibility effect. When participants categorized objects, animals and artifacts elicited a *reversed* potentiation effect (on RTs), a pattern that cannot be explained by the potentiation of motor responses elicited by object affordances. Further, this result provides evidence against the possibility that low-level stimulus features drove our effects in our earlier experiments; we used identical stimuli and timing parameters in experiment 4 as were used in previous experiments and changed only the task (i.e. upright/inverted judgments were changed to animal/artifact). The results of this experiment demonstrate unequivocally that the potentiation effect is task-dependent and may stem from differences in decisions and attentional processing (consistent with Anderson et al., 2002; Viano et al., 2008).

Though we have not used an explicit measure of attentional modulation (e.g. the P1 component; see Hillyard, Vogel, & Luck, 1998), we can speculate about the role of attention in driving our compatibility effects. If stimulus-response compatibility underlies our effects, our results suggest that upright/inverted judgments are facilitated by an attentional bias to the artifact handles, whereas the functional end of these objects (e.g. the blade of a knife as opposed to its handle) facilitates category judgments. In other words, determining an object's orientation involves attending to how it may be handled (motorically), whereas determining its category involves attending to what its function is.

Conversely, according to our results, we speculate that for animals, head/hand compatibility drives the potentiation effect in both orientation and category judgments, perhaps because animals can only be identified and not handled. We suggest that different attentional biases exist for different regions in our objects in each task and explore this possibility the General Discussion.

The results of the present experiment, support previous research that has shown that task affects the presence of the potentiation effect (e.g. Vaino, Tucker, and Ellis, 2008). Again, as in the other experiments reported here, these results challenge the interpretation of the potentiation effect as the result of an automatic activation of motor affordances as a part of an embodied object representation.

3.7 General Discussion

In the present study we investigated the embodied simulation account of the potentiation effect (e.g. Tucker and Ellis, 1998). Specifically, we aimed to determine whether the potentiation effect (i.e. facilitation of response time when the handle of a manipulable object is on the same side as the response hand) is evidence of automatically elicited, covert motor simulations that support decisions about manipulable artifacts. Previous research (e.g. Anderson et al., 2002) has provided initial evidence that motor simulation may not be responsible for generating action potentiation effects. Here, we provide further support that action potentiation effects are more parsimoniously accounted for by task-induced stimulus-response compatibility effects. There are three critical findings that support this claim. First, and most importantly, we have shown in Experiment 2 that ‘potentiation’ effects are elicited by objects that do not afford grasping (i.e. animals). Second, ‘potentiation’ effects for both animals and artifacts clearly rely on the absolute size of objects, and not on the size implied by contextual cues such as a hand. Third, the 'potentiation' effect is modulated by task demands; specifically these effects were different for orientation and categorization decisions. The embodied account of object representations would not predict these three results. We discuss the implications of each of these findings below.

Potentiation effects with animals. First, counter to predictions of theories of embodied cognition about object representations, we observed potentiation effects (or, more suitably, stimulus-response compatibility effects) for both manipulable artifacts and non-manipulable animals. According to embodied accounts of object representation (e.g. Witt et al., 2010; see Barsalou, 2008), motor simulations should be automatically elicited by the visual presentation of manipulable objects but not non-manipulable objects. The finding of potentiation effects for both animals and artifacts of objects provides evidence against this interpretation. Because animals typically do not afford grasping actions a motor simulation account cannot explain facilitation effects dependent on the locations of response hands relative to animal heads. However, one could argue that our animal stimuli were perceived as graspable. Indeed, we presented the animal and artifact images at the same relative size and this might have biased the visual system to treat all objects as graspable. Counter to this argument, priming participants with images of hands that implied the object was graspable did not influence the compatibility effects we observed, indicating that the implied size of stimuli was less important than the absolute size of the images on the screen.

Interestingly, Symes, Ellis, & Tucker, 2007 have also found potentiation effects with 3-D generated 'non-object' shapes (i.e. cylinders that have a long axis and appear graspable). They suggest that the potentiation effect may simply occur for any visual stimulus that is of the appropriate size and has a silhouette shape that affords grasping. However, we feel that this argument fails to account for the potentiation effect in our study for three reasons. First, the potentiation effect was reversed for the animals, in that it derived from head/hand compatibility rather than a tail/hand compatibility which would be consistent with grasping the animals. We recognize that the interpretation of the 'reversal' of this effect depends on our own classification of what is considered to be the 'graspable' part of an animal stimulus, but we feel this classification is justified based on our intuitive sense of how participants would pick up graspable versions of our stimuli and a small pilot study in which we found that participants pick up 3-D animal toys by their tail-ends. Second, we showed a reversal of the potentiation effect for artifacts simply by changing the task (a finding we discuss in more detail below). Third, fMRI research shows that non-manipulable objects do not engage the fronto-parietal sensory-motor networks (e.g. Chao & Martin, 2000). If non-manipulable objects, when presented on a computer screen, appeared graspable, we might expect animal stimuli to elicit activity in these regions (assuming these activations do indeed reflect modality-specific action planning). Thus, we argue that it is likely not the case that any object of an appropriate size (implied or otherwise) activates motor simulations for grasping. Instead, the current results suggest that 'the potentiation' effect does not arise from covert motor simulations automatically elicited by objects.

If potentiation is not the consequence of covert, embodied simulations, what causes it? We wish to argue that the finding of a potentiation effect for animal stimuli (with hand/head compatibility in particular) is suggestive of a more general stimulus-response compatibility effect (similar to the well-known Simon effect; Simon, 1969) that may be induced by task structure. In the Simon effect, responses are faster when an effector (hand/finger/foot) is in the same spatial location *as an attended target*. According to this interpretation, the animal head/hand compatibility effect suggests that heads bias attention and facilitate manual responses (e.g. left hand response, animal facing left). Importantly, with the animals, a similar bias appeared regardless of task, suggesting that this single region is 'salient' during both orientation and categorization decisions. There is some evidence that animal heads receive more eye movements than other regions of animals during different perceptual tasks (see Kovic et al., 2009a; 2009b). Importantly, the stimulus-response interpretation of the potentiation effect would predict a similar potentiation of eye movements and foot responses (see Craighero et al., 1999), or crossed hands. Future research should explore this possibility in more detail.

If this interpretation of the potentiation effect for animal stimuli is correct, then it is parsimonious to extend it to the potentiation effect with artifacts. In this case, handle/hand compatibility in the upright/inverted task suggests that there is an attentional bias to process object handles in this task, whereas the functional end/hand compatibility in our categorization task suggests that there is a bias to process the functional end. Overall, then, we argue that we have demonstrated that potentiation effects are not likely driven by action simulations.

Potentiation effects depend on absolute size. The second major finding of the present study is that the potentiation effect for both artifacts and animals depends on the absolute size of the stimulus (and may be less influenced by apparent or implied size). To the authors' knowledge, this is the first demonstration of the importance of absolute size. In

Experiment 1, we presented images smaller than those used in the original Tucker & Ellis (1998) study and failed to replicate the potentiation effect. Embodied cognition theory would predict that, if automatic action simulation occurs during cognitive processing of artifacts (e.g. orientation or categorization), the absolute size of the stimulus should not matter. Instead, our results suggest that stimuli must be of a particular size to successfully bias attention to different stimulus features. We speculate that the object has to be large enough such that different features fall in different regions of peri-personal space; when the stimulus is small, the critical regions (e.g. the head of the animals, or the handles of artifacts) may not independently occupy a given region of visual space that can elicit attentional biases. Future research should explore the role of absolute size in the potentiation effect.

Potentiation effect depends on task. The third critical finding of the present study is that the potentiation effect depends on task demands, a result that argues strongly against an automatic embodied simulation account of the potentiation effect. Previous research has provided some precedence for this finding (e.g. Pellicano et al, 2010; Viano et al 2008), but to the authors' knowledge this study presents the first direct evidence that a stimulus-response association changes with task demands in artifacts compared to a control stimulus category (i.e animals). We have shown that the potentiation effect for artifacts reverses when participants categorize them compared to when making an upright/inverted discrimination task. These findings suggest that the potentiation effect is not a consequence of automatic motor simulations elicited by afforded actions and strongly supports the notion that general compatibility between response hand and attention to critical stimulus features drives the effect. Although head/handle compatibility was critical for decisions about the animals in orientation and categorization tasks, the locus of stimulus-response compatibility changed for the artifacts. Specifically, handle/hand compatibility was important for orientation decisions whereas functional end/hand compatibility was important in categorization decisions; the relationship between judgment type and attentional bias to stimulus features across animals and artifacts should be investigated further.

We have suggested that our task-manipulation modified the attentional biases towards different features of our artifacts. Importantly, Hoenig et al. (2008) have argued that brain regions responsible for processing artifacts and natural objects show 'conceptual flexibility'. Using fMRI, the authors revealed that verifying object attributes differentially activated regions within object recognition networks depending on whether the attribute was dominant (e.g. verifying that “to cut” is an attribute of “knife”) or non-dominant (e.g. verifying that knives are “elongated”). When asked to verify dominant attributes (i.e. specific, action based) vs. non-dominant (i.e. general, visual based) for artifacts, greater activity was observed in the sensory-motor networks responsible for processing action. The authors suggested that this reflects the need for ‘deeper’ modal simulation of experience with objects for understanding their less obvious and more specific properties. We propose that such 'conceptual flexibility' may also be reflected in our results; changing the nature of the judgment in the task from orientation to categorization may bias attention to different stimulus features, reflecting the differential involvement of modal perceptual regions in simulating experiences with the object. It may be the case that orientation judgments about artifacts require attending what is important for use (i.e. biasing processing towards the handle), whereas categorization requires attending what is important for what they are used for (i.e. biasing attention to the functional end). Though we did not test this explicitly, recent research using event-related potentials has shown that different regions of artifacts do modulate attentional processing (see P1 differences reported by Goslin et al., 2012). Further, initial research in our lab shows a distributed pattern of eye movements when processing artifacts (Matheson & McMullen, in preparation; see Chapter 4), both towards the handles and towards the functional ends (towards the head). Together, these findings suggest that an attentional bias may exist for different parts of artifacts that depends on the task.

There are a number of additional results of the present study that are of importance. First, the potentiation effect in response to artifacts is often very small (on the order of 5 ms), as we have shown several times here (the absolute size of our effect is similar and this is reflected in our very small effect sizes). Interestingly, the effect is larger with our animal stimuli (at times twice as large). We speculate that this, too, implicates a greater attentional bias towards the heads of the animals than either the handles or the functional ends of the artifacts, a result supported by eye-tracking research (see Kovic, Plunkett & Westermann, 2009). This interesting possibility should be addressed by future research.

Second, the results of the Analysis of Variance in each experiment are consistent with the optimal linear mixed effects models. This provides confidence in the general patterns of data reported here and the interpretations of them. Providing converging statistical analyses in this way has a number of advantages in the present study (see Baayen, 2008). First, by using linear mixed effects models we were able to account for variability due to the specific stimuli in our experiment and have shown effects of object category over-and-above the effects of stimulus. Specifically, of particular importance is the fact that the linear mixed models predicted much smaller category effects after accounting for stimulus differences. Thus, using this approach, we were able to provide a much more precise prediction of differences due to object category (the size of the main effects). Further, unlike the ANOVA, the linear mixed model allows us to be confident in our generalization of our effects to stimuli beyond those used in our experiments. Finally, using linear mixed models have allowed us to show interactions between category and compatibility even after accounting for by-subject differences in the effects of these variables (in the cases where there was large variance in by-subject effects). Thus, this powerful technique allows us to make more precise predictions of the effects of our factors and their generalization beyond our study.

Finally, we want to emphasize that these results do not challenge general theories of embodied cognition, nor do they rule out the possibility that other paradigms may find evidence of embodied object representations. Our results do, however, suggest that the potentiation effect, as it is observed in the present paradigm, should not be interpreted as reflecting automatic motor simulations. If embodied theories are to be developed more thoroughly, it is important to clarify which effects support their general claims.

Conclusion

Overall, the present study challenges the interpretation of the potentiation effect as the result of automatic simulations in response to object affordances, and suggests that a more general stimulus-response compatibility underlies the effect, perhaps derived from attentional biases that are based on object size and task.

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3.9 APPENDIX A

The statistical models were computed using the *lme()* and L*MERConvenienceFunctions()* package (Tremblay & Ransijn, 2011). Models were fitted with the following method:

(1) An initial model was computed containing all the theoretically relevant fixed effects (in this case object category and compatibility), but it only included a single random effect—one for subjects. Conceptually, modelling subjects as random is similar to performing a repeated measures ANOVA, allowing for by-subject adjustments to the reaction time data, accounting for the fact that some subjects are faster than others overall.

(2) The residuals of the initial model were inspected for outliers and any violations of normality. Though we analyzed logRTs, outliers more than 2.5 standard deviation were removed from the data. This is recommended prior to fitting optimal models (see Baayen, 2008). After trimming, the initial model was refit.

(3) Next, random effects were 'forward-fitted'. With this process, different random effects structures were added and compared to the initial model to investigate whether they were warranted for inclusion. In all our analyses we looked for the same random effects structures, including a by-item intercept, and by-subject intercepts and slopes for compatibility and category. By-item intercepts allow the model to account for the fact that some items are responded to more quickly than others. Thus, this random effect, if included, accounts for the fact that stimuli used in this experiment are only a random subset of all possible stimuli, and therefore, make the optimal model more generalizable.

At this stage, only random effects that provide sufficient explanatory power over and above the by-subject random effect adjustments were retained.

(4) Next, the fixed effects were 'back-fitted'. With the random effects structure in place, the importance of each fixed effect was evaluated. To do so, a full model, which includes each fixed effect and their interactions (and the random effect structure), was fitted. Any non-significant terms were removed with each interaction until all of the highest-order interactions were significant. In this way, only the fixed effects that provide explanatory power are included. This allows us to consider the final model 'optimal'.

(5) Finally, though there is no agreed upon way of determining statistical significance (in a traditional hypothesis testing sense) of each component of the model (because there is no consensus on which degrees of freedom to use), we provide an ANOVA table using the upper bound and lower bound degrees of freedom. This allows us to readily compare the results to the more restricted ANOVA.

3.10 APPENDIX B: PART II INVESTIGATING ATTENTIONAL BIASES TO ANIMALS AND ARTIFACTS

In Part 1, I investigated two critical predictions of the embodied account of object representations, namely that a) sensorimotor simulations play a functional role in representing manipulable artifacts compared to non-manipulable animals, and b) that the visual presentation of manipulable artifacts coactivates sensorimotor simulations. In Chapter's 2 and 3, I argue that I do not have evidence for either of these predictions. In Chapter 2, a concurrent motor task affected naming latency across both artifacts and animals. I argued that this finding might reflect attentional biases that are dependent on the picture-plane orientation of the object, and that specifically the attentional bias flips from tail/handle end to head/functional end depending on the object's relationship to the occupied hand. Importantly, this effect appears to be stimulus-general. If this argument is correct, differences in naming latency reflect only a changing bias of attention, and do not support arguments for embodied object representations.

In Chapter 3, motor potentiation was observed for both artifacts and animals. Further, the direction of the motor potentiation effect reversed for artifacts when I changed the task from identification (orientation judgments) to a superordinate decison (category judgments). This strongly argues against the embodied interpretation of this effect, and is inline with a small number of findings that point towards low-level attentional for the locus of the effect (e.g. Anderson et al. 2002). I argue that faster responding with the hand that is in the same spatial location as the handle of the artifacts or the head of animals simply reflects increased attentional processing to that region of space, in which case one would expect faster responding to that location (all other things being equal).

Overall then, these results argue against the strong form of the embodied account of object representations and suggest that both manipulable and non-manipulable objects bias attention in particular ways. Perhaps most importantly, the findings reported in Part 1 suggest that the attentional bias is not fixed, but may be dependent on the cognitive task. I explore this possibility in Part 2. In Chapter 4, I adopt a descriptive eye-tracking paradigm and use eye-fixations as a proxy for covert attentional processing. I had participants verbally name or verbally categorize objects while measuring their eye movements. I show that naming and categorizing animals and artifacts resulted in similar eye fixation patterns, with more fixations towards the head or functional end of the object. However, I do show that participants look more towards the handle of artifacts than the analogous tail region of animals and interpret this as reflecting more overt attentional allocation to the handle. These results are the first of their kind to show that overt attentional processes are more distributed in manipulable artifacts than non-manipulable animals.

I investigate automatic covert attentional biases to these objects in Chapter 5. Here I adopt an electrophysiological index of attention (i.e. the P1 event-related potential) and show that handles automatically bias visual attention in a task in which object identity is incidental to the task. Overall, these results show that overt and covert attentional processes are biased by artifact and animal stimuli. I explore these possibilities in the conclusion of Chapter 6, and provide suggestions for future research.

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CHAPTER 4 VISUAL FIXATION PATTERNS DEPEND ON OBJECT CATEGORY: DIFFERENCES BETWEEN ANIMALS AND ARTIFACTS

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4.1 Abstract

Embodied theories of cognition predict critical differences in the way manipulable artifacts are represented within the cognitive system compared to non-manipulable objects such as animals. Specifically, previous research has provided evidence that simulations in modality-specific cortices, in frontoparietal action networks in particular, are functionally involved in cognitive operations (e.g. naming or categorization) of manipulable but not non-manipulable objects. However, some of these effects might be explained by differences in the distribution of low-level attentional biases to different features of artifacts and animals. To explore this possibility, we conducted a descriptive eye-tracking study in which participants were shown images of animals and artifacts and were instructed to name them. Consistent with our hypothesis, participants show a strong tendency to fixate and dwell on the heads of the animals compared to the tails; in artifacts, though participants have a tendency to fixate the functional ends compared to the handles, their eye movements do show a more distributed pattern across these two regions. We anticipate that these differences likely result in downstream effects that might explain some findings that are often interpreted as 'embodied' by implicating attention rather than motor simulations.

Key words: fixation patterns, attention, embodied cognition, object recognition, object naming

Visual Fixation Patterns Depend on Object Category: Differences between Animals and Artifacts

Embodied theories of cognition suggest that there are critical differences between the cognitive system's representation of non-manipulable objects like animals and manipulable artifacts like tools and utensils. According to these theories, such differences are largely a consequence of the afforded actions of artifacts (see Gibson, 1979) derived from a history of particular sensory-motor interactions with different objects. Consequently, these theories predict a greater involvement of sensorimotor activity in processing manipulable artifacts compared to natural objects and purport that motor simulations play a role in the representation of manipulable objects. Some support for this notion comes from functional Magnetic Resonance Imaging (fMRI) studies showing activity in sensorimotor association cortices in response to manipulable objects even when there is no specific instruction to perform actions on them. For instance, Chao and Martin (2000) revealed activity in the left ventral premotor cortex and the left posterior parietal cortex in response to pictures of tools but not animals. Similar findings have been shown by others (e.g. Grafton et al, 1997; Gerlach, Law, and Paulson, 2002). These results strongly suggest that there are differences in the way that manipulable and non-manipulable objects are represented, and these imaging studies provide neural support for the types of simulations posited by embodied theories of object representations.

In addition to neuroimaging data, behavioral research provides evidence that manipulable objects are represented differently than non-manipulable objects. For instance, Filliter, McMullen, and Westwood (2005) have shown that manipulable objects are named more quickly than non-manipulable objects, suggesting that naming objects depends on whether the object is associated with sensorimotor experiences. A difference in the conceptual processing of manipulable and non-manipulable objects appears as early as 5 years of age. For instance, Kalenine & Bonthoux (2008) used a picture-matching task to investigate the effects of object manipulabilty on matching objects that were functionally related (e.g. jacket-hanger) versus objects that were perceptually similar (e.g. jacket coat). They showed that young children are faster to match manipulable objects that are functionally related, and faster to match non-manipulable objects that are perceptually related (see also, Mounoud et al. 2007). These results provide evidence that sensorimotor experience with some objects (i.e. manipulable objects) but not others (i.e. non-manipulable objects) begins influencing object representations early in development.

However, although the above research suggests that there may be critical differences in the way manipulable and non-manipulable objects are represented, recent research in our lab (Matheson, White, & McMullen, in preparation; see Chapter 3) suggests that manipulable and non-manipulable objects may simply attract attention differently and these differences may depend on task. We presented participants with manipulable and non-manipulable objects and had them judge their orientation (upright vs. inverted). Participants were faster to respond with the hand that was in the same spatial location as the handle of the artifacts or the heads of the animals. We interpreted this finding as a reflection of a general stimulus-compatibility effect for object regions that attract visual attention (see also Anderson, Tamagishi, and Karavia, 2002). These findings raise the important question of whether there are differences in the way visual information is extracted from manipulable and non-manipulable objects. Any differences in the way that objects in these categories are visually scanned/explored might be expected to influence processing ‘downstream’ and therefore could provide insight into behavioural effects that are often interpreted as ‘embodied’. Further, an investigation of the visual exploration of manipulable and non-manipulable objects could reveal a number of additional insights, including which visual features are favoured during the perception of animals and artifacts.

To the best of the authors’ knowledge there has only been one attempt to investigate these issues explicitly. In two different published studies, Kovic, Plunkett and Westermann (2009a; 2009b) used eye-tracking technology to monitor participant eye-movements while they engaged in different tasks with different categories of objects. In the two studies, participants were shown images of animate objects (e.g. cat, butterfly, frog) or inanimate objects (e.g. chair, shoe, apple) under three different viewing conditions: they were told to a) ‘Look at the <TARGET PICTURE>’ (e.g. ‘Look at the cat’ if the item was a cat, b) ‘Look at the picture’ (i.e. a more general instruction to visual inspect the visual image), or asked c) ‘What’s this?’ (i.e. an instruction to identify the object). The authors hypothesized that participants would direct eye-movements more consistently with animate objects (i.e. more fixations towards the head of the animate object) compared to the inanimate objects (i.e. a broader distribution of fixations). While the results showed that, overall, viewing condition had little effect on looking behaviour, the general hypothesis of more consistent eye movements towards the heads of animals and more distributed patterns in the inanimate objects was supported.

The study by Kovic et al. (2009a; 2009b) provides only preliminary evidence that looking behaviour differs between animate and inanimate objects, and hints toward differences in the way these objects are visually explored. However, these data do not allow us to directly address differences between *manipulable artifacts* and *non-manipulable objects* and leaves a number of important issues unresolved. First, in Kovic et al. (2009a; 2009b) some of the animate objects were highly manipulable (e.g. household cat) and some of the inanimate objects were not easily manipulable (e.g. bicycle). This makes it difficult to compare these eye-tracking results to previously reported imaging results (e.g. Chao & Martin, 2000) and behavioural studies (e.g. Filliter, McMullen & Westwood, 2005) that were primarily interested in object manipulability. Thus, we are limited in our ability to interpret the differences reported by Kovic et al. as differences in object manipulability *per se* (see Salmon, Filliter, & McMullen, 2010). Second, there was a high degree of variability in the visual perspective of the images used in that study, with some objects presented in profile, some in depth, some oriented towards the left and some oriented towards the right. The effects of this type of view-point variability on visual processing is well documented (e.g. see Milivojevic, 2012; see Thierry, Martin, Downing, & Pegna, 2007 for effects on visual electrophysiological components), and further, the heterogeneity in perspective might have driven some of the looking behaviour observed in their study (i.e. the saliency of different components of the object would depend on the image). For instance, eye-movements might be influenced by whether the handle of an object is partially obscured, or if the head of the animals falls near central vision. Finally, it is unclear what the experimental manipulations of task (i.e. questions they asked participants) used by Kovic et al. (2009) allow us to address. A more theoretically driven manipulation would have participants name versus categorize the objects. These tasks require object identification at different levels of specificity.

Indeed, it is well established that these two tasks recruit different brain regions, with categorization tasks apparently drawing on apparent motor simulations more than object decision tasks (e.g. Gerlach, Law, and Paulson, 2002). Further, performance of naming and categorizing objects results in different effects of object manipulability (e.g. effects of manipulability reverse; see Salmon, Matheson & McMullen, submitted). Differences in visual exploration of manipulable and non-manipulable objects could underlie these effects and are to date, unknown.

We sought to address this issue by adopting a descriptive eye-tracking paradigm and having participants either name or categorize images of manipulable artifacts (i.e. tools and kitchen artifacts) or non-manipulable objects (i.e. animals). In the present investigation, images were shown in profile-view and oriented to the left or the right. Consistent with Kovic et al. (2009a), and in accordance with our earlier research showing stimulus-response compatibility effects between object regions and responses (Matheson, White, & McMullen, in preparation), we hypothesized greater consistency in eye movements with the animals, with most fixations occurring on the head; conversely, we hypothesized that there would be more inconsistent or variable visual exploration of the manipulable objects, with fixations occurring more across the entire extent of the object, including the functional end (e.g. a saw's blade) and the graspable end (e.g. an object's handle). These predictions would generally support Kovic et al.'s (2009a; 2009b) finding. Further, we anticipated that task would affect visual exploration, with categorization and naming resulting in a reliance on different regions. We have shown that categorizing manipulable objects produces a stimulus-response compatibility effect with an advantage when functional end of an object and response hand are spatially compatible . This suggests that categorization might result in a greater attentional reliance on the functional ends of manipulable objects. Finally, we analyzed fixations after the first saccade on each trial. We took this measurement as an index of where participants initially oriented their eyes. We predicted that initial fixations would be drawn to regions that were the most salient for the task. Thus, we predicted that the head region for animals and the handle region for artifacts would attract initial fixations.

4.2 Methods

Participants

8 participants were tested (all females, *M age* = 22.13, *SD* = 4.34 years old). All had normal or corrected-to-normal vision and spoke English as a first language.

Materials.

40 greyscale photographs of natural objects (i.e. animals) and 40 photographs of man-made objects (i.e. tools and kitchen artifacts) were used (see Table 1 for a list of the objects). Each object was presented on a white background in profile view, once facing to the right and once facing to the left in both a naming and a categorization condition (thus, participants saw each image 4 times). Participants sat approximately 75 cm from the monitor which meant that the stimuli subtended approximately 23 X 17 degrees of visual angle.

A number of interest areas (IAs) were defined for each object and drawn by hand. For the animals, interest areas included a rectangular region encompassing the head and one encompassing the tail-end. Similarly, for the artifacts, interest areas included a rectangular region encompassing the functional end (e.g. the blade of the axe or the spout of the coffeepot) and another encompassing the handle. Two other interest areas were defined. First, a rectangular region encompassing the entire object was created (i.e. a whole object IA) and then this region was divided in half creating a left and right image IA. See Figure 4.1.

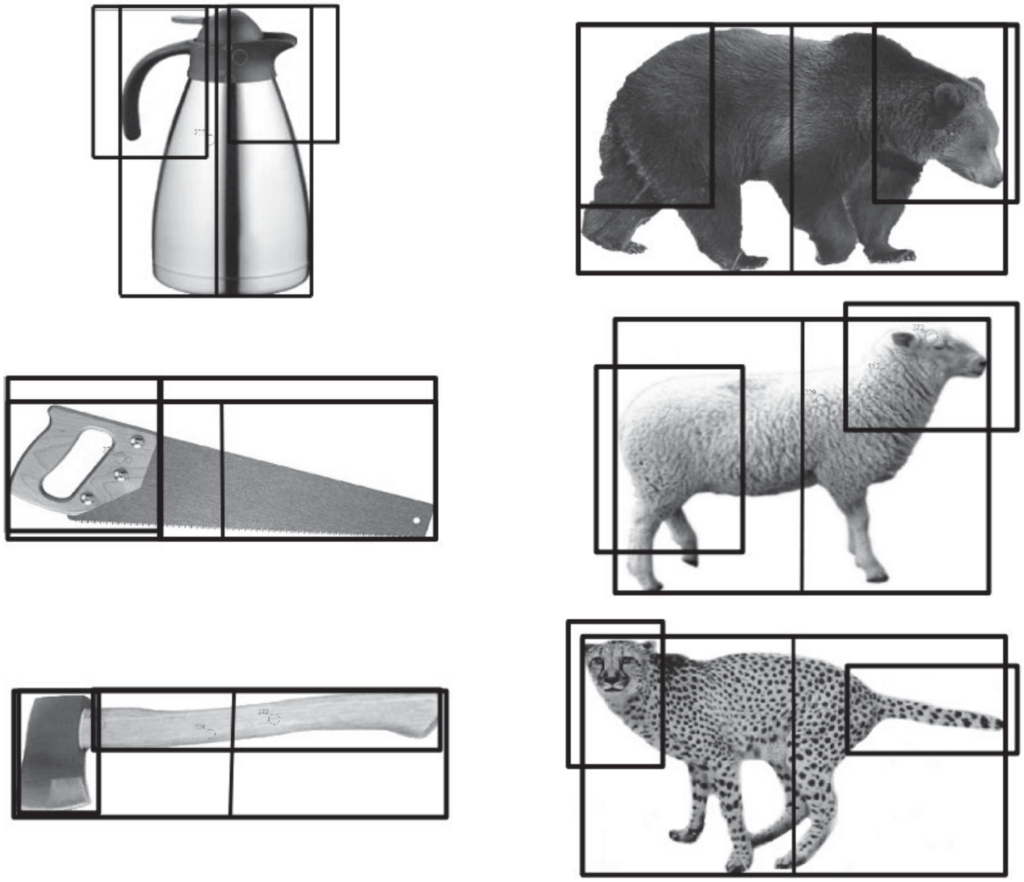

Figure 4.1. Examples of images used and the rectangular interest areas (IA) drawn for each object. Objects from the artifact category (left) and the animal category (right) in both vertical orientations (left and right) are represented. Each object was encompassed into a whole object rectangular IA that was split in the middle into right and left halves. The handles, functional ends, heads, and tails, are encompassed by hand-drawn rectangular interest areas. Note that the sizes and shapes of interest areas vary widely (e.g. compare the cheetah head IA and the axe handle IA).

Stimuli were presented on a 17 in. CRT monitor with a refresh rate of 75 Hz and a screen resolution of 1024 X 768 at 96 DPI. Presentation was controlled using Windows

XP (Microsoft, California) running Experiment Builder Experiment software (*v.* 1.5.201 SR Research Ltd., Mississauga, ON).

Eye movement data (fixations) were collected with an Eyelink II Head Mounted Eye-tracking system (*v.* 2.22, SR Research Ltd., Mississauga, ON) sampling at 500 Hz, with a spatial accuracy of .05 degrees.

Table 4.1. List of individual objects used in the naming and categorization tasks.

Artifacts		Animals	
Axe 1	Kettle 2	Bear1	Giraffe 1
Coffeepot 1	Knife 1	Bear 2	Giraffe 2
Coffeepot 2	Knife 2	Cheetah 1	Horse 1
Coffeepot 3	Mug 1	Cheetah 2	Horse 2
Frying pan 1	Mug 2	Deer 1	Lion 1
Frying pan 2	Pitcher 1	Elephant 1	Lion 2
Handsaw 1	Pitcher 2	Elephant 2	Seagull 1
Handsaw 2	Plantwaterer 1	Elephant 3	Sheep 1
Iron 1	Saucepan 1	Fox 1	Zebra 1
Kettle 1	Saucepan 2	Fox 2	Zebra 2

Procedure

Each participant completed 160 trials (i.e. each image oriented towards the left or the right, and under both naming and categorize instructions). Breaks were presented every 40 trials. Name and categorize trials were randomly presented (rather than blocked) to make the immediate task less predictable. In this way, we hoped to limit anticipatory eye-movements. Before the experiment (and after each break), the eye-tracker was calibrated using a nine-point calibration. Using this calibration technique, eye-movements were accurate to within 0.5 degrees.

Each trial was preceded by the presentation of a small fixation circle. Participants were instructed to fixate the circle before the experimenter initiated the trial. Following this, the eye-tracking system began recording eye-movement samples. Each trial began with the appearance of text instructing the participant to either “Name” or “Categorize” the object. The text was presented centrally and remained on the screen for 1000 ms. Following this, a brief fixation-cross appeared for 300 ms, followed by the presentation of the object for 1200 ms. Participants were instructed to give a verbal response and were encouraged to take enough time to ensure 100% accuracy. The participants were instructed to provide the first name that came to mind, and to categorize the objects with the words ‘animal’ and ‘artifact’. A fixation-cross remained on the screen until the experimenter recorded the accuracy of the response and initiated the next trial.

Eye-tracking data processing

With the Eyelink II system, fixations are automatically defined as any period that is not a blink or a saccade. Blinks are defined as any period in which data is missing for three or more samples; saccades are defined as eye-movements that are 0.5 degrees of visual angle or greater and exceed a velocity (30 degrees/sec) and acceleration threshold (8000 degrees/sec). DataViewer software (SR Research Ltd., Mississauga, ON) was used to extract fixation data for each trial during the 1200 ms period in which the object was presented. Data were organized by interest area (IAs), each specific to a particular image. For the first analysis, we extracted the number of fixations and total dwell time within each interest area for each item. Additionally, we conducted a second analysis in which the second fixation of each trial was dichotomously coded as either 'incompatible' (i.e. after the first fixation on the trial, which was in the center of the image, participants made a saccade and ultimately fixated the handle or the tail-end) or 'compatible' (i.e. after the first fixation on the trial, which was in the center, participants made a saccade and ultimately fixated the head or the functional end); additionally, any saccades that were upwards (towards the top of the image) or downwards (toward the bottom) were coded as 'other' and excluded from the analysis. This gave us an index of the initial eye-movement on each trial, and allowed us to determine whether there was a tendency to initially fixate the animal heads or artifact functional ends[18].

Analysis

In the first analysis, the number of fixations (i.e. fixation count) and total dwell time (i.e. dwell time in milliseconds across all fixations) were recorded as the dependent measures. To be included in the analysis, fixations must have come from trials in which participants responded correctly. Means were submitted to a 2 (category; animals vs. artifacts)) X 2 (interest area; (head/functional end vs. tail/handle) X 2 (task; name vs. categorize) repeated-measures Analyses of Variance (ANOVAs). Additionally, given that there were known differences in the interest area sizes of our stimuli[19], we performed an analysis on adjusted dwell times. To calculate our adjusted dwell times we used the formula in *(1)*:

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[18] The definition of compatibility we have used is relatively arbitrary. For simplicity (and to be consistent with definitions used elsewhere in research in our lab) we defined eye-movements towards the head/functional end as compatible, Also note that one subject made few fixations towards the compatible or incompatible ends (i.e. this subject ended up making fixations that were coded as either upwards or downwards). Because of missing data, this subject was removed from this analysis.

[19] See Appendix A.

$$(1) \qquad AdjDwellTime = \frac{RawDwellTime}{\left(\frac{IAarea}{TotalScreenArea}\right) TotalTrialDwellTime}$$

With this formula, raw dwell times are scaled as a function of the proportional size of the interest area in question (e.g. the lion's head) and the total time spent fixating the object. This measure reduces the influence of an interest area's overall size on the magnitude of the measure (i.e. without the scaling, if fixations were completely random we would predict longer dwell times on larger areas).

In the second analysis, the proportion of fixations towards the 'compatible' end were recorded, and submitted to a 2 (category; animals vs. artifacts) X 2 (task; name vs. categorize) ANOVA.

4.3 Results

Analysis of *fixation counts* comparing handle/tail interest areas versus functional-end/head interest areas.

The ANOVA[20] revealed a significant effect of task, *F* (1, 7) = 9.03 *p* = .02, $ή^2_G$ = .02, with more fixations occurring during naming trials (*M* = 1.19, *SD* = .23) than categorization trials (*M* = 1.12, *SD* = .27). There was also a significant effect of interest area, *F* (1, 7) = 139.83 *p* < .001, $ή^2_G$ = .79, with more fixations of the functional/head interest areas (*M* = 1.76, *SD* = .39) than the handle/tail interest areas (*M* = .54, *SD* = .16). Finally, there was a main effect of object category, *F* (1, 8) = 7.56, *p* = .028, $ή^2_G$ = .07,

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[20] As a measure of effect size we present the generalized eta squared. Unlike partial eta square (in which the number of factors in an experiment can influence the calculated size), generalized eta squared is designed to reduce the influence of the number of factors in an experiment, giving values that are easily comparable across experiments with different designs; however, the measure still follows conventional definitions for small, medium, and large effects (see Olejnik & Algina 2003).

with more fixations on the animals (*M* = 1.23, *SD* = .31) than the artifacts (*M* = 1.06, *SD* = .23).

Importantly, as hypothesized, the Interest Area X Category interaction was significant, F (1, 7) = 105.64, p < .001, $ή^2_G$ = .61. This pattern is shown in Figure 4.2.

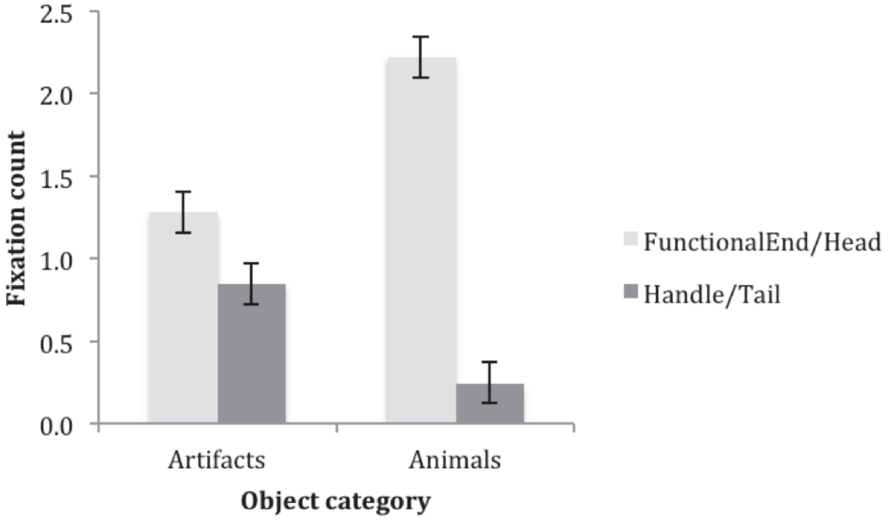

Figure 4.2. Total fixation count as a function of object category and interest area collapsed over task. Error bars represent Fisher's Least Significant Difference.

This interaction suggests that fixations differed for the animals and the artifacts. More specifically, in the animals, there were more fixations towards the heads (*M* = 2.22, *SD* = .53) than the tail ends (*M* = .25, *SD* = .12); in the artifacts, though there were more fixations towards the functional ends (*M* = 1.28, *SD* = .26) than the handles (*M* = .85, *SD* = .21), this difference was smaller. (Fisher's Least Significant Difference tests showed that these differences were significant in both categories of objects, though inspection of Figure 4.2 reveals a larger difference in animals than artifacts).

The three-way interaction was not significant, *F* (1, 7) = 1.04, *p* = .341 , $ή^2_G$ < .001.

Analysis of *dwell time (ms)* comparing handle/tail interest areas versus functional-end/head interest areas.

The ANOVA revealed a significant effect of interest area, F (1, 7) = 75.03, $p <$ .001, $\acute{\eta}^2_G = .84$, with more time fixating the functional end/head regions (M = 431.72, SD = 84.29) than the handle/tail regions (M = 118.16, SD = 25.79). Importantly, as hypothesized and consistent with the fixation count analysis, the Interest Area X Category interaction was significant, F (1, 7) = 229.51, p < .001 , $\acute{\eta}^2_G = .65$. This pattern is shown in Figure 4.3.

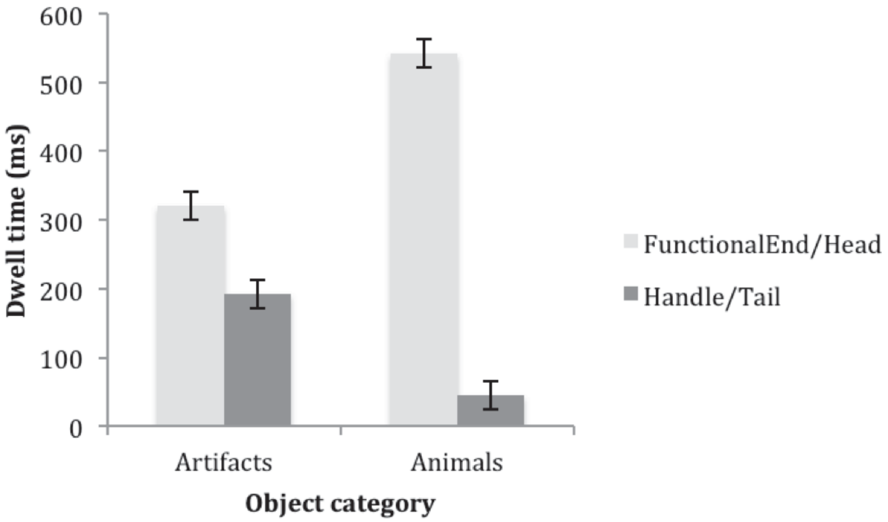

Figure 4.3. Effects of total dwell time (ms) on object category as a function of interest area. Error bars represent Fisher's Least Significant Difference.

As in the fixation count data, this interaction reflects the fact that the cumulative dwell time on the two ends of the objects differed for the animals and the artifacts. More specifically, in the animals, dwell time was higher for the heads (M = 542.30, SD = 119.18) than the tail ends (M = 45.29, SD = 15.03); in the artifacts, though there were more fixations towards the functional ends (*M* = 321.14, *SD* = 55.07) than the handles (*M* = 193.01, *SD* = 41.39), this difference was smaller. (Fisher's Least Significant Difference tests showed that these differences were significant in both categories of objects).

Unlike in the fixation count data, the analysis of dwell time revealed a significant Interest Area X task interaction, *F* (1, 7) = 5.77, *p* < .04, $\acute{\eta}^2_{G}$ = .006. This pattern is shown in Figure 4.4.

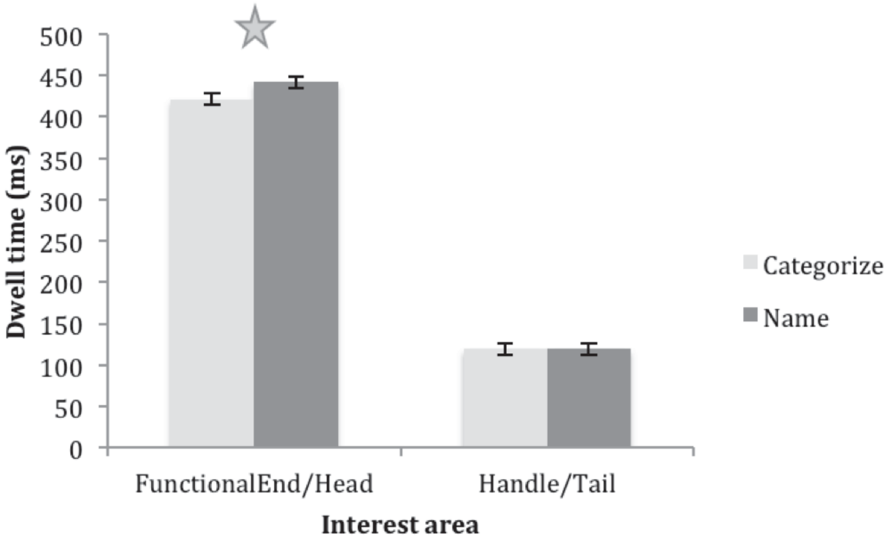

Figure 4.4. Total dwell time (ms) as a function of question block and interest area. Error bars represent Fisher's Least Significant Difference. Starred difference indicates significant difference.

This interaction shows that, though participants dwelled within the handle/tail region of the objects for about the same amount of time for both categorization (*M* = 119.14, *SD* = 30.52) and naming (*M* = 119.13, *SD* = 27.07), fixations were longer on the functional end/head region in naming (*M* = 441.91, *SD* = 75.73) than in categorization (*M* = 421.54, *SD* = 92.35). (Fisher's Least Significant Difference showed that this difference was significant = 14.18).

Again, there were no other significant effects, $p > .05$, including the three-way interaction, F (1,7) = .602, $p = .463$, $ή^2_G$ = .004.

Overall, the results of the analysis on fixation counts were similar to the results of the analysis on dwell time. See Appendix (4.6) for further analyses.

Analysis of dwell time (ms) adjusted for interest area size.

The analysis on adjusted dwell time was similar to the analysis on raw dwell times. The ANOVA revealed a significant effect of interest area, F (1, 7) = 90.17, $p < .001$, $ή^2_G$ = .87, with more time fixating the functional end/head regions (*M* = 2.98, *SD* = .52) than the handle/tail regions (*M* = .84, *SD* = .19). Unlike with raw dwell times, the analysis with adjusted dwell times revealed a significant effect of category, F (1, 7) = 9.36, $p < .001$, $ή^2_G$ = .08, with longer dwell times overall on animal parts (*M* = 2.03, *SD* = .22) than the artifact parts (*M* = 1.79, *SD* = .29).

As in the previous analysis, the Task X Category interaction was significant, F (1, 7) = 6.8, p = .035, $ή^2_G$ = .006. Again, this interaction shows that, though participants dwelled within the handle/tail region of the objects for about the same amount of time for both categorization (*M* = .083, *SD* = .23) and naming (*M* = .84, *SD* = .2), dwell time remained longer on the functional end/head region in naming (*M* = 3.05, *SD* = .2) than in categorization (*M* = 2.91, *SD* = .59). (Fisher's Least Significant Difference showed that this difference was significant = .084).

Finally, and most importantly, the Interest Area X Category interaction remained significant with the adjusted dwell time measure, F (1, 7) = 184.78, p < .001, $ή^2_G$ = .61. This pattern is shown in Figure 4.5. This interaction reflects the fact that that the adjusted dwell time on the two ends of the objects differed for the animals and the artifacts. More specifically, in the animals, dwell time was higher for the heads (*M* = 3.37, *SD* = .6) than the tail ends (*M* = .02, *SD* = .08); in the artifacts, though there were more fixations towards the functional ends (*M* = 2.59, *SD* = .49) than the handles (*M* = 1.47, *SD* = .49), this difference was smaller. (Fisher's Least Significant Difference tests showed that these differences were significant in both categories of objects = .25).

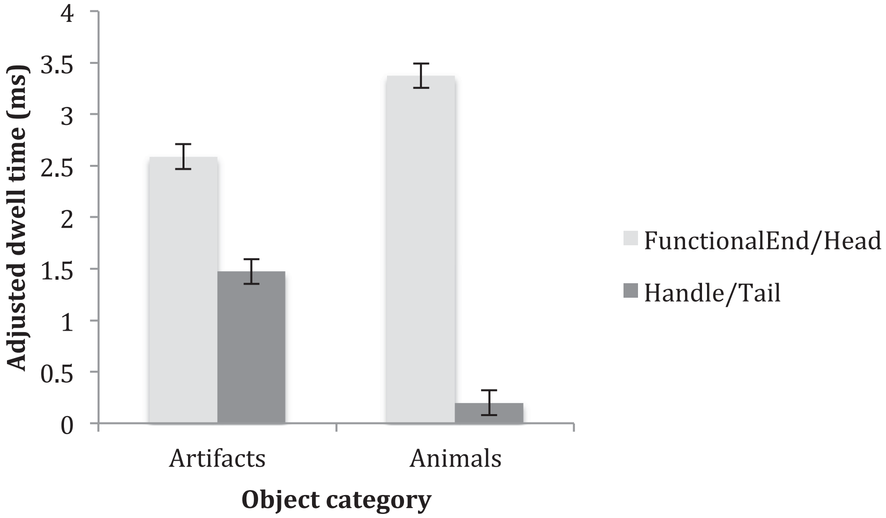

Figure 4.5. Total adjusted dwell time (ms) as a function of object category and interest area. Error bars represent Fisher's Least Significant Difference.

Analysis of initial eye-movements. The only significant effect in the ANOVA was an effect of category, *F* (1, 6) = 88.86, *p* < .001, $\acute{\eta}^2_G = .75$, with a greater proportion of compatible (i.e. towards the heads and functional ends) fixations in the animals (*M* = .96, *SD* = .04) than the artifacts (*M* = .70, *SD* = .09). No other effects were significant, p > .05. See Figure 4.6.

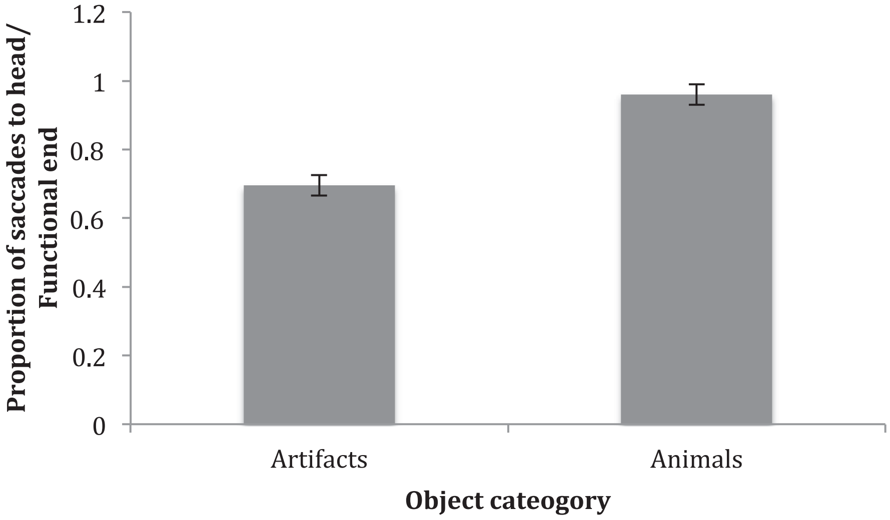

Figure 4.6. Proportion of saccades to the head/functional end of objects. Error bars represent Fisher's Least Significant Difference.

4.4 General Discussion

There are three main findings of our descriptive investigation of eye movements on manipulable and non-manipulable objects. First, we supported our main hypothesis and showed that there were more fixations (and greater dwell times) on the heads of animals compared to the tail-ends, and though there was a tendency to fixate (and dwell on) the functional ends of the artifacts more than the handles, this difference was smaller (and therefore, there were more fixations and longer dwell times on the handles of the artifacts compared to the tails of the animals). This demonstrates a more distributed pattern of eye movements across different features in the artifacts compared to the animals. This result is consistent with the reports by Kovic et al. (2009a; 2009b) who showed fairly consistent fixations towards animal heads and more distributed patterns of fixations with inanimate objects. Specifically, we show that the handles were fixated (and dwelt on) more than the analogous, tail regions of the animals. This suggests that our participants did extract useful information from the handles region of the artifacts to perform the tasks. Additionally, we show that the more distributed fixation pattern with 'inanimate' objects is seen with manipulable artifacts *per se*, which are a specific subset of the type used in the Kovic investigations. This result is consistent with the notion that the handles of objects afford action and so elicit special attentional processes (e.g. Anderson, Tamagishi, and Karavia, 2002; Tucker and Ellis, 1998), (though still, not as much as the functional ends in our naming and categorization tasks). Though eye-movements are only a proxy of visual attention we can speculate that, though the functional ends of artifacts are the most salient features of the object in both tasks, handles do attract overt attentional processing in the form of greater fixations and longer fixation dwell times than the tails of animals.

Second, contrary to our hypothesis, our categorization and naming tasks had little effect on eye-movement patterns between objects, and it appears that the goal of categorization versus naming does not alter the relative reliance on the two areas. Importantly, however, we have shown that task does affect the overall reliance on the functional/head versus the handle/tail for dwell times; specifically, our participants dwelled on the functional end/head for longer periods during naming than during categorization overall (regardless of object category). This result, along with the finding that our participants made more fixations during naming than categorization, suggests that our task manipulation did alter looking behaviour in general, but these effects did not depend on object category. Further, this result suggests that naming requires more fixations (and longer dwell times on the functional end/head), a result that is not that surprising given that naming requires subordinate identification, and more details are likely needed by the visual system to perform this task (see Rosch et al 1976). Though, based on our earlier behavioural studies of motor potentiation (Matheson, White, & McMullen, in preparation; see Chapter 3), we speculated that the categorization task might change the relative reliance of fixations between the handle and the functional end, this was not the case. However, the differences between the tasks used in our current eyetracking study and the task used in the potentiation experiments make this finding difficult to interpret. For instance, in the current investigation, participants were not instructed to make speeded responses (and in fact were instructed to take as much time as necessary) and gave vocal responses rather than manual responses. At the very least, we show that overt fixations are more distributed in the artifacts compared to the animals, and this suggests one way in which low-level visual attention differs between these two categories of objects.

Third, the overall pattern of results is reflected in the analysis of first fixations. That is, there was a large tendency to initially saccade towards, and then fixate on, the animal heads (on 96% of the trials), while the tendency to saccade to the functional ends of the artifacts was much lower (70% of the trials). This suggests that, regardless of whether our participants were naming or categorizing animals, there was a tendency to orient their gaze towards the animal heads; however, with the artifacts, there was a more distributed tendency, and the first fixation was away from the functional/tail end about 30% of the time. Again, using eye movements as a proxy for covert attentional process this strongly suggests that the heads of the animals provide a salient cue to the attentional system, while the salience of artifacts is more distributed across its functional end and handle.

These results provide evidence that there are differences in the ways in which we look at objects we can manipulate (i.e. tools and kitchen materials) vs. things we cannot (i.e. animals). These differences might underlie effects reported from imaging and other behavioural research. Future research should investigate the consequences of eye-movement behaviour on extrastriate visual processing with neuroimaging during naming and categorization. For instance, a significant question that the current eye movement data raise is, Do we observe fronto-parietal activity in response to manipulable artifacts because people look at the handles? If so, this would question whether such neural activity reflects differences in object conceptual representations, or simply differences in the preparation of action (see Milner & Goodale, 1995).

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4.6 Appendix A

We performed an additional analysis to address two main issues. First, in the analysis reported in the main body of the text, we used interest areas that encompassed the functional end/heads of the objects or the handles/tails of the objects. Because we defined these interest areas by hand they are not of equal size. Thus, effects may have been due to size of interest area rather than perceptual significance of the area, with larger areas expected to garner more fixations and dwell time. To address this we measured the total area (in pixels) of each interest area for each image. We submitted the averages to a 2 (interest area; functional-end/head vs. handle/tail) X 2 (category; animal vs. artifact) Analysis of Variance. The analysis revealed a significant effect of category, $F = (1, 156) = 14.86$, $p < .001$, with larger interest areas in our animals ($M = 143003.8$, $SD = 45531.96$) than the artifacts ($M = 114107.9$, $SD = 49384.44$). No other effects were significant, $p > .05$. This main effect suggests that indeed the interest areas were larger for animals. Consequently, with random eye-movement patterns we would expect to see more fixations (or higher dwell time) on the animals than the artifacts, a result that we do indeed report in our initial analysis. Unfortunately, we cannot rule out this confound as a potential explanation for that effect in our initial analysis. However, we argue that this confound cannot explain the critical Category X Interest Area interaction, as the pattern of eye movements in the two interest areas is different for the two categories (that is, the difference between the head vs. tails compared to the difference between the functional end vs. handle), a pattern that cannot be explained by interest area size.

Second, we addressed whether our participants showed any bias in fixating (or dwelling) on one side of the screen. To do so, we split our whole-object interest area into a ‘left side’ and a ‘right side’, and submitted fixation counts and dwell times to t-tests. Neither analysis revealed a significant effect, $p > .62$, demonstrating that there was no bias to fixate one side of the image.

Finally, one other note is of interest. It could be argued that the main effect of object category might be best explained by differences in age of acquisition, familiarity, or the like. In general, it might be assumed that categories that are less familiar require more fixations before they can be successfully named. Unfortunately, we cannot rule out this possibility and this remains an important idea for future research[21].

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[21] We thank Dr. Susanne Ferber for this insight.

CHAPTER 5 EARLY VISUAL ATTENTION TO ANIMALS AND ARTIFACTS: ERP EVIDENCE FOR SELECTION OF HANDLES

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5.1 Abstract

In the object perception literature, previous research has demonstrated that participants are faster at making a response (e.g. object orientation decision) with the hand that is aligned with the handle of a manipulable object. According to the embodied cognitive account of object representation, this finding suggests that the presentation of a manipulable object automatically elicits sensorimotor simulations of the respective hand and these simulations facilitate the response, decreasing its latency. However, one would also expect faster responding with a hand that is in the same spatial location as a handle if handles automatically attract visual attention (i.e. stimulus-response compatibility). In the present study, we modified the Posner-style attentional cuing paradigm to test this hypothesis. Participants were shown target dots in the left or right visual field and had to press a button to indicate their location (i.e. target detection). Each dot was 'cued' by a centrally presented artifact or animal, oriented towards the left or the right. Each image was oriented such that the functional-end/head or the handle/tail was in the same spatial location as the target dot. We showed that a) participants are better at detecting target dots cued by handles, and b) that the P1, an index of early visual attention, is greater in response to targets cued by handles than targets cued by functional-ends. This result suggests that object handles automatically bias attention. This attentional bias may account for earlier behavioural findings, without any recourse to embodied theories of cognition.

Key words: P1, Posner-cueing, attentional bias, category-specificity, attention, ERPs

Visual attention to the parts of animals and artifacts: Evidence for early selection for handles

Much behavioural research has revealed an intimate link between the visual perception of manipulable artifacts (e.g. tools) and motor responses (i.e. potentiated action). For instance, Tucker and Ellis (1998) report that participants are faster at making button responses with the hand (either the right or left) that is compatible with the orientation of an object’s handle even when object orientation is incidental to the task. A similar ‘potentiation effect’ has been observed in a number of similar studies, in which large objects can potentiate ‘power grips’ and small objects potentiate ‘precision grips’ (e.g. Tucker and Ellis, 2001). Additional support for the association between the perception of artifacts and motor responses comes from object priming studies. For instance, Helbig et al. (2006), had participants name pictures of manipulable artifacts. The images were primed with pictures of artifacts that afforded a congruent grasp (e.g. a frying pan primed by a dust pan) or an incongruent grasp (a frying pan primed by a banjo). They showed that naming accuracy was higher when the target objects were primed with congruent objects than incongruent objects (see also Helbig, Steinwender, Graf, & Kiefer, 2010.) Overall, the potentiation effect and the effects of manipulable object primes on object naming suggest that viewing manipulable artifacts automatically activates simulations of sensorimotor programs and this activation can facilitate object identification.

One interpretation of these findings is that they reflect a difference in the way manipulable artifacts are represented in the brain compared to non-manipulable objects (e.g. animals; see Mahon & Caramazza, 2009 for discussion of theories of object semantics). Indeed, manipulable objects are named more quickly than non-manipulable objects when word frequency was controlled (Filliter, McMullen, & Westwood, 2005), suggesting that naming objects depends on whether the object is associated with sensory-motor experiences. To account for these differences, ‘embodied theories’ of cognition suggest that object representations are spread across modality-specific cortices, and the visual presentation of objects activates associated motor, auditory, and somatosensory processes and these processes are invoked to different extents in different cognitive tasks (e.g. Barsalou, 2008; see Witt et al 2010). From an embodied perspective, the visual presentation of objects automatically activates these associated processes and these processes can facilitate performance on cognitive tasks like object naming.

However, despite the growing support for embodied theories of object representation, in particular from cognitive linguistic tasks (e.g. property generation; see Barsalou, 2008; see also Pulvermüller & Fadiga, 2010), the degree to which the visual presentation of manipulable objects automatically invokes motor processes, and the extent to which these processes are involved in cognitive tasks such as object naming, is unclear. Though it is known that the visual presentation of an object can activate neurons in the motor system (e.g. the ‘canonical’ neurons, see Fadiga et al., 2000), and though this type of activation provides some support for the general ideas of distributed, modality-specific object representations that are central to embodied theories, a small number of behavioural studies have shown that motor potentiation effects (e.g. the visual presentation of an artifact results in faster button presses when the response hand and object handle are spatially congruent) might be best explained by low-level attentional effects. For instance, Anderson, Yamagishi, and Karavia (2002) have shown that left/right-hand motor responses are faster when compatible with manipulable object handles (e.g. scissors) *and* salient, non-manipulable object features (i.e. clock hands). This finding cannot reasonably be explained by automatic activation of associated motor processes because clock hands should not elicit motor simulations. According to the authors, this effect likely reflects attentional processes that bias button responses to one region of space based on attended, or salient, object features (i.e. object handles and clock hands). This finding is supported by research from our lab (Matheson, White, & McMullen, in preparation; see Chapter 3) that has shown potentiation in response to artifact handles *and* animal heads. Further, we have shown that whether or not an artifact's handle potentiates a response depends on the task; during a categorization task, the objects' functional end (e.g. saw blade), rather than its handle, can actually potentiate a motor response. Again, this finding does not support an embodied theory of object representations. Other studies have shown that attention to irrelevant features (e.g. a dot that appears with the object) can eliminate the potentiation effect (Vaino, Ellis, Tucker, 2007), strongly implicating attentional processes in generating the effect, and it is known that changing the participant's task (e.g. from making upright/inverted orientation judgments to making judgments about object colour) can also reverse the potentiation effect (Pellicano et al., 2010). If such effects are associated with low-level visual attention, this precludes the necessity of positing embodied object representations, and would force scrutiny upon the theory.

Overall then, low-level visual attention may play a role in generating the behavioural effects that are often interpreted as motor potentiation due to embodied object representations. Because of the consequences this explanation has for embodied theories, it is important to determine the role of attention in generating potentiated responses.

Event related potentials (ERPs), measurements of the average electrical changes of the brain recorded at the surface of the scalp, are well suited to addressing this issue. This technique is known for its superior temporal resolution (on the order of milliseconds) and has been instrumental in characterizing early visual attentional processes (see Luck, 2005). That is, research has shown that an early component, recorded over occipitoparietal electrodes, is sensitive to attentional manipulations. This P1 component (i.e. the first, large, positive deflection observed in the grand average waveform) is enhanced (i.e. larger) in response to target stimuli (e.g. dots) that fall within the attended visual field rather than the unattended visual field, and it has been argued that this reflects an increased gain of the response within extrastriate visual regions that map object features or extrapersonal space (see Hillyard, Vogel, & Luck, 1998; Yantis & Serences, 2003; Luck, Woodman, & Vogel, 2000). For instance, Magnun & Hillyard (1991), adopting the widely used Posner attentional paradigm (Posner, 1980) had participants respond to target bars that were presented in the left and right visual fields. The location of the target was preceded by an arrow that pointed towards it (i.e. a 'valid' cue) or an arrow that pointed away from it (i.e. an invalid cue). The authors reported larger P1s (and N1s under some conditions) to validly cued targets (primarily at contralateral electrode sites). They interpreted this as reflecting sensory 'gain' at early-visual processing stages. Further, they suggest that this early selection of stimulus location accounts for faster responding to that location. Indeed, attention to a particular stimulus or location is expected to result in faster reaction times to that stimulus or location, all other things being equal. This interpretation has been supported by other studies using the same Posner-type paradigm (e.g. Eimer, 1994). In the present study we exploited the P1 as an index of early visual attention to explore the automatic distribution of attention in response to artifacts. If low level visual attention is biased automatically towards artifact handles, this might explain typical embodied effects, 'motor potentiation' in particular.

Very few ERP studies have investigated early visual processing in response to manipulable artifacts and non-manipulable objects using ERPs. In one study, Handy et al. (2003) had participants respond to target gabor-gratings that appeared in either the right or left visual field by pressing a left button for left-targets and a right button for right-targets (i.e. target detection). Importantly, images of manipulable artifacts (i.e. tools) or non-manipulable objects (e.g. animals) appeared as cues on each trial, simultaneously presented in the right and left visual fields. The authors reported larger P1s (i.e. P1 enhancement) to targets cued by artifacts, primarily when right-targets were cued by artifacts in the right visual field. The authors suggest that manipulable artifacts attract attention automatically in the right visual field.

This finding shows that the P1 is a good candidate for measuring early attentional processes and demonstrates that manipulable artifacts may attract attention in a unique way. Further, it shows that attentional biases can be measured in the absence of a task that explicitly requires participants to process the identity of objects (i.e. automatic attention to objects). This study provides 'proof of concept' that objects can be used as 'cues' in target localization tasks, analogous to the typical symbolic arrowheads used in the Posner paradigm. However, the study by Handy et al. (2003) does not address the specificity of the attentional bias they report. That is, it remains unclear whether the handles of the artifacts are particularly salient features and whether this feature attracts early visual attention *per se*. One study relevant to this issue measured the P1 (among other components) in response to kitchen utensils and tool-objects that were oriented to the right or the left during a categorization task (Goslin et al, 2012). The authors showed some effects of object orientation; namely, there appeared to be larger ipsilateral P1s when the object handle fell in the right visual field. Though the authors ultimately interpret this as evidence for early integration of motor and attentional processes this study does not allow us to determine whether handles automatically draw attention. Indeed, low-level stimulus differences may account for any P1 differences observed in this study (as the ERPs were measured in response to different visual images). Further, this study did not include a control stimulus (for example, asymmetrical, non-manipulable objects) and so it is unclear whether their P1 effect would be observed to other types of objects that do not have motor associations. Finally, given the set-up of the task (and the fact that the P1 was only a peripheral interest in the study) it is unclear what the *a priori* predictions are, and therefore it is unclear how their effects map onto the hypothesis that handles attract attention.

Overall then, behavioural research suggests that motor potentiation results might not reflect embodied object representations in which the visual presentation of objects automatically elicits activity in multiple modality-specific cortices, but rather might reflect a more basic visual attentional bias that is generated in response to the visual stimuli. Such a bias is expected to lead to faster responding to cued locations, regardless of whether the cue affords action. Further, the P1 ERP component is an excellent index of early visual attention.

In the present experiment, we measured the P1 in response to targets that were spatially cued by an object. On each trial, an object cue was presented centrally, oriented facing the right or the left. Following this, a small black circular target appeared. The target was shown in the left or the right visual field and, by virtue of object orientation, was cued by an artifact handle, an artifact functional end, an animal head, or an animal tail (see Methods for details). This set-up allowed us to properly exploit the P1 as an index of early visual attention. Our interpretation of the P1 is in line with Hillyard, Vogel, and Luck (1998) who suggested this component reflects gain control within early extra-striate visual cortices. Our hypotheses were as follows. If handles draw attention, and if P1 enhancement is an index of increased early visual attention, then we should observe P1 enhancement in response to targets that are cued by artifact handles compared to artifact functional ends. Similarly, we predict that because motor potentiation has been observed in response to animal heads (Matheson, White, & McMullen, in preparation; see Chapter 3), and there are increased eye fixations on animal heads (Matheson & McMullen, in preparation; see Chapter 4), we should observe P1 enhancement to animal heads; conversely, however, animals or artifacts may broadly draw attention and therefore we would not see any effects of the horizontal orientation of the cue on the P1.

This experimental set-up has a number of strengths. First, the paradigm borrows heavily from the well-established Posner cueing paradigm (Posner, 1980), in which target localization is cued validly (e.g. with an arrow pointing to the correct location) or invalidly (e.g. with an arrow pointing to the incorrect location). By analogy, we have defined our object images as cues that ‘point’ to the target locations congruently or non-congruently with the object features we hypothesize attract attention. Specifically, we defined the left-right asymmetry of our objects as ‘arrows’ pointing in the direction of the head or the functional end. We recognize this definition is arbitrary, but other research in our lab (Matheson, White, & McMullen, in preparation; Chapter 3) suggests that this is a reasonable way to define the asymmetrical features of the two object categories. Second, we have clear *a priori* predictions based on the usual interpretations of the P1. This allows us to directly assess the notion that object handles attract early visual attention. Third, we are measuring P1s in response to target dots, which are the same on every trial. Previous research has measured P1s in response to different images (Goslin et al., 2012), which may have low-level image differences that drive effects on the P1. In our experiment, the P1 response of interest is elicited by the same physical stimulus on every trial, and only the preceding cue changes.

One final strength of the present study is that we have explored the effects of the cues on ERPs by using the Mass Univariate Analysis (MUA) procedure of Groppe et al. (2011a; 2011b). (See the methods for more details.) This analysis approach allows us to identify non-predicted differences in the ERPs to the cue objects, and we speculate about the observed differences in the Discussion.

5.2 Method

Participants

Twenty-two participants were recruited from Dalhousie University or surrounding area (9 males; mean age = 21.87, all right-handed). All gave written consent to participate. The procedure was approved by the university’s ethics board.

Materials

In all experiments, 40 greyscale photographs of natural objects (i.e. animals) and 40 photographs of man-made objects (i.e. tools and other manipulable human artifacts) were obtained from various photographic databases available online (see Table 5.1 for list of objects). Each object in the table was shown in right/left orientations twice. These images served as 'cues' on each trial. Animals were used as control stimuli because they are non-manipulable and, like our manipulable artifacts, when they are shown in profile, they have a high degree of left/right asymmetry. Each object was presented on a white background in a side/profile view. The raw images of the two categories were equated on average area and average physical (i.e. pixel) luminance using graphics manipulation software. The stimuli were presented at approximately 10 degrees of visual angle at a viewing distance of approximately 66 cm. In addition to the cues, solid black circles were used as 'targets'. Targets were presented with a diameter of 1 degree. The targets were presented with their center 1 degree to either the left or the right of each cue (i.e. never overlapped with the image, with half a degree of white space between the edge of the target and the edge of the cue image). See Figure 5.1 for example stimuli.

Stimuli were presented on a 45 cm wide Asus LCD monitor (ATI Radeon 9600 Series) with a refresh rate of 60 Hz and a screen resolution of 1440 X 900 pixels at 96 DPI. Presentation was controlled using a custom python script running in Windows XP (Microsoft, California). Eye movement data were monitored with an Eyelink II Desk Mounted Eye-tracking system (*v*. 2.22, SR Research Ltd., Mississauga, ON) sampling at 500 Hz, with a spatial accuracy of .05 degrees. An eye movement was triggered whenever the recorded position of the eye moved 3 degrees in any direction from a central fixation with a saccade. Saccades were defined as eye movements that reached a velocity of at least 22 degrees/sec.

Table 5.1. List of individual objects used in experimental tasks. Numbers correspond to unique instances of objects.

Artifacts		Animals	
Axe 1	Kettle 2	Bear1	Giraffe 1
Coffeepot 1	Knife 1	Bear 2	Giraffe 2
Coffeepot 2	Knife 2	Cheetah 1	Horse 1
Coffeepot 3	Mug 1	Cheetah 2	Horse 2
Frying pan 1	Mug 2	Deer 1	Lion 1
Frying pan 2	Pitcher 1	Elephant 1	Lion 2
Handsaw 1	Pitcher 2	Elephant 2	Seagull 1
Handsaw 2	Plantwaterer 1	Elephant 3	Sheep 1
Iron 1	Saucepan 1	Fox 1	Zebra 1
Kettle 1	Saucepan 2	Fox 2	Zebra 2

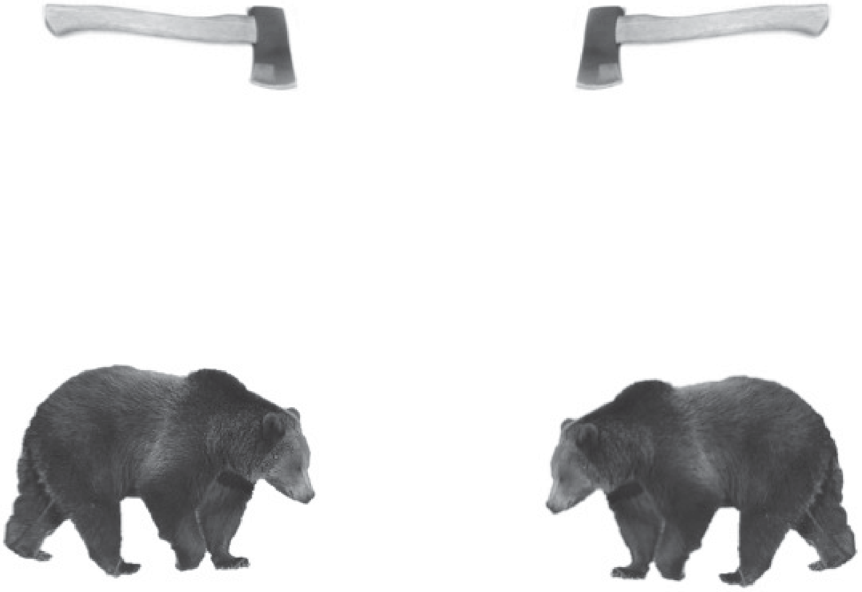

Figure 5.1. Examples of the stimuli used in the present experiment from each category.

ERP recording procedures

Continuous EEG data was acquired from 32 Ag/AgCl electrodes using the BioSemi ActiveTwo recording system (Metting van Rijn, Peper, & Grimbergen, 1990) digitized at 2 kHz and stored offline for later analysis. The electrodes were embedded in an elastic nylon cap at their standard locations (according to the 10-20 coordinate system). To measure horizontal eye movements, additional electrodes were placed at both external canthi. Further, electrodes placed over the left eye (fronto-polar) and under the left eye (inferiorly) allowed us to detect any eye-movements that might not have triggered the eye-link system. With this system, a sterile elctroconductive gel is used to enhance recording. Two electrodes were placed directly over the mastoids (bilaterally) to be used as references in post processing.

Procedure

After signing consent and having the experiment explained in some detail, participants were fitted with the electrode cap and electrodes were put into place. Next, the eyelink monitor was calibrated using a 4 point calibration. To do so, participants put their chin in a chin rest mounted on the desk approximately 12 cm high (the chair was adjusted so this height was as comfortable as possible). Once calibrated participants completed a short practice session with images that were not used in the experiment. In the experiment, each trial began with the presentation of a fixation cross (.8 degrees wide) for 2000 ms. The cue object was presented centrally (facing either the left or the right) for a period between 650 and 850 ms (randomly chosen on each trial). The image remained on the screen and the target dot appeared for 100 ms. The cue image remained on the screen for an additional 400ms. (This was done to ensure that there was no ERP elicited by the offset of the cue that could affect the P1 response of interest.) Participants had 6000 ms to respond before an error would appear. The inter-trial interval was 1000 ms. Participants were instructed to localize target dots by pressing the ‘z’ key if the target dot was on the left or the ‘/’ key if it was on the right. Trials were self paced and initiated with the ‘space bar’ key. Participants were encouraged to take breaks when needed. See Figure 5.2 for a schematic of the trial sequence.

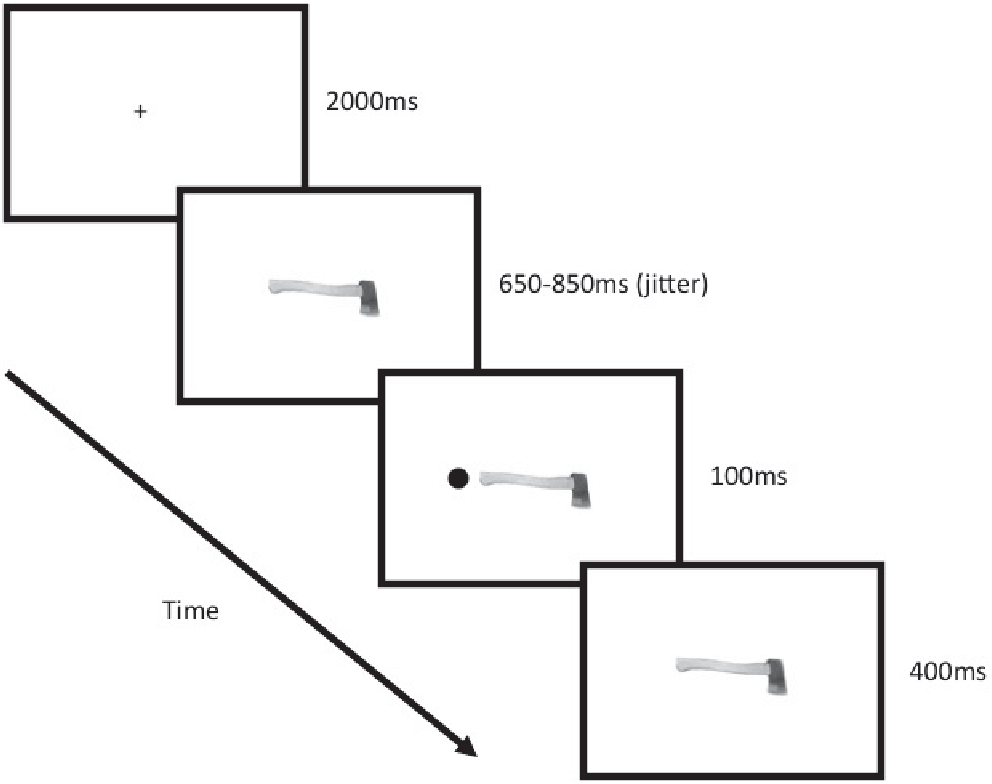

Figure 5.2. Schematic representation of the timing and events of the experimental paradigm.

The use of the chin rest ensured a constant viewing angle and reduced extraneous movement. Importantly, on any trial in which the Eyelink monitor detected a saccade outside of the predefined central region, or the Eyelink monitor lost track of the pupil during an eye blink, an error message appeared encouraging participants not to move their eyes. These trials were ‘recycled’ and randomly presented at a later point in the experiment. Thus, overall, participants saw each image 4 times (twice facing left, and twice facing right, cued on the left or the right) for a total of 80 trials per condition.

ERP Data preprocessing and analysis

Data were re-referenced to the average of the two mastoids upon import to the EEGLAB toolbox (*v.* 9.0.8.6b Delorme & Makeig, 2004), as it is implemented in

MATLAB computing software (*v.* 7.7.0.471; Mathworks, MA). Raw ongoing EEG data were filtered with a bandpass filter (.3-40 Hz cutoffs) and visually inspected for artifacts (this filter, as implemented in EEGLAB, uses a Fourier-transform). On a small number of subjects, an electrical artifact appeared in one electrode and was interpolated using the interpolation tool in EEGLAB. The raw data were epoched with the ERPLAB (http://erpinfo.org/erplab) toolbox with a 200 ms pre stimulus baseline and a 300 ms post stimulus time window. Two sets of epochs were created. First, to test our main hypothesis, epochs were generated with respect to the target-dot stimulus. Second, to explore further differences in processing animals and artifacts, epochs were generated to the presentation of the cue (i.e. object) stimulus. Once epoched, artifacts were removed using a simple threshold-based rejection (any deflections larger than +/- 100 µV); because eye blinks were eliminated in the experimental set up, very few trials (7.3% of all trials) were rejected (i.e. due to skin potentials or other movement artifacts). Finally, ERPs from single trials were averaged for each subject.

P1 analysis strategy. The P1 was characterized as the mean amplitude of a preselected time window surrounding the peak of the first positive deflection. We selected data between 120 and 160 ms for the P1, which is about 20-40 ms later than the P1 observed in low-level visual attention paradigms (see Mangun, Hillyard, & Luck, 1993). This peak was observed broadly over bilateral posterior occipitoparietal electrodes. To best characterize this peak, and to increase statistical power, we collapsed data from three electrodes in the left (P3, PO3, PO7) and right (P4, PO4, PO8) hemispheres.

P1 data were aggregated and submitted to an Analysis of Variance (ANOVA), as it is implemented in the *ez()* package (*v*. 4.1.1, Lawrence, 2012) in *R* statistical computing software (*v*. 2.15.1, R Core Team, Vienna, Austria). To increase statistical power, we collapsed mean amplitude measures across hemispheres (i.e. targets that fell into the left and right visual fields) into ipsilateral and contralateral conditions. Thus, we used a 2 (category; animals vs. artifacts) X 2 (cue; functional-end/head vs. handle/tail) X 2 (hemisphere) repeated measures ANOVA.

Analysis strategy of ERPs in response to cues with mass univariate procedure. In addition to the targeted analysis of P1 differences, we performed an exploratory analysis of the timing and the topography of the evoked potentials in response to the cues (rather than targets) using the mass univariate data analysis procedure developed by Groppe et al. (2011a). Though we are comparing ERPs to different physical stimuli, we feel that this exploratory analysis could provide preliminary insight into potential differences that occur when processing cues. The mass univariate approach is more general than the traditional statistical analysis of ERPs, in that it does not require researchers to select time-windows or electrode regions *a priori*. The mass univariate procedure performs *t*-tests between waveforms of interest at every time-point and electrode. This technique has a number of advantages for exploratory analysis over traditional event-related potential techniques that implement the Analysis of Variance (ANOVA). First, rather than aggregating waveform data into point estimates like peak amplitude or peak latency, the mass univariate approach incorporates a broader range of data and is useful in identifying reliable differences in timing that might not be detected otherwise (in particular in outside of time windows and regions of interest). Second, because of these sensitivities, researchers do not have to predict *a priori* the timing and distribution of any potential effects, and are therefore open to discovering unpredicted, meaningful differences.

Finally, this technique allows researchers to identify where and when differences emerge between two ERPs. Together, these advantages make this approach well suited to investigating the any potential differences between ERPs in response to animal or artifact cues.

Importantly, the mass univariate approach is made possible by the application of procedures that effectively deal with multiple comparisons. The number of comparisons made in a typical procedure can reach the tens of thousands, and therefore the risk of a large number of false positives is high. Though there are a number of possible procedures available to researchers to address this issue, we have adopted to control for the false discovery rate (FDR) based on the algorithm described by Benjamini & Yekutieli (2001) as it is implemented in the mass univariate toolbox. This procedure limits the number of expected false discoveries (i.e. given the number of comparisons being made) that one expects to make while maintaining sufficient power (i.e. weak family-wise error rate control) for correcting for the number of comparisons.

The mass univariate analysis proceeded in the following way. After preprocessing, data were epoched with a 200 ms baseline period and a 300 ms post-stimulus period. For each subject, trials for each epoch were averaged, and difference waves were calculated between conditions of interest for each electrode (i.e. animal left vs. artifact left; animal right vs. artifact right). Then, for each time point (at each of the 32 electrodes), a repeated measures *t*-test (two-tailed) was conducted within the 100 – 300 ms latency range (against the null hypothesis that the difference is 0). Separate analyses were conducted for cues facing left and cues facing right.

5.3 Results

Behavioural Results. To verify that participants were on task and to explore the effect of the cue on target localization, we submitted behavioural accuracy and reaction time data to a 2 (category; artifact vs. animal) X 2 (compatibility; functional-end/head vs handle/tail) Analysis of Variance (ANOVA). For this analysis, compatibility was defined with respect to the congruence of the target and the orientation of the objects (i.e. which features cued the target). For instance, a left target paired with a left oriented (i.e. left-hand graspable) artifact/animal was defined as 'Handle/Tail Compatibility' (similarly for the right). Conversely, a left target paired with a right oriented artifact/animal was defined as 'Functional End/ Head Compatibility'.

Accuracy was overall very high (> .99%)[22]. The ANOVA revealed a Category X Compatibility interaction, *F* (1, 21) = 6.89, *p* = 002, η^2_G = .03. This interaction is due to a significant difference (calculated with Fisher's Least Significant difference) between compatible artifacts (*M* = .997, *SD* = .005) and incompatible artifacts (*M* = .993, *SD* = .01), while there is no significant difference between compatible animals (*M* = .996, *SD* = .006) and incompatible animals (*M* = .997, *SD* = .006). No other effects reached significance, *p*s > .05. See Figure 5.3.

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[22] Note that the high accuracy rate represents a ceiling effect, and therefore the interpretation of the pattern of results should be made with caution.

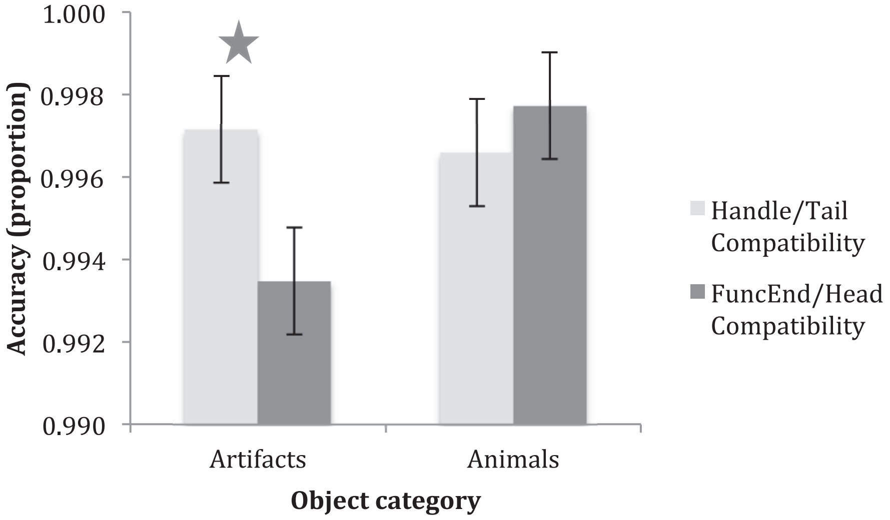


Figure 5.3. Behavioural accuracy (proportion) as a function of compatibility and category. Error bars represent Fisher's Least Significant Difference.

To analyze reaction time, only correct trials were used. Additionally, reaction times less than 200 ms or greater than 2000 ms were excluded (this procedure removes extreme values that were due to responses that were too fast to have been processed and responses that were too slow). We then removed outlier RTs that were greater than 2.5 standard deviations from the mean on a subject-by-subject basis (2.35% of trials). The ANOVA revealed a significant effect of object category, $F\ (1,21) = 4.92$, $p = .004$, $\eta^2_G = .0004$, due to faster responding to artifacts ($M = 391.88$, $SD = 126.43$) than to animals ($M = 397.10$, $SD = 132.94$). No other effects were significant, *p*s > .05. See Figure 5.4.

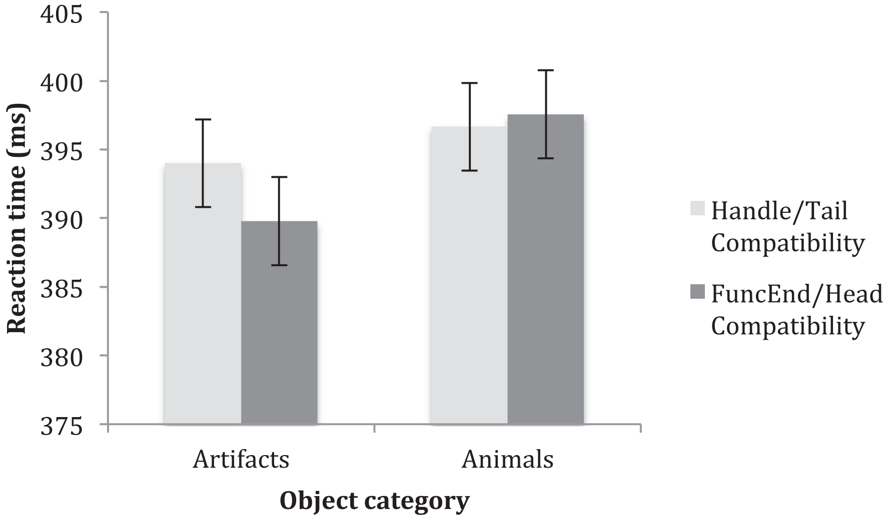


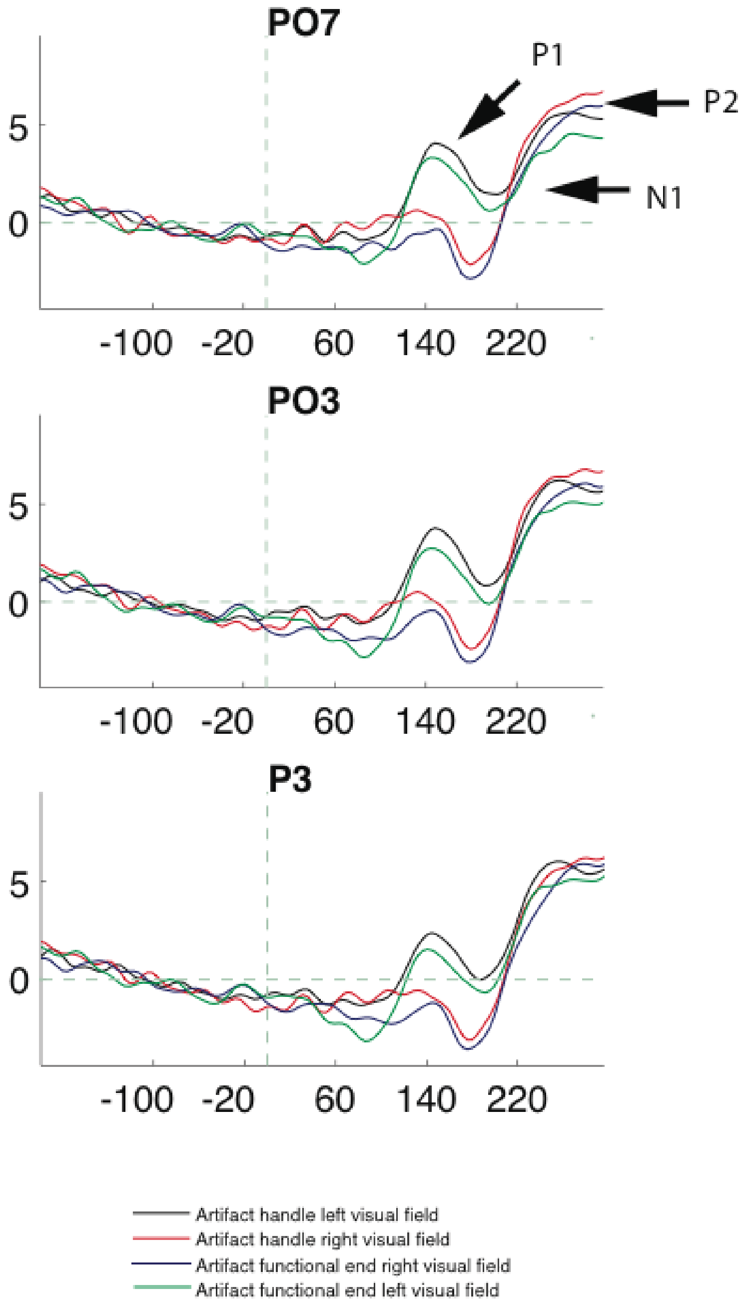
Figure 5.4. Reaction time (ms) as a function of compatibility and category. Error bars represent Fisher's Least Significant Difference.

In summary, participants responded quickly and with high accuracy to both artifacts and animals, though there is evidence that a target response is more accurate (but not faster) to targets cued with artifact handles. Further, we have revealed a general category effect, with artifact cues resulting in faster target localization overall.

P1 results. Grand average waveforms are shown in Figure 5.5 for early ERPs in response to targets in the left and right visual fields. Clear P1, N1 peaks are shown, with a large P2 positivity at the end of the epoch. These waveforms show that the P1 waveform is fairly consistent at the selected electrodes.

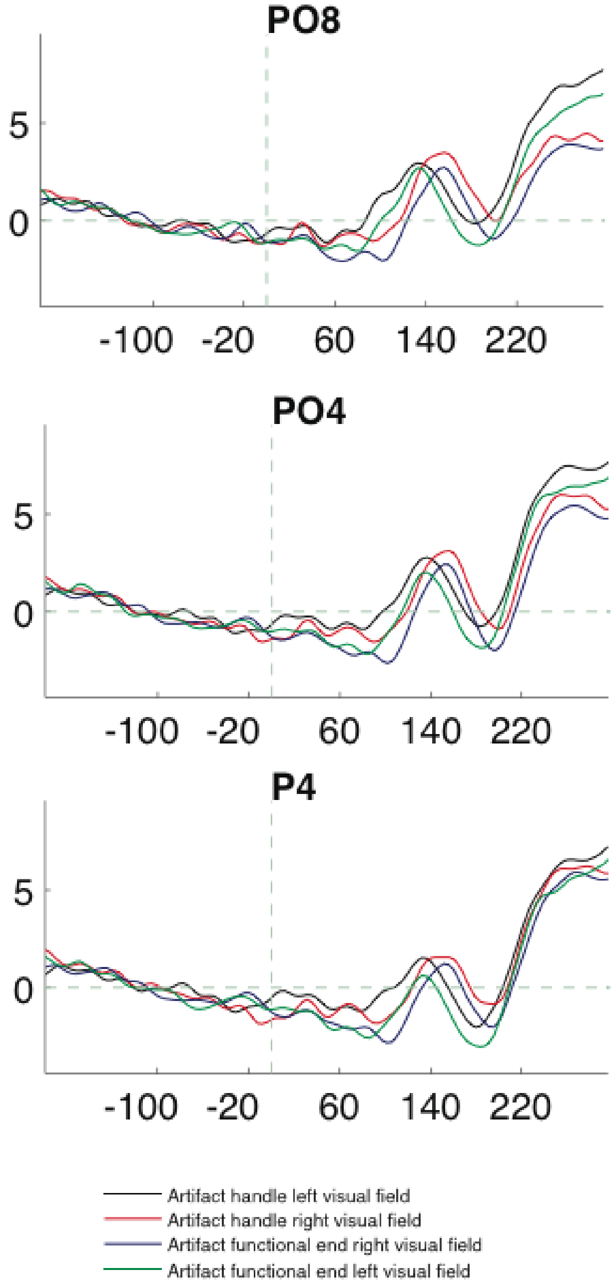
Artifact cues
Left hemisphere ROI

a.



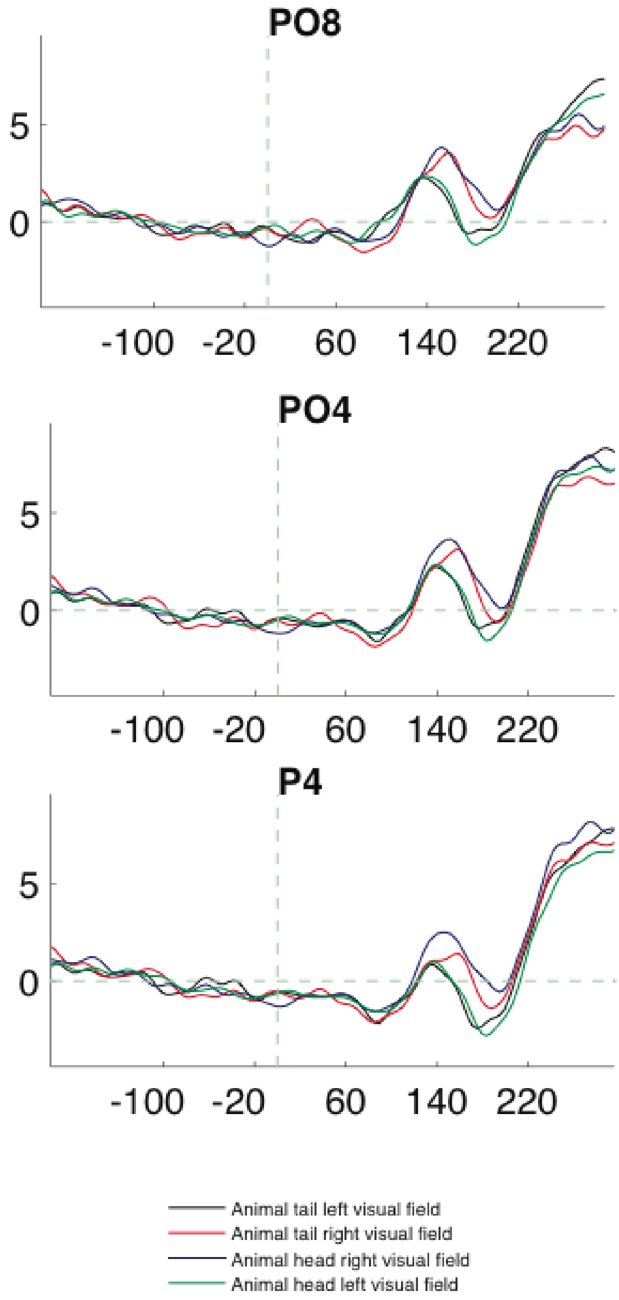
Artifact cues
Right hemisphere ROI

b.



Animal cues
Right hemisphere ROI

c.



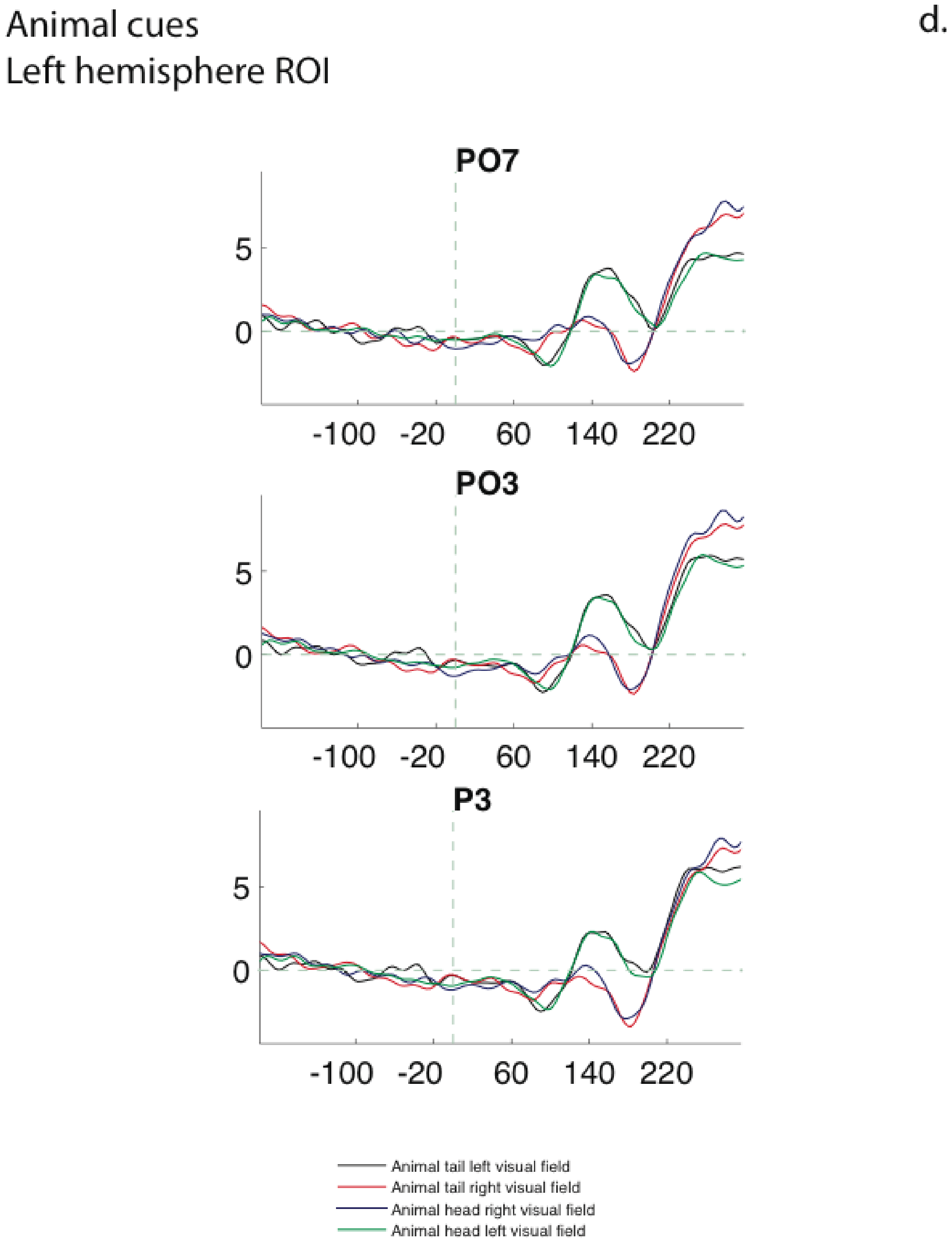


Figure 5.5. Grand average waveforms, measured in microvolts across time, in response to left and right targets to the four possible cued conditions. In a) artifact cues from left hemisphere ROI; b) artifact cues from right hemisphere ROI; c) animal cues from right hemisphere ROI; d) animal cues from left hemisphere ROI.

Figure 5.6 shows timeseries topoplots for targets cued by animal and artifact across the epoch. The topoplots show a strong positivity (especially ipsilaterally) in response to targets. Importantly, the scalp distribution within the P1 time window (120 – 160 ms) is very similar across cue types. Larger effects within the P1 time window are observed over ipsilateral electrode sites.

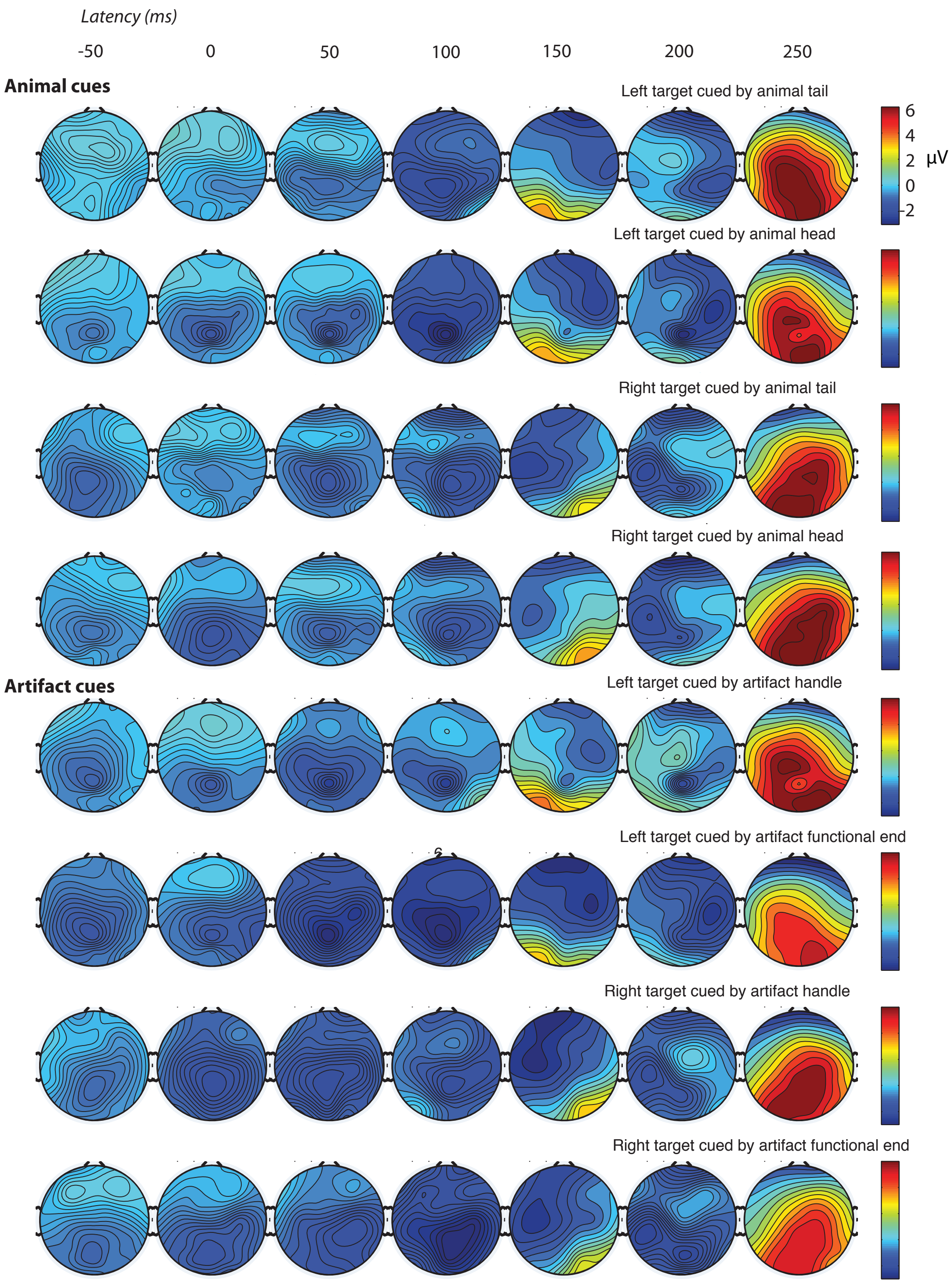
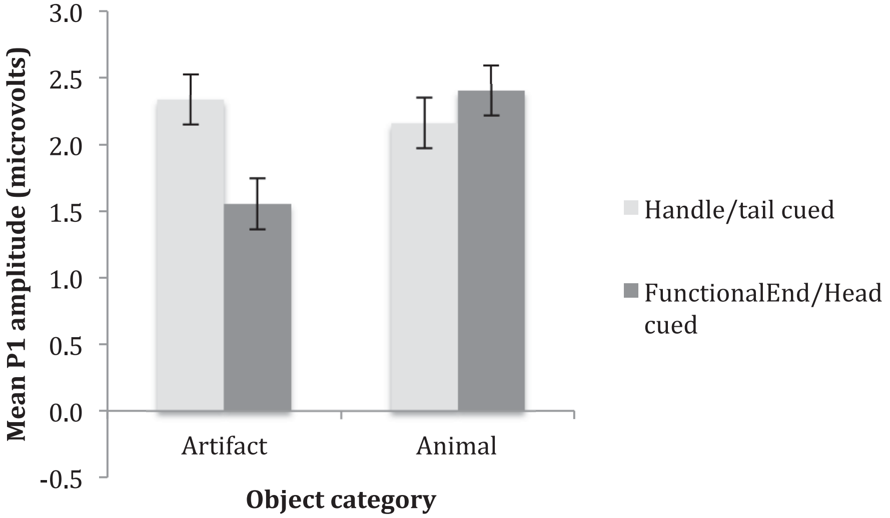


Figure 5.6. Topoplots for targets cued by animals or artifacts. Latency indicated at top.

The 2 (category) X 2 (cue region) X 2 (hemisphere) repeated measures ANOVA revealed a significant effect of hemisphere, *F* (1, 21) = 15.88, *p* = .0007, η^2_G = .102, demonstrating larger P1s in response to ipsilateral (*M* = 2.11, *SD* = 1.65) compared to contralateral (*M* = .61, *SD* = 2.31) targets. The pattern of results suggests that cue region affected P1s in artifacts but not animals, with the ANOVA showing a Cue Region X Category interaction *at* the traditional statistical threshold, *F* (1, 21) = 4.06, *p* = .057, η^2_G = .014. This interaction appeared because of a greater effect of cue region for the artifacts than the animals. Specifically, we observed P1 enhancement in response to targets cued by artifact handles (*M* = 1.62, *SD* = 2.1) compared to artifact functional ends (*M* = .81, *SD* = 2.36) (Fisher's Least Significant Difference = .77). Though the difference in the animals was in the hypothesized direction, with larger P1s in response to targets cued by animal heads (*M* = 1.63, *SD* = 1.77) than animal tails (*M* = 1.39, *SD* = 2.01), it failed to reach significance. See Figure 5.7.

Ipsilateral hemisphere



Contralateral hemisphere

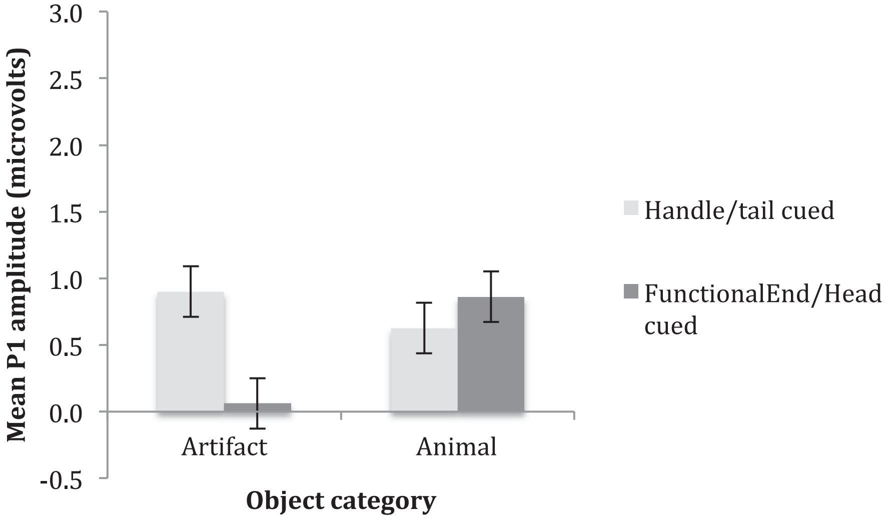


Figure 5.7. Plots of the mean P1amplitude as a function of category, cued region, and hemisphere. Error bars represent Fisher's Least Significant Difference.

Summary of P1 effects. The visual presentation of targets resulted in relatively localized P1s regardless of the object cue. However, in line with our main hypothesis, analysis of the mean amplitudes revealed P1 enhancement to targets that were cued by artifact handles compared to targets that were cued by artifact functional ends (e.g. a blade of a saw). There was no statistical difference between P1s to targets cued by animal heads or tails.

Analysis of ERPs in response to cues using Mass Univariate Statistics. Figure 5.8 shows the results of the mass univariate analysis with FDR correction for the differences between animals and artifacts (animals – artifacts) that were oriented towards the left and right[23].

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[23] MUA was also carried out comparing right animals vs left animals, and right artifact vs left artifacts, but showed no significant differences at any time point or electrode. This analysis eliminates concern that P1 responses to targets within a category are due to any physical property of the stimulus that changes with left/right orientation.

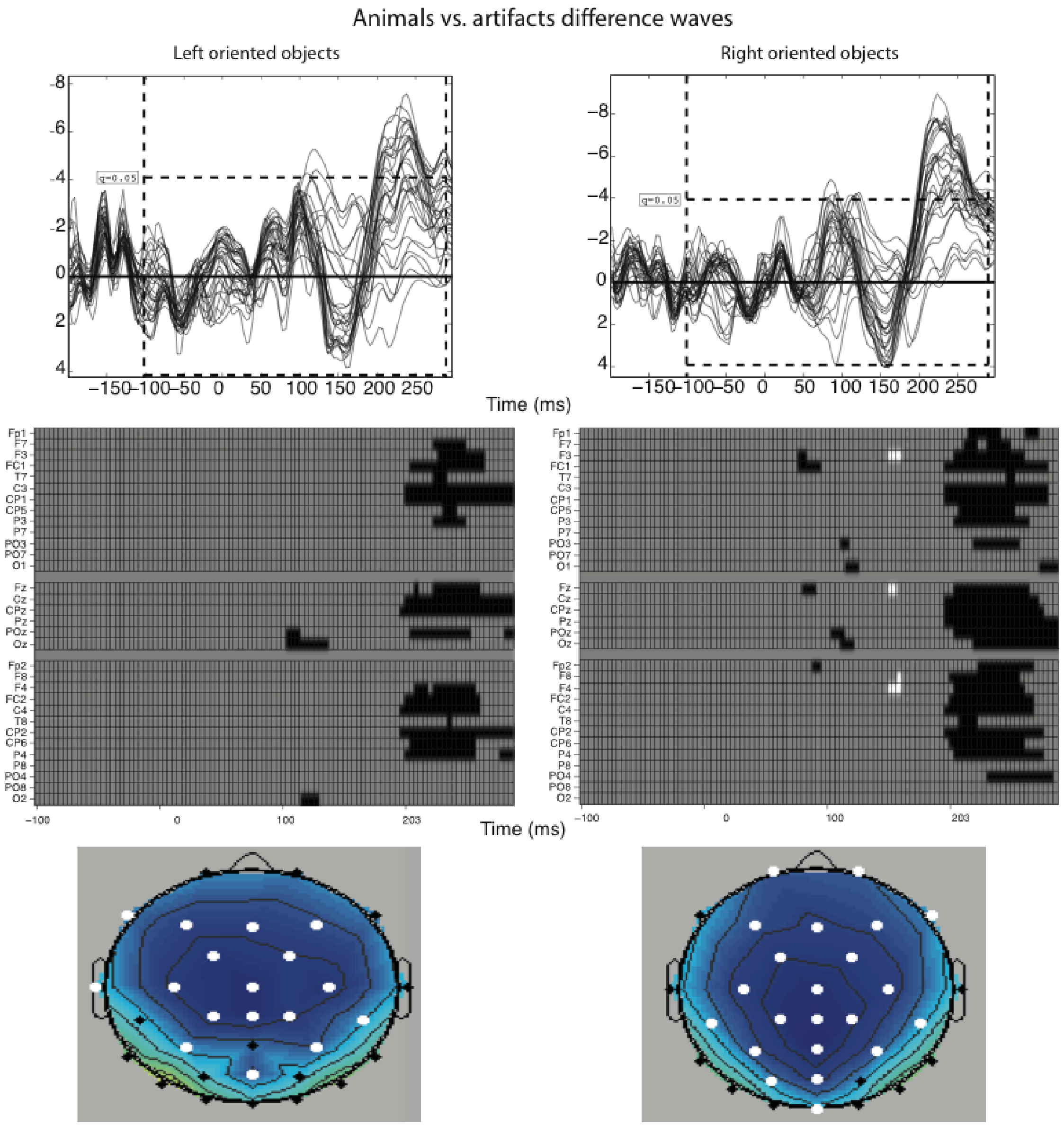

Figure 5.8. (Top) Butterfly plots of t-scores for difference waves for left and right animal vs artifact comparisons. Vertical dashed lines indicate selected time window. Horizontal dashed lines indicate calculated *t*-value based on FDR correction. The calculated *t*-score is represented on the *y*-axis, and time is on the *x*-axis. (Middle). Raster plots showing significant *t*-scores (black = significant with animals > artifacts; grey = non-significant; white = significant, artifacts > animals) as a function of time (in ms) and electrode (labels given on the *y*-axis). (Bottom). Topoplots of voltage distribution at 230 ms after cue presentation. White dots correspond to significant electrodes as determined by MUA; black dots are non-significant electrodes.

Animal left vs Artifact left. Figure 8 shows a raster plot of *t*-test results at each time point (along the *x*-axis) for each electrode (along the *y*-axis). Highlighted in black and white are time points that reached significance after FDR. As can be seen, there are widespread differences through the central electrodes in the later time window (centered approximately around 230 ms). In this case there are larger negativities for animals than artifacts. Two posterior-central electrodes showed significant differences at about 100 ms.

Animal left vs Artifact right. Results for the right-oriented objects are shown in Figure 5.8. The results with the right oriented objects are comparable to the results with the left, in that there are widespread differences across the central scalp at the later time window (centered at about 230 ms). These differences indicate larger negative amplitudes to animals than to artifacts. However, unlike with the left animals, the right animals show robust differences across a small number of central and left frontal electrodes starting at about 80 ms (centered at around 83 ms). These differences occur well before the later differences at appear over distinct, circumscribed electrode sites.

Summary of mass univariate analysis. With both left- and right-oriented object cues, animals evoked a greater negative potential than artifacts beginning at about 200 ms and lasting until about 275 ms. These differences were observed in central and lateral frontal and parietal electrodes (and were absent in occipitotemproal electrodes). Interestingly, in the right-oriented objects, differences emerged at about 80 ms, centered on frontocentral and left frontal electrodes. These early differences were in the same direction, with greater negativity for animals than artifacts. Curiously, there is evidence of an early (i.e.

100 ms) difference in central occipital and occipitoparietal electrodes for left-oriented objects.

5.4 Discussion

In the present experiment we measured the P1 as an index of early visual attention to object features. In light of the growing evidence for 'embodied' object representations, it is important to investigate low-level attentional explanations of common phenomena, including the potentiation effect (e.g. Tucker & Ellis, 1998; Matheson, White, & McMullen, in preparation; see Chapter 3). In support of our hypothesis, we showed greater P1 amplitudes (bilaterally) to target dots cued by artifact handles than artifact functional ends (e.g. the blade of a saw). In comparison, though there was a trend for larger P1 amplitudes to targets cued by animal heads compared to animal tails, there were no significant differences. Consistent with this electrophysiological result, we showed clear performance benefits for detecting targets cued by artifact handles compared to artifact functional heads. We interpret these findings as support for the notion that low-level visual attention is biased towards artifact handles and this facilitates responses to targets in the same visual field (for similar results see Matheson, White, and McMullen, in preparation; Chapter 3). According to this argument then, low-level visual attention may account for some embodied effects, the potentiation effect in particular. Indeed, if object handles biased attention to the same visual field of targets, then we would expect superior button press performance with the hand that is congruent with the visual field, all other things being equal. This would suggest a simple stimulus-response compatibility effect. Extending this, if there is a bias to attend to object handles then we might expect to observe activity in reaching and grasping areas of the dorsal stream (e.g. Chao &

Martin, 2000) as the brain automatically prepares a motor response. Contrary to the embodied theory of object representations however, this activity does not necessarily reflect an object representation that is spread across multiple modality-specific cortical sites.

How would low-level visual attention act on artifacts differently than another object category (e.g. animals)? Though a typical information processing explanation may suggest that life-long experience with artifacts results in a biased object directed attention during a ‘bottom-up’, feed-forward pass through the visual system, we feel that results with of the mass univariate analysis suggests an intriguing alternative. First, there are very clear ERP differences between the artifact and animal cues, appearing at approximately 230 ms broadly across central and lateral frontal and parietal electrodes. This timing is in line with some previous ERP research on object categorization showing P2 differences in explicit categorization of animals versus non-animals (250 ms – 350 ms reported by Antal et al., 2000). In line with this previous research, we argue that this early difference may reflect an implicit categorization of the object categories. These broad differences suggest that by the time the target dots appeared in our paradigm, the objects have been differentiated and categorized. Though we cannot provide precise localization information, and despite the known problems with speculating about the location of ERP generator sources (see Luck, 2005) the observation of these differences occur later in the time window is consistent with the notion that categorization may happen at ‘higher level’ cortices. These processes then could provide input into extrastriate cortices to bias visual attentional process or increase neural gain of the critical region, specifically artifact handles. Importantly, our results suggest that this process does not bias attention in a region-specific way for the animals (as we saw no P1 differences), though there appears to be a trend in the predicted direction. Whether or not these differences arise because of a categorization process that differentiates *animals* from *artifacts* (e.g. the role of animacy detection; see McCarty, Gao, & Scholl, 2009) or *artifacts* from *animals* (e.g. a process guided by the planning of reaching and grasping, e.g. Handy et al., 2003), or some combination of both, remains unclear from the present data. Future research could use source localization to estimate the origin of the categorization differences, and determine whether these hypotheses are likely.

The MUA revealed one other, unexpected yet potentially interesting finding. For the right oriented objects we show localized differences measured over frontal electrodes that occur early in the time window, starting at about 80 ms. These differences might reflect even earlier categorization of the objects than what is reflected in the P2. Indeed, ERP research of visual scenes has shown that the brain can categorize scenes with living things in them very quickly, by approximately 150ms (Thorpe, Fize, & Marlot, 1996), and Bar et al. (2006) have provided a model of fast categorization of objects based on a feed-forward, low-spatial frequency analysis of the visual image that subsequently biases processing in ventral visual areas through re-entrant connections. The results of our MUA might reflect these purported early categorization process.

With evidence that the cues are categorized by at least 230 ms, our P1 results to targets suggest that feedback from higher cortical centers to extra-striate areas can bias attentional process, demonstrated as an early selection for artifact handles. This resultant bias of visual attention to artifact handles is associated with superior target detection. We argue that these combined behavioural and ERP effects suggest that some embodied effects might simply reflect differences in attentional allocation to manipulable artifacts and non-manipulable animals.

However, there are a number of caveats to this interpretation that are important to discuss. First, we wish to argue that the process we have revealed here might underlie motor potentiation effects, eliminating the need to posit modality-specific motor simulations in response to artifacts. According to this argument then, motor potentiation effects might be due to low-level visual attentional bias, rather than embodied object representations. However, unlike potentiation experiments (e.g. Matheson, White, & McMullen, in preparation; Chapter 3), in which participants engage in a visual cognitive task such as orientation decisions or object categorization, participants in the present experiment were not explicitly instructed to process the object cues. Thus, the P1 effects we report here reflect more ‘automatic’ biasing of attention. Though we would argue that this bias would exist regardless of task, as it happens early (i.e. at the level of P1), future research could adopt paradigms better suited to addressing this issue.

Second, according to our interpretation, categorization of the object cues led to visual attentional bias in early extrastriate cortex for artifact handles. In previous research, we have also shown motor potentiation effects in response to animal heads. However, we do not observe significant attentional bias to animal heads in the present experiment (though we observe a non-significant trend for this). One possible explanation is that animals are salient enough as an object category that they broadly attract attention, therefore eliminating a bias to one particular feature. Indeed, using a change detection paradigm, New, Cosmides, & Toobey (2007) have shown that animals do seem to broadly capture attention in visual scenes (but tools do not), an effect they interpret as reflecting a category specific tuning of low-level attention. If they are correct, we would expect no difference in P1 responses based on animal head or animal tail cues. However, the lack of difference in P1 responses based on the animal cues does stand in contrast to our motor potentiation results of faster responding with the hand that is congruent with the animal head (Matheson, White, & McMullen, in preparation; Chapter 3). Again, this difference may also be related to the fact that the P1s measured in the present paradigm measure ‘automatic’ biasing of attention, as participants were not explicitly making cognitive decisions about the animals or artifacts. Again, future research could adopt paradigms that are well-suited to address this issue.

A third caveat of our interpretations is that, though we did equate the cues on some low-level stimulus features (e.g. average pixel luminance and overall image area), the results of the MUA of the cues could still reflect low-level stimulus properties. Specifically, the ERPs recorded to these two categories are responses to different physical stimuli, and not all physical properties could be equated (e.g. contrast, the number of concave vs. convex corners). However, the MUA revealed differences at about 230 ms, a latency we feel that is sufficiently late in the epoch to suggest a cognitive difference rather than a purely low-level visual difference based on the physical properties of the stimuli. Thus, we suggest that the P2 differences revealed by MUA likely do not reflect low-level stimulus characteristics.

Fourth, we have observed greater P1 amplitudes in response to targets cued by artifact handles than artifact heads, and have interpreted this as an *enhanced* P1 response to artifact handles. However, an inspection of Figure 5.7 shows that the absolute P1 response to targets cued by animal tails, animal heads, and artifact handles are all similar, and it is the P1 response to the artifact functional head that is *smaller*. Thus, one could argue that our results reflect a P1 *suppression* to artifact functional ends rather than a P1 enhancement to artifact handles. However, this argument rests upon the assumption that target P1 responses should be equal. Granted, this is a reasonable assumption given that they are elicited by the same physical stimulus on every trial. However, it is unclear whether we are justified in this assumption, given the observation of ERP differences to the two types of cues (in the MUA). From the present paradigm, it is not clear that we could expect P1s of comparable amplitudes in response to targets cued by artifacts vs. animals. Indeed, the absolute amplitude of a given ERP component is generally not informative (see Luck, 2005). Therefore, we argue that the critical interaction between cued end and category can be interpreted as supporting our main hypothesis. Though we cannot rule out the possibility of P1 suppression in the present result, we feel that our interpretations are justified based on the predicted, *a priori*, pattern of P1 results.

Finally, one additional caveat is worth noting. Upon inspection of the grand-average waveforms in Figure 5.5, there is some hint of the presence of a C1 component (a small, early positive deflection thought to originate in V1). This component is sometimes observed in attentional paradigms, and it is thought to arise because of the anatomical characteristics of the calcarine fissure (see Di Russo et al., 2001). Close inspection of the waveforms suggest a qualitative difference between C1s to targets cued by handles vs functional-ends, and this difference seems to persist at the latency of the P1 (e.g. PO7). This could suggest that the P1 differences we observe here do not reflect differences in P1 proper, but are actually extended attentional effects at the level of C1. Importantly, most ERP research studies do not show attentional effects on the C1 component though fMRI studies have reported attentional effects in V1 (see Luck & Kappenman, 2012 for a discussion of the 'cognitive penetrability' of V1 activity). However, at least one study shows attentional effects on the C1 component (see Kelly, Gomez-Ramirex, & Foxe, 2008, who optimized the conditions for observing the C1). Thus, though our data do not allow us to determine if my P1 effects are extended effects of the C1, future research can explore this hypothesis. An intriguing possibility is that the ecologically relevant cues used in this experiment resulted in re-entrant attentional effects before extrastriate P1 generators, biasing processing in V1.

Conclusion

Using the P1 as an index of early visual attention, we have shown that artifact handles automatically bias attentional processes that are associated with superior target detection performance. This finding provides an alternative explanation of embodied interpretations of the potentiation effect, and suggests low-level visual attention plays a role in the early processing of manipulable versus non-manipulable objects.

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CHAPTER 6 CONCLUSION

6.1 OVERVIEW OF RESULTS

In the collection of studies reported here I investigated the embodied cognitive account of object representations. I focused, in particular, on the ‘conceptualization hypothesis’ (Shapiro, 2011) of object representations, and adopted visual cognitive paradigms for which embodied theories make strong predictions. I tested two critical predictions of the conceptualization hypothesis. According to these theories (e.g. see Barsalou, 2008), sensorimotor experiences constrain cognition such that object concepts are represented in a distributed manner by simulations within modality-specific cortices. The first critical prediction of this framework is that sensorimotor simulations play a *functional* role in representing manipulable objects but not non-manipulable objects; specifically, these simulations should causally influence successful performance of tasks such as object naming. The second critical prediction is that, for manipulable objects, there should be a *correlational relationship* between the visual processing of objects and sensorimotor activity; specifically, we should observe evidence that sensorimotor simulations are coactivated during the visual presentation of manipulable objects. In the first two chapters of the present thesis, six experiments were described that failed to support these predictions.

First, in Chapter 2, I adopted a concurrent motor paradigm (c.f. Witt et al., 2010) in an attempt to disrupt motor simulations during an object naming experiment. In two experiments, concurrent motor activity was shown to interfere with or facilitate object naming across manipulable (artifacts) and non-manipulable objects (animals). I concluded that, because squeezing affected naming of across both object categories there was little evidence for embodied representations from this paradigm. Further, the reversal of the effect I observed between the two tasks, due to the picture-plane orientation of the object images, strongly suggests a more general, non-specific effect of the concurrent motor task. I speculate that this effect is caused by differences in attentional biases to objects that are created with respect to the participant's hand. Regardless, the results do not support the predictions of embodied object representations.

In Chapter 3, I adopted a paradigm that is often argued to reflect the automatic elicitation of object affordances (Tucker & Ellis, 1998). In this paradigm, participants made object orientation or category judgments about objects by pressing a key. Participants were faster when the handle of manipulable objects was congruent with the response hand. One interpretation of this result is that, consistent with the embodied account of object representations, the potentiated motor response reflects activity in sensorimotor areas that arises during the visual presentation of the object. However, in my experiments, participants were faster when the response hand was congruent with the animal heads; thus, I observed so-called 'motor potentiation' for both manipulable artifacts and non-manipulable animals. In addition, motor potentiation actually reversed in artifacts during category decisions. Because a) motor potentiation was observed for animals (i.e. a category of object for which we should have no motor associations) and b) motor potentiation for artifacts reversed (with respect to the orientation decision task) from handles to functional ends, I concluded that this paradigm does not provide evidence for embodied object representations. I speculated that the results pointed to a more general, non-specific, stimulus-response compatibility effect in which responding is faster to the visual field that is congruent with the locus of an attentional bias.

The failure to find a functional role of motor simulations in visual cognitive tasks (i.e. Chapter 2) is consistent with recent research on working memory (e.g. Pecher, 2012), and the failure to find correlational evidence of sensory motor simulations in motor potentiation paradigms (i.e. Chapter 3) is consistent with a small number of studies that used the similar 'potentiation' paradigms but found evidence for more general stimulus-response compatibility effects (e.g. Anderson et al., 2002).

Overall, the effects reported in my experiments are suggestive of more general phenomena, ones that are not category-specific but that might be paradigmatically specific and rely more on low-level attentional processes. In Part II of the present thesis, I investigated the hypothesis that differences in covert or overt attention might underlie some of the 'embodied' phenomena that are often reported. In a descriptive investigation, in Chapter 4, I measured participants' eye movements while they named and categorized artifacts and animals. As predicted, I showed that participants had a strong tendency to direct gaze towards animal heads and a more distributed tendency to direct gaze towards artifact handles and functional ends. These effects were present in both tasks. I interpreted this tendency to reflect overt allocation of attention to salient features. Finally, in the last experiment reported here (Chapter 5), I adapted a Posner-style cueing paradigm and exploited the P1 event-related potential (ERP) component as an index of covert low-level visual attention. I showed that artifact handles automatically attract visual attention, and that this effect is associated with higher accuracy to detect targets when they are cued by object handles. I suggested that visual attentional mechanisms might serve as a foundation for 'embodied' effects, without any recourse to embodied object concepts. Over all then, using the paradigms I adopted here, I do no not provide evidence for embodied object representations, but do provide evidence that general cognitive process (i.e. covert and overt attention) can differ for animals and artifacts. Below, I discuss these results in relation to research on embodied object representations and in relation to what is known about visual attention mechanisms.

6.2 RELATIONSHIP TO EMBODIED MODELS AND GENERAL THEORETICAL FRAMEWORK

In Chapter 1, I introduced a number of possible models that provide a framework for understanding embodied theories of object representations. These were the convergence-divergence framework of Damasio and colleagues (see Meyer & Damasio, 2009) and the perceptual symbols systems theory of Barsalou and colleagues (Barsalou et al., 2003). I have argued that the results of the present thesis challenge embodied accounts of object representations. Given these interpretations, the questions I hope to address in this section are a) Are the present results consistent with these models, and b) Is embodiment wrong?

According to the convergence-divergence zone model (Meyer & Damasio, 2009), and the perceptual-systems model (Barsalou et al, 2003), modality-specific information converges on higher-order neural regions that receive information about the relative timing and distribution of different features of experience (e.g. the visual, auditory, and sensorimotor activity associated with the visual presentation of a hammer). In cognitive tasks (e.g. recognition or recall) these higher-order convergence zones can initiate simulations of appropriate combinations of modality-specific information to facilitate performance ‘offline’. For instance, these models predict that, when asked to recognize a hammer, higher-order convergence zones initiate the suite of modality-specific simulations that make up the representation of the hammer and these simulations are used to perform the cognitive task. However, I have shown that interfering with these simulations (with a concurrent motor task) does not affect visual cognitive performance in category-specific ways, nor do I find behavioural evidence of incidental simulations in sensorimotor cortices that are modality-specific (with the potentiation paradigm). These are two major predictions that follow from embodied models. Thus, in general, the current results are not consistent with a strong interpretation of them. It seems that a strong form of the embodied hypothesis of object representations cannot be maintained.

This raises the question of whether we should abandon embodied theories. In Chapter 1, I reviewed a body of literature relevant to the question of embodied object representations, from neuroimaging, neurophysiology, neuropsychology, development and behavioural research. I argue that evidence from none of these paradigms provides evidence for a strong form of the embodied hypothesis. Indeed, 'a smoking gun' against the strong form of the hypothesis is that apraxics, with deficits in the planning and execution of action on objects, can show spared visual cognitive performance (e.g. object naming; see Negri et al 2007). The results presented in this thesis add to this literature and cast further doubt on the strong form of the embodied hypothesis. However, as with many theories in cognitive psychology, the strong form is usually hard to retain. Thus, we might ask whether there is a weaker form of the embodied hypothesis that can be retained and if so, how?

Barsalou's perceptual symbols theory (Barsalou et al. 2003) suggests that attention can prioritize different aspects of an experience. Extending this, this prioritization might occur during cognitive tasks, with higher-order convergence zones retro-activating *only a subset* of the associated modality-specific information. Thus, there may be a differential weighting of different modalities depending on the task (see Meyer & Damasio, 2009; Barsalou et al, 2003). If this feature of the model is valid then this might provide a way of retaining a weaker form of he embodied hypotheses despite the evidence presented in this thesis. Namely, the tasks I have focused on are all visual cognitive tasks, and I have used visual stimuli in naming and other identification or categorization tasks to investigate embodied predictions. However, if the weighting of visual information is high in such cases (because, say, the visual signal is strong and constantly present, i.e. there is a high signal-to-noise ratio), one could argue that there is little need to rely on simulations in other cortices. According to this line of reasoning, my results may simply imply that embodied effects are not detectable with these visual paradigms because sensorimotor simulations are not needed or they are not invoked.

Both the Barsalou and the Damasio models suggest that retroactivations are not complete. This raises the questions as to whether there are many ‘routes’ to performance on cognitive tasks (e.g. naming). More specifically, perhaps object names can be retrieved through any modality, and therefore any given modality-specific retroactivation may not be *necessary* to perform the tasks but it might be *sufficient*. Similar to the arguments above then, one could argue that under certain circumstances cognitive performance can be supported by many different modality-specific representations. In this case, I am arguing, the same overt behavioural performance (i.e. saying the word “hammer”) is supported by different retroactivations in different contexts (ie. visual retroactivation and auditory retroactivation in one case, visual retroactivation and sensorimotor retroactivation in another). Indeed, neuropsychological patients provide evidence that there can be modality-specific routes to object names. For instance, visual agnosics, who have difficulty identifying objects by vision often retain the ability through some other modality (i.e. haptic exploration; see Farah, 1990). A similar phenomenon is nicely demonstrated in a case of optic aphasia, in which the patient could not retrieve object names from visual stimulation but could from other modalities like somatosensory (see Hillis & Caramazza, 1995). Obviously, this characterization of embodiment is theoretically flexible—perhaps too flexible, in that it could account for many different behavioural findings *post hoc*[24]. This is highly undesirable as I argued in the introduction that a strength of embodied theories is that they make strong *a priori* predictions about behaviour (i.e. the behaviours I have studied in this thesis). Over all then, though I think there are ways embodied theories can flexibly accommodate my present findings (specifically, the lack of support for them), they would need to do so by sacrificing a great deal of their purported strengths.

Thus, I have failed to support a strong form of the embodied hypothesis, and attempts to retain the hypothesis in this case pushes us towards a 'slippery slope' in understanding the present results and the large body of literature form many paradigms. This raises the question: Is embodiment wrong? The large body of literature outside of visual cognition in support of embodiment cannot be ignored, and therefore embodied theories are likely useful in explanations of cognitive phenomena (again, see Barsalou

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[24] Unfortunately, if this characterization of a weaker form of embodiment is valid, it suggests that behavioural tasks in neural-typical individuals (using naming latency, button press-accuracy and reaction time, and the other main dependent variables of cognitive psychology) might not be optimal for studying embodiment *in general.*

2008; Pulvermüller, 2005[25]). Indeed, a need to retain embodied models seems necessary. However, whether embodiment is needed to explain the results that I have presented, or the collection of visual cognitive literature showing a tight coupling between vision and action, is certainly questionable. If embodiment is not useful in explaining these results, what do we make of the tight coupling between vision and action that is seen in neuroimaging (e.g. Chao & Martin, 2000) and behavioural research (e.g. Bub & Masson, 2010)? Research from at least two areas addresses the discrepancy between embodied evidence in language and action understanding vs. in the visual paradigms I used here. First, in general, the relationship between vision and action has been well established for some time (e.g. Ungerleider & Mishkin, 1992) and is well described in the neuropsychological 'two-streams' hypothesis of Milner and Goodale (1995). The two-streams hypothesis suggests that visual information is parsed into two streams depending on the types of transformations they perform on incoming visual information. Ventrally, invariant information about objects and their form is processed, and dorsally, variant information (e.g. location and movement information) and calculations needed to plan and guide movements are executed (see Milner & Goodale, 2005). Under this characterization, it is no surprise that we observe activity in frontoparietal networks in response to the visual presentation of an object, and the fact that the visual presentation of

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[25] At first glance, there appears to be a discrepancy between the visual perception literature, presented here, and the literature on language and action understanding. Though there is much evidence that is consistent with embodied cognitive hypotheses in this literature, the appropriate interpretation of them is in dispute. Indeed, Mahon and Caramazza (2008) suggest that at best this literature shows that abstract concepts are 'enriched' by sensorimotor activity, which provides a context within which an abstract concept is activated.

a graspable object can facilitate a grasp is also not hard to reconcile. In fact, according to this theory, we *expect* activity in both streams in response to the visual presentation of an object. However, this activity does not necessarily constitute an object 'concept' or an embodied representation; simply, it reflects the types of transformations an active organism needs to perform actions on manipulable objects. That is, this activity reflects *action*, not semantics. Overall then, though the literature I reviewed in the Chapter 1 is consistent with embodied object representations, they are not demonstrative of them. Rather, the results from these studies might simply be suggestive of the ways in which the brain transforms visual information into the programs for action.

This line of thought is consistent with other research exploring the unique processes involved in manipulable object processing. For instance, Adamo and Ferber (2009) demonstrated that the presentation of a manipulable object can reduce the attentional blink for subsequent manipulable objects that are related by action (e.g. a hammer and a nail), but only when the items are presented visually (and not by their linguistic counterparts). They argue that the visual presentation of the object leads to action-related activity that biases processing of subsequent stimuli, but only in visual paradigms. This might help explain why researchers find consistent evidence for embodiment in language tasks, but, like the results reported in this thesis, the results from visual tasks appear to be best explained by other, non-embodied effects.

A similar conclusion was reached by Mahon and Caramazza (2009) after an analysis of the fMRI literature on frontoparietal activations in response to the visual presentation of objects. These authors suggest that the relevance of frontoparietal activations is restricted to theories of action but not theories of object semantics (2009, pg. 40). I suggest that much of the excitement generated by embodied theories should be re-assessed in this way. Indeed, future embodied research must focus on the extent to which sensorimotor simulations are used in different cognitive tasks, if they are used at all. This sentiment was nicely summarized by one recent author, who wrote:

> “In summary, the current popularity of embodied accounts of cognition has generated a wealth of extremely interesting data. Many of the experiments conducted are elegant. However, the best interpretation of these data is not always clear…In general, contrasting embodied with disembodied cognition diverts focus away from the question of the nature of this embodiment. Investigators are often permissive in accepting data as confirming embodied accounts.” (Chatterjee, 2009, pg 91).

Before leaving this point, I want to address one more important issue with respect to how my results fit with general cognitive theories. In the second part of this thesis I provide evidence of attentional differences that exist between manipulable artifacts and non-manipulable animals. These differences, too, are not demonstrative of embodiment, as they likely simply reflect differences in the goals of the cognitive task. Specifically, the visual presentation of a graspable object might direct attention in such a way that facilitates say reaching and grasping, but these differences are not part of an ‘embodied object representation'.

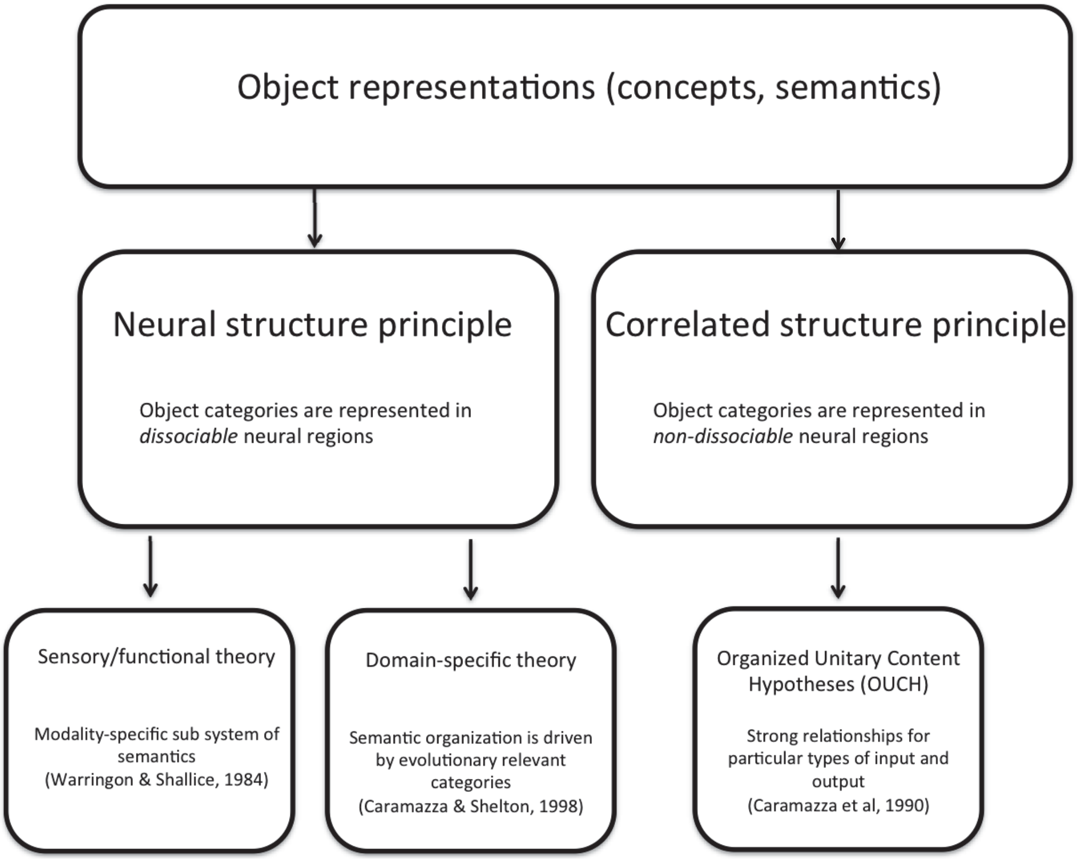

Figure 6.1. Schematic representation of the review provided by Mahon and Caramazza (2009), summarizing a number of theories regarding object representations (or object semantics or concepts).

However, though I have failed to support embodied theories, the results of the present experiments are not readily accounted for by any single, alternative theory of the organization of object concepts (e.g. semantics). I have summarized the most recent, comprehensive review of alternative theories, as described by Mahon and Caramazza (2009), in Figure 6.1. While some of these theories are amodal (e.g. domain-specific theories, Organized Unitary Content Hypothesis), some are at least partially modality specific (e.g. Sensory/functional theory). I wish to highlight that these theories are not necessarily orthogonal, or mutually exclusive, and indeed Mahon and Caramazza (2009) provide the insight that "…a single dimension will not be sufficient to explain all aspects of the organization of object knowledge in the brain" (pg. 42). In Part I of the present thesis I selected paradigms that are well suited to testing embodied predictions of object representations, but they are not well- suited to testing the other types of models summarized by Mahon and Caramazza (2009) (and indeed, this is a general challenge when attempting to pit amodal vs modal theories against each other). To the best of my knowledge, these amodal theories would simply predict no effects between the critical conditions used in the studies reported here (according to these theories, motor activity, for the most part, reflects only the *output* of a given cognitive process). In Part 1 of the present thesis, I observe effects in both objects and animals, not simply null effects. Thus, these models, too, do not necessarily suggest an alternative account of the effects of the concurrent motor tasks or motor potentiation I observe in Part I. Below I suggest a general hypothesis about the distribution of attention that might best account for the results presented here.

6.3 A FEW POINTS ON HOW ATTENTION POINTS

In Part 1, I showed affects on object naming and category decisions that were not category specific, but appeared to occur for both types of object. I interpreted these results as reflecting an attentional bias. Importantly, the pattern of results across all studies reported in this thesis strongly suggests that this attentional bias is flexibly determined by aspects of the experimental task. In Chapter 2, I introduced the concept of an 'attentional vector' to describe the asymmetrical bias of attention that is caused by these objects, and to imply that it is directional and can flip. However, this concept is very similar to attentional models that include ‘saliency maps (Koch & Ullman, 1985), ‘attentional templates’ (Desimone & Duncan, 1995), or ‘attentional gradients’ that are suggested by ERP research (i.e. lower amplitude ERPs the further away a target is from the current focus of attention; see Eimer, 1997) and behavioural studies (i.e. reaction times increase as target eccentricity increases; see LaBerge & Brown, 1989). I introduce the novel language of ‘vectors’ simply to reflect the hypothesis that the distribution of spatial attention elicited by animals and artifacts is not symmetrical and can flip.

Before describing how attentional vectors might change as a function of task, it is important to note a few other aspects of visual attention are relevant to understanding the current set of results. First, it is widely accepted that attentional allocation is mediated by parallel processes that are driven by a) qualities of the stimulus (e.g. the contrast or brightness; what is typically referred to as ‘bottom-up’ processes) and, b) the goals and psychological sets (i.e. response sets, affective states) of the observer (what is typically referred to as ‘top-down’ processing); further, it is know that there may be overlapping systems that direct attention to object features and to regions of space (see Corbetta & Shulman, 2002). Finally, it has been argued that ‘top-down’ signals can bias visual processing in at least four different ways, by: a) enhancing neural responses to attended stimuli, b) supressing neural responses to competing stimuli, c) increasing the baseline firing rate of neural systems responsible for processing an attended object feature or region of space and d) increasing sensitivity of neuronal populations to attended object features or regions of space (see Kastner & Ungerleider, 2000). Taken together, I argue that bottom-up and top-down attentional biases shape the direction of the attentional vector caused by my stimuli and are determined by the nature of the task. Importantly, unlike a strictly ‘bottom-up’ saliency map (e.g. Koch & Ullman, 1985), I argue that the asymmetry of the attentional bias can flip, rendering different features of the artifacts and animals more ‘salient’ (or, importantly, their corresponding locations in space) depending on what cognitive task the participant performs. These biases likely take the form of one (or more) of the mechanisms of attention identified by Kastner & Ungerleider (2000).

Figures 6.2-6.5 schematically summarize my results and are offered as an explanation of the current set of behavioural and neurophysiological results. Additionally, I believe they provide strong hypotheses for future research. In this figure, the examples of stimuli are shown along with the hypothesized changes in the attentional vectors. The critical result is reproduced in the figures. Below, I describe each hypothesized shift in the attentional vector and provided suggestions for future research.

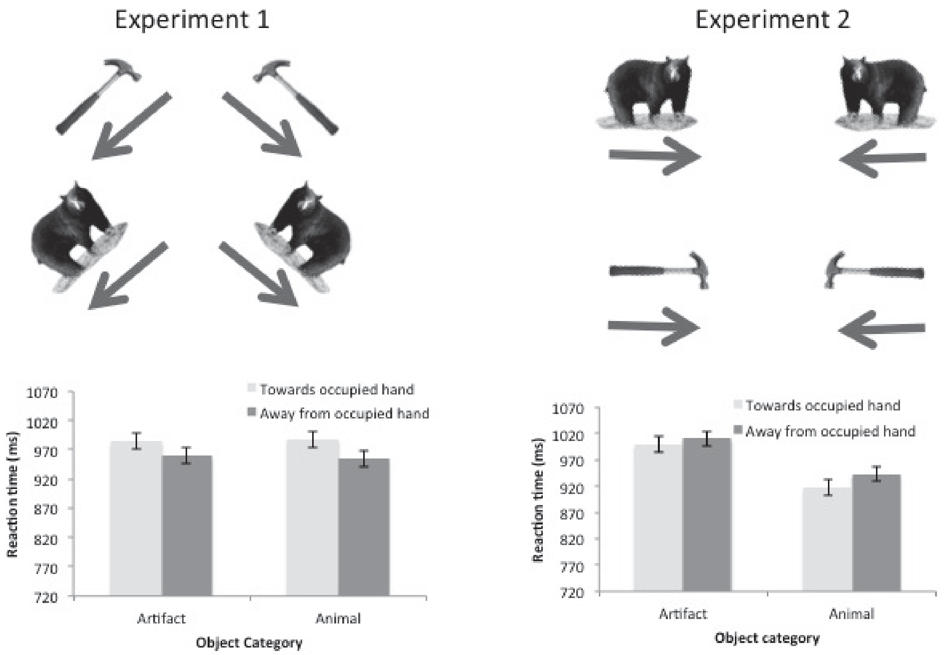

Figure 6.2. Attentional vector account of results from concurrent motor-naming task reported in Chapter 2. Arrows represent hypothesized changes in vector direction.

In Figure 6.2, I show the results of the concurrent motor task. The important finding in this study was that naming was slower when the handle/tail-ends of the objects were presented towards the occupied hand in Experiment 1, in which the objects were rotated within the picture plane, but faster when the objects were oriented more 'canonically'. In Chapter 2, I proposed that when the object is oriented at 45 degrees (from horizontal) in the picture plane (Experiment 1), the relationship between the object and the hand is more obvious to the participant (i.e. the objects are 'pointing' towards or away from the hand). I suggest this led to an attentional bias that favoured the handle/tail-end. By virtue of the relationship with the hand, I propose that this bias led to interference (perhaps through competition for attention in the area of the hand; see Desimone & Duncan, 1985) and resulted in slower naming. However, in Experiment 2, by orienting the objects on the horizontal plane, this bias shifted (i.e. the relationship to the hand was less obvious). Now the attentional bias favoured the functional-end/head of the object, perhaps because this region is most important for naming (and indeed, the results of eye-tracking experiments in Chapter 3 support this). With attention away from the area of the hand there was no competition and therefore no interference. I suggest this led to the facilitation in Experiment 2. Overall then, I hypothesize that the attentional vector shifts depending on the picture-plane orientation of the object and its relationship to the hand. This can be explored in further research by using standard target detection or localization tasks (with objects as cues) while manipulating hand posture and picture plane orientation.

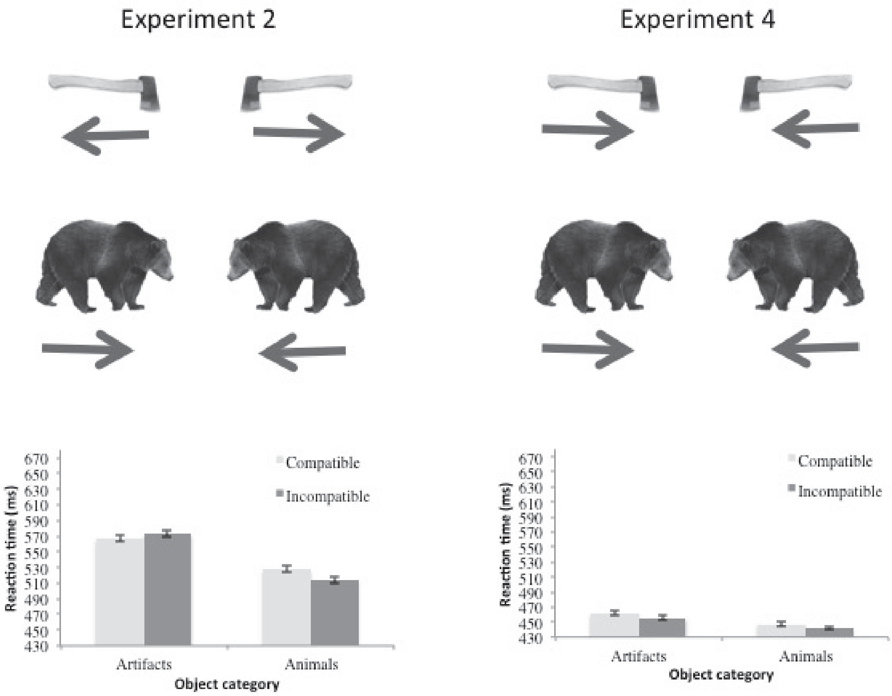

Figure 6.3. Attentional vector account of results from motor potentiation paradigm in Chapter 3 in which participants made orientation decisions (Experiment 2) and category decisions (Experiment 4). Arrows represent hypothesized changes in vector direction.

In Figure 6.3, I show that results of the potentiation experiments (Chapter 3), in which participants made orientation or category judgments. In Experiment 1, in which there were no effects of ‘compatibility’, I suggested that the stimuli were not large enough to induce the attentional bias that underlies the stimulus-response compatibility effect. However, in Experiments 2 & 3, in which participants made object-orientation decisions, I showed small but reliable potentiation when the handle was ‘compatible’ with the response hand and when the head was ‘compatible’ with the response hand. In this case, I argue that the attentional bias favoured the animal heads and the artifact handles. This is plausible because the participants were instructed to ‘define orientation with respect to how you would use the object’. This would have made the handle particularly important (i.e. ‘salient)’ for their decisions, and there appears to be a general bias favouring animal heads. However, in Experiment 4, in which participants categorized objects, I suggest the attentional vector flipped, favouring the functional end (and remained the same for the animals). In this case, the functional-end/head would have been important for the task, as it is informative about the object category. Thus, in these experiments, I argue that the faster responding with the ‘compatible’ response hand simply reflects the bias of attention to one side of space that depended on the object category and task. Future research can investigate this hypothesis by deliberately attempting to flip the attentional bias under different task instructions, with different object types, to determine the conditions under which stimulus-response compatibility is observed.

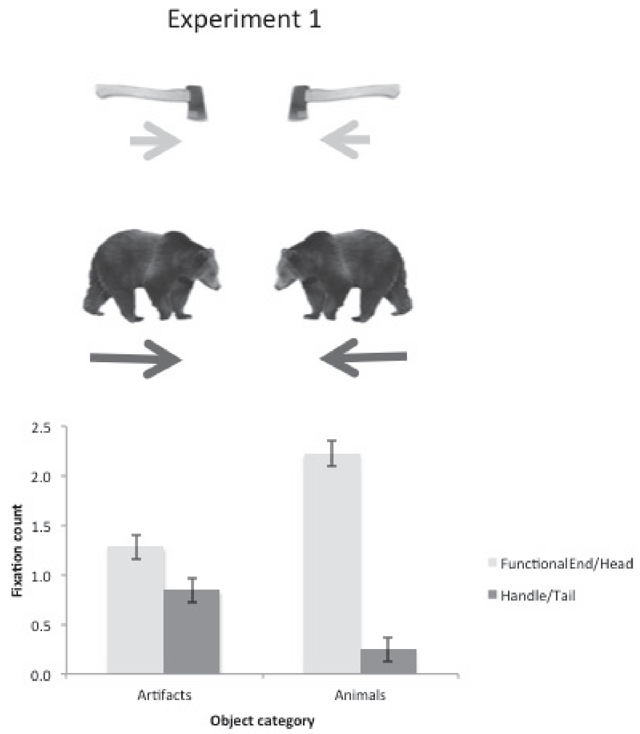

Figure 6.4. Attentional vector account of results from eye-racking experiment (Chapter 4). Arrows represent hypothesized changes in vector direction and strength.

In Figure 6.4, the eye-tracking results strongly suggest that under extended viewing conditions (i.e. 1200 ms), the functional-ends/heads bias overt attentional processes in both naming and categorization. However, the artifact handles do attract attention (as I observed a more distributed tendency to fixate the artifacts), suggesting that this attentional bias is either weaker in artifacts, or perhaps flips on a trial-to-trial basis.

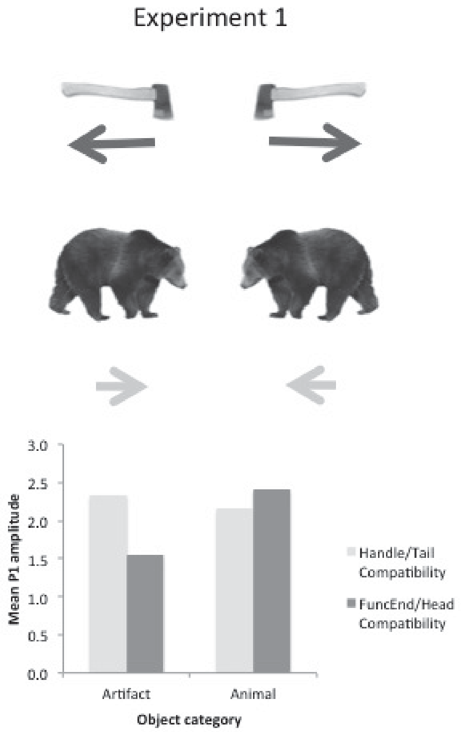

Figure 6.5. Attentional vector account of results from Chapter 5. Arrows represent hypothesized changes in vector direction.

Finally, in Figure 6.5, I show the results of the ERP experiment investigating P1 enhancement to target dots cued by different object features. As argued in Chapter 5, there was an attentional vector that favours the handle during brief, incidental presentations. Though there was a P1 trend that suggested an attentional bias towards animal heads (consistent with the hypotheses of other studies), it was not reliable (and there was no behavioural trend either). This suggests that the strength of the attentional vector is not equally applied to all objects but can depend on object category. Future research should adopt the Posner-style cuing paradigm I have adopted here to investigate other conditions that may lead to, and alter the direction of, the attentional bias I observed here. Further, future research can explore the notion of an attentional vector more deliberately by manipulating the eccentricity of the targets with respect to the hypothesized attentional focus (c.f. Eimer, 1997). If the attentional vector is a useful way of explaining the distribution of attention to animals and artifacts, one would predict systematic decreases of P1 responses as target eccentricity increased.

Overall then, the notion of an attentional vector (i.e. an attentional bias) can provide an account for the variety of (and sometimes counterintuitive) results reported in the present thesis. Recent research shows that attentional biases in visual scenes can vary as a function of affective state (e.g. Niu, Todd, & Anderson, in press), a finding that suggests one way in which attentional biases can be flexibly applied to visual stimulation. Here, I am suggesting the bias varies as a function of cognitive task. Importantly, it is well established that attentional biases can either be a) space based or b) object based (see Logan, 1996) and these biases may share overlapping (yet also have distinct) neural underpinnings (e.g. Fink et al., 1997). The present series of results seems to suggest that the objects draw attention to different regions of space (e.g. the stimulus-response compatibility findings, as well as the P1 enhancement findings are certainly consistent with this notion), though the data or the tasks used here do not allow me to definitively suggest whether the attentional bias I am arguing for is space- or object-based (or, perhaps, both). A major goal of future research will be to determine the direction, strength, and spatial and object-based properties of attentional vectors.

6.4 CAVEATS AND FUTURE DIRECTIONS

There are a number of important general caveats of the interpretations of the present results (beyond those discussed for each individual study). I will attempt to address these here and provide directions for future investigations of embodied object representations.

First, in my experiments, I selected artifacts like tools and kitchen utensils (because they are all clearly manipulable) and animals as the non-manipulable control. Such a choice was motivated by the need for an object category that is highly non-manipulable yet directionally asymmetrical. By selecting artifacts and animals, I have introduced a number of possible confounds, including low-level visual features (contrast, number of convex vs. concave angles), and differences based on variables such as 'animacy' (i.e. whether the objects are self-directed agents), 'threat' (i.e. lions are more threatening than coffee pots), 'emotional valence' (elephants are cute but pots are not), and known differences in features like 'age of acquisition' or 'familiarity' (see Salmon et al., 2010). However, it is unlikely that such confounds underlie the naming interference/facilitation, motor potentiation, or eyetracking and P1 results of the present thesis. If such confounds were a concern, future research could explore similar paradigms using a non-object category, such as letters or numbers (as they are non-manipulable, yet directionally asymmetrical). Indeed, the potentiation, naming, and P1 paradigms are all well-suited to that type of stimulus. However, one potential confound may be of pertinent interest to future research. Though I equated my animal and artefact stimuli on average luminance, there may be differences in spatial frequencies of the object parts (e.g. the handle vs. the functional end or the head vs. the tail)[26]. Such differences could result in processing biases favouring one object feature of the object over another. This remains an important avenue for future research.

Another caveat to the interpretation of the behavioural results of Part I is that one could still argue that the animals were perceived as manipulable. I attempted to rule this argument out in the concurrent motor paradigm by rotating images in the picture-plane (which led to a reversal of the effect) and in the motor potentiation paradigm by presenting hand primes that implied manipulable or non manipulable animals (which resulted in faster decisions over all, but did not influence the direction of the effects in either artifacts or animals). In both cases, I have argued that these results suggest that the animals were not seen as manipulable. However, one could argue that my manipulations did not reduce the apparent manipulability of the animals because there is no way to reduce apparent manipulability of animals when they are presented as pictures. However, this interpretation could not explain the interference/facilitation effect observed in the concurrent motor experiments, nor could it explain the reversal of the potentiation effect in artifacts in the motor potentiation experiments. Thus, this argument is not strong.

Another caveat to the interpretations I have discussed here relates to the issue of the possibility that modality-specific simulations are weighted differently in different tasks, and the reliance of modality-specific simulations will depend on the quality of the signal. The visual paradigms used in the present thesis might have provided sufficient information to participants to successfully perform the cognitive tasks without invoking sensorimotor simulations. Ideally, one could compare performance on the types of tasks

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[26] Special thanks to Dr. Susanne Ferber for this suggestion.

used here by using different modality-specific eliciting stimuli (visual presentation of a hammer, auditory presentation of a hammer, tactile etc). However, the paradigms used in the present experiment, because they are dependant on the directional asymmetry of objects, are not well-suited to these types of comparisons. However, there is at least one manipulation that would be useful in exploring this possibility. According to this 'weighting' hypothesis, degrading the visual stimulus (for instance, by spatial filtering or masking), should induce a greater reliance on sensorimotor simulations. This technique may be used to further explore embodied predictions. Namely, the paradigms described in the present thesis could be adopted for use with degraded stimuli. Support for embodied predictions would come from results that showed category-specific effects of say squeezing a sponge, or category-specific effects on potentiation. Future research can explore this possibility[27].

An additional caveat comes from a weakness of behavioural paradigms when addressing questions about embodiment. I have argued that there is no functional role for sensorimotor simulations in object naming and have suggested that those results, along with the 'smoking gun' finding in the neuropsychological literature on apraxia—showing that apraxic patients can still name manipulable objects—challenges the strong form of the embodied hypotheses. However, in neuropsychological patients, substantial reorganization of neural systems underlying task performance, or compensatory mechanisms, may account for their intact performance. Further, there is no guarantee that

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[27] Of course, the issue of differential weighting does not necessarily account for the results in the experiments in Part 1 of the present thesis. I observed sensorimotor related effects for a category of object that should not weigh on sensorimotor simulations in any task.

the critical sensorimotor simulations I attempted to disrupt by having participants squeeze a sponge were *in fact* disrupted. A stronger approach—though considerably more intensive—is to disrupt frontoparietal activation in individual participants using transcranial magnetic stimulation (TMS; see Walsh & Cowey, 2000). With this procedure, researchers can confidently disrupt normal neural processing in relatively circumscribed regions of the frontoparietal network that are activated in response to manipulable objects but not non-manipulable objects. To really strengthen this approach, researchers could perform fMRI on individual subjects to localize the frontoparietal regions of interest on a *per subject* basis. The embodied hypothesis would predict that such disruption should impair visual cognitive tasks about manipulable objects but not non-manipulable objects. Future research should adopt these methods.

I have one final suggestion for future research. Though I think we have to abandon the strong form of the embodied hypothesis, the possibility of delineating the extent to which certain tasks are 'embodied' is worth pursuing. One ERP component that might be well suited to this pursuit is the lateralized readiness potential (LRP; see Praamstra, 2007). This potential is derived via subtraction technique, and is thought to reflect contralateral motor activity before the onset of the overt behavioural response (e.g. button press). Thus, in principle, this component can be used as an index of motor potentiation. Specifically, researchers can exploit the LRP to reveal motor simulations during a behavioural paradigm like the one used Chapter 3 (of the potentiation effect). The size of the LRP can be used as an index of the degree of motor simulation used on different trials. Animal and artifact cues can be presented centrally (oriented to the right or the left) and participants can make responses to centralized targets (say a colour judgment, or a categorization judgment of pre-target cue, i.e. a task that ensures a button press). Importantly, embodied theories would predict a) LRPs would be larger for hand-responses that are spatially congruent with the presentation of a handle and b) the size of the LRP should be related to either the latency of response or accuracy (i.e. if performance is facilitated by sensorimotor simulations). In this way, future research can explore the degree to sensorimotor simulations contribute to performance (of course, this is assuming they contribute at all).

One final point is of importance, and has broad implications. I have argued that my results do not reflect embodied object representations and simply reflect an attentional bias that depends on the task. I have also argued that my results do not fit with strong interpretation of the convergence-divergence framework. This is certainly the case on first glance, however there is at least one interpretation of the CDZ framework (Meyer & Damasio, 2003) that would actually fit with the current attentional account of my results (and therefore would point to a *type* of embodiment, though not necessarily the strong form of the embodied hypothesis I tested here). This interpretation is completely speculative and theoretical. I argued that ‘top-down’ processes influenced the attentional bias elicited by the stimuli used in this thesis. Of course, one of the strengths of Damasio’s framework is that it eliminates (or at least makes explicit) what is meant by top-down influences. In the attentional literature, the neural attentional networks are well described (e.g. Posner & Rothbart, 2007). In one description, Kastner and Ungerleider (2000) suggest that frontoparietal regions are likely responsible for biasing early visual areas (resulting in one or more of the four neural modulations discussed earlier). In this literature, the candidate cognitive process that these regions are thought to execute is ‘working memory’ (see Corbetta and Shulman, 2002). In these models, ‘working memory’ holds something like a ‘response set’ in mind, and working memory can therefore direct attentional resources. However, I will argue for an alternative interpretation of this notion. Rather than these frontoparietal regions reflecting a cognitive process best described as ‘working memory’, these regions are the higher-order convergence zones described by Damasio and represent the disposition to retroactivate modality-specific cortical simulations. In this characterization, these regions can bias simulations in modality-specific cortices (again, presumably through the four mechanisms described by, Kastner and Ungerleider (2000). What is reflected then in these regions are not sensitivities to spatial regions or object features guided by attention (that is, are not necessarily ‘attentional modulations’) but rather they reflect *embodied, modality-specific imagery*. According to this interpretation, task instructions result in particular retroactivations that favour processing of different object features or regions of space. Thus, one could argue that the heightened neural responses in response, for instance, to targets that are in the same location as a handle reflect a retroacivation of a ‘spatial image’ for that region of space, driven in part by that presence of an object handle in that location (see Chapter 5). Again, hebbian associations could underlie the spread of such activation (i.e. we often act on things we can manipulate in the regions of space that we can manipulate them in). Extending this, perhaps we are faster at responding with a hand that is compatible with the handle (in orientation judgements) or the functional end (in categorization judgments; see Chapter 3) because higher-order convergence zones, under specific task instructions, retroactivate ‘images’ of object features that ultimately facilitate processing of the stimulus and leads to a faster responding to that region of space. In this way, then, imagery (in this case in the visual cortices mapping object features and peri-personal or extra-personal space) underlies task performance.

This interpretation of Damasio's CDZ framework then does suggest that the attentional effects I report in the present thesis can be interpreted as *embodied imagery* for regions of space or object features. Though I find this idea intriguing, I understand that it might just simply be an alternative language that describes the attentional and working memory literature (i.e. a rose by any other name…). A careful consideration of the similarities of the predictions of working memory/attention models and the predictions of a CDZ framework interpretation is beyond the scope of this thesis, but is perhaps a valuable investigation for future theory on embodied simulations and their relationship to attention. At the very least I am suggesting the possibility that aspects of my visual attention may be synonymous with embodied imagery.

6.5 SUMMARY

The research presented in the present thesis argues against a strong form of the embodied hypothesis of object representations, demonstrating that sensorimotor simulations do not functionally relate to object concepts in a category-specific way, and that sensorimotor simulations are not likely manifest behaviourally. Further, I have provided some initial support for the idea that some effects of embodiment might be best explained by low-level visual attentional differences to the stimuli, without recourse to embodied object representations. Though embodied hypotheses remain seductive in their explanatory potential, and though there is a great deal of research supporting embodied hypotheses from other domains in cognitive neuroscience and psychology, research from the visual-cognitive tasks used here does not provide support for some of the critical predictions of the theory. We should not abandon embodied theories, nor should we stop pursuing embodied hypotheses, but we should not hastily accept results as demonstrations of embodiment without remaining open to other explanations, amodal or otherwise.

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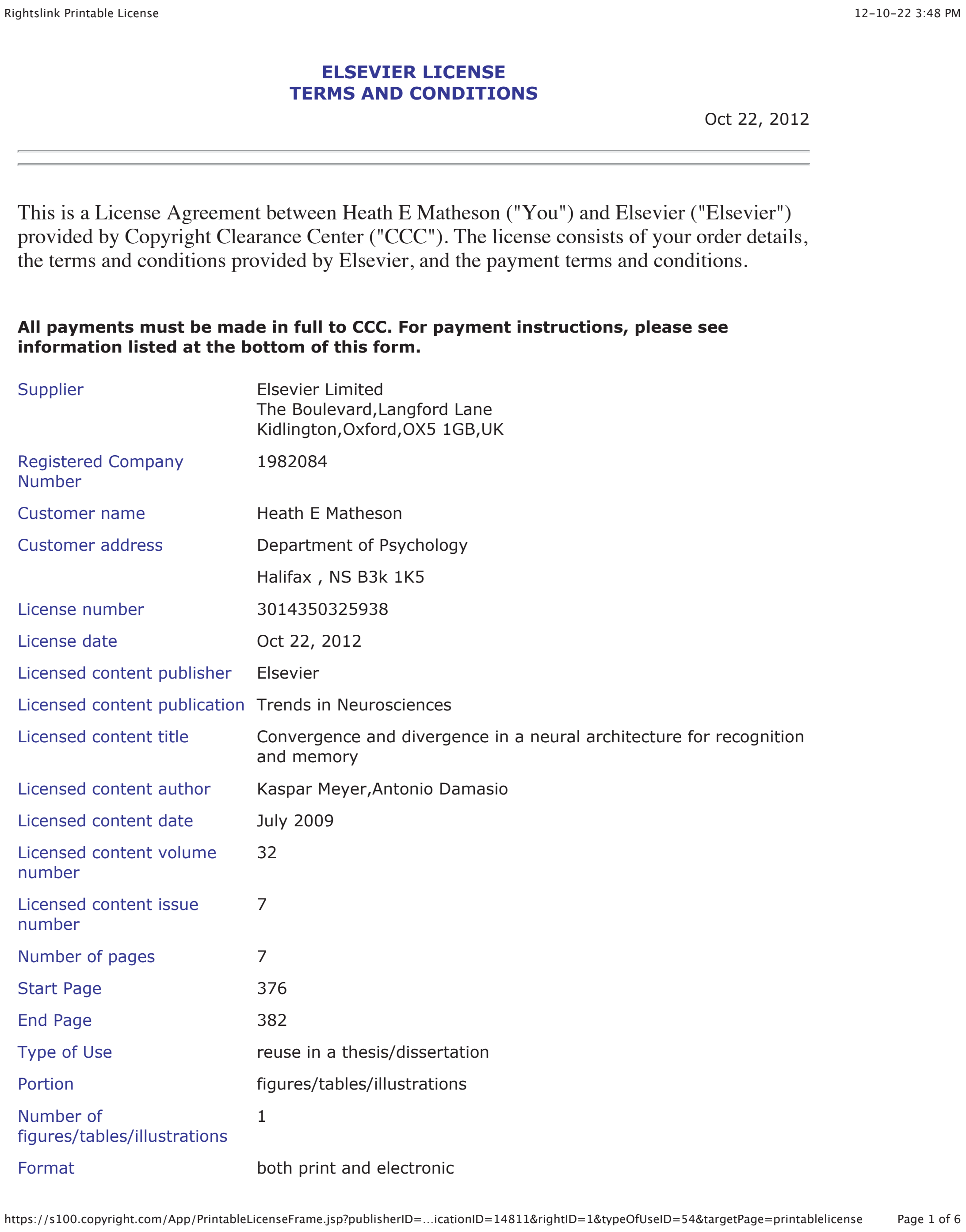

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