Language and the Hands: The Effects of the Hands on Semantic Processing

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Declaration

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Abstract

The hands are closely tied to language through their role in gestures, sign language, and the mirror neuron system for grasping. Studies within embodied cognition have found that motor resonance occurs when people observe graspable objects represented as pictures or words. This has led to questions about the influence of the hands on reading. This experiment investigated the effects of the hands on semantic processing. Participants completed a semantic categorization task and a visual task in two different postures: a proximal posture in which their hands were near the text, and a distal posture in which their hands were in their lap and out of view. It was hypothesized, in line with previous research, that semantic processing would be reduced when the hands were in the proximal posture because of a trade-off between semantic and spatial processing. To the contrary, results showed no effect from the hands on semantic processing. Response times were slower in the proximal posture condition than in the distal posture condition of the visual task. The semantic processing of tool words was faster for the proximal posture condition, but this was not significant. Results suggest that the effects of the hands on semantic processing are not robust, and that further research is necessary to clarify any influences of the hands on reading. Future experiments on a possible facilitation effect from the hands when semantically processing graspable objects would be beneficial in shedding light on the relationship between the hands and higher levels of cognition.

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Introduction

The hands and language are uniquely connected. This relationship has been observed in the gestures used by hearing individuals (Goldin-Meadow, 1999), the gestures of children during language development (Iverson & Goldin-Meadow, 2005), and in the many sign languages of the world (Corina, Vaid, & Bellugi, 1992). The discovery of a mirror neuron system for grasping (Rizzolatti & Arbib, 1998) provides evidence for the interconnectivity of the language and motor systems in the brain. This interconnectivity has become the focal point of a new viewpoint within cognitive science: embodied cognition. Motor resonances have been observed not only when people view pictures of graspable objects (Chao &Martin, 2000), but also when they view words representing objects and actions (Chao, Haxby, &Martin, 1999). If motor resonance is present when reading words, perhaps having one's hands close to words would also have an effect on reading.

The act of reading has been transformed with the advent of computers, and it is becoming more common to read with one's hands further away from the text. Despite this change, many people still report preferring to print their reading material, without a clearer reason other than "I just like to hold it" (Davoli, Du, Montana, Garverick, & Abrams, 2010). This intuitive thinking may have some merit if it serves as a cognitive advantage to have one's hands near the text. If the hands have an effect on semantic processing then it may alter our decisions regarding our preferred reading medium. A study by Davoli et al. (2010) found a reduction in semantic processing when one's hands were near to the text. The tasks in the experiment were questionable, however. Participants judged the degree of sensibleness for a number of sentences, and performed the Stroop task (Stroop, 1935) in various postures. Both of these tasks presented the possibility for confounding variables, so although Davoli et al. (2010) concluded that semantic processing is reduced when one's hands are near the text, it remains unclear if semantic processing was properly measured.

This project aims to investigate the relationship between one's hands and semantic processing through an experimental paradigm involving two tasks: a semantic categorization task and a visual task. Chapter one explains the relationship of the hands to language in the form of gesture, how the origins of language may be rooted in gesture, and the mirror neuron system for grasping. Chapter two outlines six main claims of embodied cognition and evidence for and against these claims. The third chapter describes the application of embodied cognition to studies on vision and language. Chapter four outlines research on

vision and the hands, and the experiments by Davoli et al. (2010). The experimental design is described in chapter five, and the results are presented in chapter six. Chapter seven contains a discussion of the results, an evaluation of the experimental design, ideas for future research, and the conclusion.

Chapter One

Gesture and the Origins of Language

1.1. Gesturing in Humans

Gestures are a universal human phenomenon. They accompany speech, occur in early childhood, and are a vital form of communication for those with impaired hearing. Goldin-Meadow (1999) discussed two forms of gesture: gestures that substitute for speech and gestures made by speakers. Gestures that substitute for speech include "emblems," such as making the "okay" sign by putting one's thumb and index finger together. Emblems are communicative; the individual making them has a communicative intention with the sign that is independent from speech. There are also full sign languages such as ASL (American Sign Language) that are structured at morphological, syntactical, and phonological levels and show left hemisphere dominance in the same way as spoken languages (Goldin-Meadow, 1999, p. 420). Goldin-Meadow (1999) proposed that gestural communication uses grammatical structure only when it must bear the full burden of communication. Gestures that accompany speech are generally assumed to reflect the speaker's emotions and feelings. Gestures play a role in speech production even when the gestures are not visible to the speaker or the listener, as it has been shown that blind individuals gesture, as do speakers when talking on the phone (Fischer & Zwaan, 2008).

There are two important questions to answer regarding gestures that accompany speech: do they communicate the same thing to different addressees, and does the gesture communicate what it was intended to communicate? Gestures accompanying conversation, narratives, explanations, and descriptions of objects and actions have all been assigned the same meaning by many different independent observers (Goldin-Meadow, 1999, p. 421). An experiment by Garber, Alibali, and Goldin-Meadow (1998) asked children to explain their solution to a set of math problems and identified procedures in their solutions that were only conveyed through gesture during the child's explanations. The children later assessed the procedure on a rating task that did not involve any gesturing. Children rated solutions derived from the procedures they conveyed using gestures as more "acceptable" than solutions derived from procedures they did not convey. This experiment showed that gesture is a vehicle for expressing knowledge, and that this knowledge is accessible in other tasks that do not involve gesture and are not tied to the hands.

Goldin-Meadow (1999) discussed that sign languages differ from spoken languages in one important feature: they are spatially expressed. This distinction could mean that sign languages are processed differently in the brain than spoken languages. Spoken language is generally considered to be processed primarily in the left hemisphere, whereas spatial processing generally occurs in the right hemisphere. When an individual has a lesion in the left hemisphere, spoken language functioning is often impaired. If there is a lesion in the right hemisphere, it is often spatial processing that suffers. To investigate whether sign language was in a similar area in the brain, experimenters observed if there were the same deficits in signers when they had brain lesions. They found that when brain lesions were in the left hemisphere, signers showed language deficits, and when brain lesions were in the right hemisphere, they had spatial deficits. The results matched what was found for speaking individuals, and support the theory that signing is processed as linguistic information rather than spatial information (Goldin-Meadow, 1999, p. 420). Emblems and uncommunicative hand movements were not processed in the left hemisphere by either signers or speakers, implying that signs that are organized around linguistic principles are processed in a way more similar to language. Gestures which form part of an expression of a larger meaning therefore depend essentially on left hemisphere mechanisms (Arbib, 2005, p. 160).

Young children gesture before they produce speech, and production of gesture-plus-word combinations (such as pointing at a cup while saying the word “cup”) tend to precede two-word combinations (Iverson & Goldin-Meadow, 2005). Iverson and Goldin-Meadow (2005) explored whether the gestures children use to refer to specific objects are related to the emergence of verbal labels for objects and whether the production of gesture-plus-word combinations has a relation to the emergence of two-word utterances (p. 367). They studied ten children making the transition from one-word to two-word utterances and found that many of the lexical items the children produced in gesture first quickly became part of their verbal lexicon. Also, children that were first to create gesture-plus-word combinations were first to create two-word combinations. These observations revealed that changes in gesture not only predate language but also predict changes in language. Gesture, therefore, plays a crucial role in language development.

1.2. Gestural Origins of Language Evolution

It has been hypothesized that the emergence of language came at some point about 50,000 years ago at the same time of the first archaeological discoveries of art and burial

rituals (Arbib, 2005). Arbib (2005) argues that *Homo sapiens* were "language ready" and that language formed as a way for humans to transfer skills needed to master human technology. Once the human brain was "language ready," humans transferred skills and information through cultural transmission, which works on time scales many orders of magnitude faster than organic evolution (Tomasello, 1999, p. 4). If this is the case, how did humans evolve a "language ready" brain? Arbib (2005) promotes the hypothesis that a form of "protosign" provided essential scaffolding for the emergence of "protospeech." Arbib (2005) argues that during the biological and cultural evolution along the hominid line, advances were made to both protosign and protospeech and that they fed off of each other in an expanding spiral. As a result of this interaction, protosign was not able to achieve the status of a full language prior to the emergence of early forms of protospeech (Arbib, 2005, p. 148).

1.2.1. Definitions of Protolanguage

Arbib (2005) defines "protosign" as protolanguage communicated primarily through manual and facial gestures, and "protospeech" as protolanguage communicated primarily though vocal gestures. Arbib's (2005) notion of protolanguage differs from the definition given by Bickerton (1995). Bickerton (1995) defines protolanguage as a form of communication that is made up of utterances with a few lexical items but without syntactic structure. The definition can be applied to pidgins, infant language, and "languages" taught to apes (Arbib, 2005, p. 148). Bickerton (1995) proposed a hypothesis of language evolution in which *Homo erectus* spoke a form of protolanguage and that the evolution of Universal Grammar caused protolanguage to evolve into language. Contrary to Bickerton (1995), Arbib (2005) believes that the human brain was "language ready" and that language evolved holistically in that the protolanguage spoken by humans began as unitary utterances that would be expressed with a number of words if it were translated into modern-day language. Syntax and words evolved culturally according to Arbib (2005) through a process called fractionation. During fractionation the larger utterances of protolanguage were replaced by semantically smaller units, and grammatical rules emerged to help clarify the structure.

1.2.2. The Mirror System Hypothesis

Arbib (2005) proposed a Mirror System Hypothesis based on experimental findings that a mirror system in area F5 of the macaque premotor cortex links observation and

execution of manual actions (p. 149). The F5 area is homologous to the Broca's area of the human brain. The Mirror System Hypothesis states that the parity requirement, or what counts for the speaker must count in relatively the same way for the hearer, is met because the Broca's area evolved on top of a mirror system for grasping with its capacity to generate and recognize a set of actions (Arbib, 2005, p. 149). The processes concerning the production of word sounds is located primarily in the Broca's area in the brain, whereas processes concerning the recognition of word sounds is located primarily in the Wernicke's area (Arbib, 2005). Arbib (2005) notes that despite the hypothesis being Broca's-centric, there are interactions between several areas within the brain in the monkey including between the parietal (PF), temporal (STS), and premotor (F5) and that these findings "provide an evolutionary basis for the integration of Wernike's area, STS and Broca's area in the human" (p. 150). The Mirror System Hypothesis uses neurological findings to support the claim that hand movements were fundamental for the evolution of language.

Arbib (2005) defined seven stages of the evolution of language to explain how the mirror system for grasping observed in monkeys could be central to the evolution to human language (Arbib, 2005, p.150):

Stage 1: Grasping.
Stage 2: A mirror system for grasping shared with the common ancestor of human and monkey.
Stage 3: A simple imitation system for grasping shared with common ancestor of human and chimpanzee.
Stage 4: A complex imitation system for grasping.
Stage 5: *Protosign*, a manual-based communication system, breaking through the fixed repertoire of primate vocalizations to yield an open repertoire.
Stage 6: *Protospeech*, resulting from the ability of control mechanisms evolved for protosign coming to control the vocal apparatus with increasing flexibility.
Stage 7: *Language:* the change from action-object frames to verb-argument structures to syntax and semantics; the historical (rather than biological) co-evolution of cognitive and linguistic complexity.

The evolution from a simple system for grasping to the development of imitation is important in explaining advanced communication systems such as language because imitation is a uniquely human ability. It is generally accepted that monkeys have a very limited

capacity for imitation, though further study is still needed (Arbib, 2003). Apes are, however, adept at tool use (Mulcahy & Call, 2006; Tomasello, 1999; Breuer, Ndoundou-Hockemba, & Fishlock, 2006). Although chimpanzees (and likely the other ape species as well) are very good at learning about the dynamic affordances of objects, they are not very good at learning a new behavioral strategy from others (Tomasello, 1999). Whereas human children will imitate an adult even if their method is less efficient at achieving a goal, a chimpanzee will ignore any demonstration and attempt the route they see as most efficient (Nagell, Olguin, and Tomasello, 1993).

The form of imitative learning observed in children is important for the cultural transmission of information (Tomasello, 1999). The development of a complex imitation system for hand movements may have been adaptive in supporting an increased transfer of manual skills and therefore likely preceded the evolution of protolanguage in whatever modality (Arbib, 2005, p.157). According to Arbib (2005), "protosign exploits the ability for complex imitation of hand movements in order to adapt this imitation to the needs of communication, and that the resulting protosign provides scaffolding for protospeech but that both develop together thereafter" (p. 158).

1.3. Mirror Neurons

Mirror neurons were first discovered in the monkey brain (Rizzolatti & Arbib, 1998). These neurons discharged not only when monkeys performed the action of grasping an object, but also when they observed a human or other monkey grasping an object. Mirror neurons discharged only when the monkey observed another individual reaching for an object, but not when the individual was making the same movement with no object present. This 'observation/execution matching system' is referred to by Arbib (2003) as the *mirror system for grasping.* The mirror neurons that discharged in the monkey brain were located in area F5, the rostral part of the monkey ventral premotor cortex (Rizzolatti & Arbib, 1998). This area is the monkey homolog of Broca's area in the human brain. Broca's area is an important language area of the brain, especially for speech. Lesions in this area lead to Broca's Aphasia. Positron emission tomography (PET) data has revealed that Broca's area also becomes active during the execution of hand and arm movements, during mental imagery of hand grasping movement, and during tasks involving hand-mental rotations (Rizzolatti & Arbib, 1998).

Rizzolatti et al. (1996) conducted a study to determine if there were mirror neurons in the human brain that also discharged when grasping an object or observing another person grasping an object. They compared three experimental conditions: object observation (control condition); grasping observation (participant observed someone else grasp an object); and object prehension (the participant grasped the object). They found that in humans the Broca's region was activated in both the execution and observation of grasping. This overlap of the language centers of the brain and the location of mirror neurons for grasping supports the theory proposed by Arbib (2003) that the capacity for language may have evolved out of this original mirror system for grasping. Both the F5 and Broca's areas have neural structures that control oro-laryngeal, oro-facial, and brachio-manual movements, and they both are endowed with mechanisms that link action perception and action production (Rizzolatti & Arbib, 1998, p. 192). A manual gestural system may have evolved out of exploiting this mirror system for grasping, and paved the way for an open vocalization system now known as speech (Rizzolatti & Arbib, 1998).

The fact that part of the mirror system is located in a speech area may also provide a mechanism mediating motor resonance in reading (Fischer & Zwaan, 2008, pp 830-831). Mirror neurons still discharge even when there is some degree of abstraction away from visually given information. For example, mirror neurons are activated by actions towards hidden objects as long as the monkey knows that they are present (Fischer & Zwaan, 2008, p. 829). Mirror neurons in the monkey generally respond only to transitive (object-related) acts but not intransitive (gestural) acts (Corballis, 2010, p. 25). Humans, in contrast, have mirror neurons that respond both to transitive and intransitive acts, which may have evolved as a way to comprehend symbolic acts as well as those that are object-related (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995). Even static images that only implied an action triggered mirror neurons in humans (Fischer & Zwaan, 2008). A study by Nishitani and Hari (2002) found that watching photographs of a person adopting different lip postures triggered a series of activation in successive processing stages in the brains of viewers. These activations were very similar for both the passive viewing and active imitation conditions (Fischer & Zwaan, 2008).

Buccino et al. (2005) discovered that mirror neuron resonance for oral communication in humans is limited to conspecifics. Participants in the study viewed videos of different animals performing mouth-related actions: humans lip-reading, monkeys lip smacking, and dogs barking. They found an overall reduction of brain activity in the frontal operculum with the most activation occurring when viewing humans, decreased activation when viewing

monkeys, and no activation when viewing dogs. It seems, therefore, that mirror neurons are active only when an observer is able to match the observed action with his or her own action repertoire[1].

The discovery of mirror neurons provides evidence that our hands, and body, may play an important role in higher levels of cognition, from imitation to language. This discovery has led to broader research on the relationship between the body and higher cognitive processes. These new areas of research are centered on the concept of embodied cognition.

[1] Calvo-Merino, Glaser, Grèzes, Passingham, and Haggard (2005) found higher levels of motor area brain activity in dancers when they observed movements that were part of their dance repertoire. Further research by Cross, Hamilton, and Grafton (2007) found a positive correlation between perceived motor expertise and activation in brain areas involved in both action observation and simulation in participants trained to perform novel dance moves.

Chapter Two

Embodied Cognition

2.1. A New Viewpoint

Traditionally within cognitive science the mind has been viewed as an abstract information processor. The mind's connection to the outside world has been seen as having little theoretical importance (Wilson, 2002). It was not considered relevant to study perceptual and motor systems to understand central cognitive processes (Wilson, 2002, p. 625). Experiments tended to limit sensory and motor processing in order to isolate central cognitive processes of interest (Fischer & Zwaan, 2008). Recent studies of the influence of motor activity on higher level cognition gained much attention in a research community interested in a broader understanding of human cognition. This research presented the possibility that language comprehension may involve or be influenced by components of the motor system. These components, known as "motor resonances" may even be required for language to function properly (Fischer & Zwaan, 2008). A notion central to the idea of embodied cognition is that cognition is *grounded* in perception and action. The viewpoint of embodied cognition states that cognitive processes have their roots in the body's interactions with the world (Wilson, 2002, p. 265). Both the perceptual processes that feed into cognition and the actions selected by and guided through cognition are essential to our understanding of cognition as a whole (Fischer & Zwaan, 2008).

2.2. The Six Claims of Embodied Cognition

Wilson (2002) distinguished six claims made by researchers regarding embodied cognition. Some of the six claims are more controversial than others. This chapter draws heavily from Wilson's (2002) review of the main views of embodied cognition.

2.2.1. Claim 1: Cognition is Situated

The claim that cognition is situated is the idea that cognitive activity takes place within the context of a real-world environment, and therefore inherently involves both perception and action (Wilson, 2002, p. 626). Wilson (2002) states that *situated cognition* is cognition that occurs in the context of task-relevant inputs and outputs. During cognitive processing, perceptual information and motor activity continues to affect processing and the

environment in ways that are task-relevant. Some examples of situated cognition are driving, holding a conversation, or walking around a room imagining how to reposition the furniture (Wilson, 2002, p. 626). These are examples of "on-line" cognition, because there is task-relevant input and output involved. "Off-line" refers to cognition that takes place in the absence of task-relevant input and output, and is therefore not situated. Examples of non-situated cognition are planning, remembering, and day-dreaming within contexts that are not directly relevant to plans, memories, or day-dreams (Wilson, 2002, p. 626).

A common argument is that situated cognition played an important role in our evolutionary history (Wilson, 2002). This argument states that before civilization, the survival value of mental abilities was based on the usefulness of these abilities in situations that demanded immediate responses, such as avoiding predators and obtaining food. According to Wilson (2002), this argument tends to overlook the importance of off-line cognition for our survival, and it may overemphasize the importance of on-line cognition. For example, hunting for food came later in human evolution. Before hunting, humans mostly relied on gathering for food. The act of gathering food would likely involve off-line cognition because it would involve remembering the terrain and the impact of the weather. Situated cognition would be useful during the actual act of gathering, but whether it would be necessary to have more advanced abilities than any foraging animal is questionable. Skills for avoiding predators such as the fight-or-flight response are ubiquitous among animal species, so it remains unclear how much extra benefit situated cognition would have provided for humans that would distinguish them significantly from other animals. It is likely that off-line preventative and communication measures were increasingly used by humans to avoid predators. Wilson (2002) argues that focusing too much on situated cognition could detract from these species-defining features of human cognition.

Barsalou (1999a) argues that language was originally used by early humans for immediate, situated, indexical purposes. Language could have been used to describe where prey was found, procedures for hunting them, and assigning hunting roles (Barsalou, 1999a, p. 65). Barsalou (1999a) states that even information about the past or future, such as describing good hunting terrain, is still related to situated uses of language because it could become relevant on later occasions. For example, if an adult described the location of a cave to a child it may not have immediate use, but perhaps on a different occasion the child may need to seek shelter from a storm and remember the cave. In this situation, the stored information serves situated action (Barsalou, 1999a, p. 66).

Wilson (2002) argues that some of the examples of situated language given by Barsalou (1999a), such as relaying hunting terrain information, are not actually examples of situated uses of language. In fact, although the example of providing information to a child about a cave could become useful in a situated circumstance, it is not a situated use of language in itself. According to Wilson (2002), off-line functions of language were likely also used early on in human evolution. Some examples of early off-line functions of language could include: absorbing parental edicts about avoiding certain behaviors, deciding on a planned activity such as going to the river to cool off, and remembering instructions for materials to fetch for tool manufacturing (Wilson, 2002, p. 627). Once the representational capacity of language emerged, one would expect that the full capacity of language—both situated and non-situated use—would be utilized. The claim for the centrality of situated cognition is not strongly persuasive, Wilson (2002) argues, due to the vast number of exceptions that are equally important to the understanding of human cognition.

2.2.2. Claim 2: Cognition is Time Pressured

According to Wilson (2002), the claim that cognition is time pressured is based on the observation that situated cognition must cope in "real time." In contrast to traditional artificial intelligence models which generally build up and manipulate internal representations of a situation without any time pressure, an animal in a real environment does not have this luxury. Rather, an animal must cope with predators, prey, terrain and objects in its environment as quickly as possible in order to survive. Time pressure is thought to be important to cognition because it causes a "representational bottleneck." In a time-pressured environment, it may not be possible to build up a complete mental model of the environment. Instead it could require the organism to use cheap and efficient tricks for generating situation-appropriate action on the spot. This compromise that the organism must make could have far-reaching consequences for cognitive architecture (Wilson, 2002, p. 628). Wilson (2002) states that the force of this argument rests upon the assumption that animals and humans have evolved so that they can overcome this representational bottleneck and are capable of functioning "normally" in time-pressured situations (p. 628). However, many times humans are not successful in coping with the representational bottleneck. The vast majority of our daily tasks are not time pressured, and it is only certain specific tasks, such as changing lanes in heavy traffic, that involve the representational bottleneck. Despite this fact, there are still many domains, such as perceptuomotor coordination, that function in "real time." Skilled

hand movements, such as the manipulation of objects in the environment, are an example of a time-locked perceptuomotor activity (Wilson, 2002, p. 628). Nevertheless, it is hard to generalize that all forms of cognition are time pressured.

2.2.3. Claim 3: Cognitive Work is Off-Loaded to the Environment

This claim states that we tend to exploit the environment in order to reduce cognitive workload due to limits on our information-processing abilities (Wilson, 2002). Although we use off-line cognition, sometimes we are forced to function on-line. Wilson (2002) describes two types of strategies used to cope with the representational bottleneck. The first is relying on preloaded representations that were acquired through prior learning. In the case of novel tasks, cognitive workload can be reduced by using the environment itself in strategic ways rather than fully encoding it. This strategy also includes using *epistemic actions* to change the environment to reduce the remaining cognitive workload. These strategies are used not only in time pressure situations but also for tasks that can be taxing for attention and working memory. Off-loading seems to be particularly useful for spatial tasks, but it can also apply to a wide range of different cognitive tasks, such as doing math with a pencil and paper and counting on one's fingers. In these situations, the cognitive system is exploiting environmental resources to gain knowledge that will be useful at a later time, if at all. Symbolic off-loading on to the environment does not need to be formalized and can even be applied to gesturing while speaking. Research has shown that gesturing while speaking helps the thought process of the speaker, besides being communicative (Goldin-Meadow, 1999).

2.2.4. Claim 4: The Environment is Part of the Cognitive System

The claim that the environment is part of the cognitive system is based on the insight that the body and environment play a role in assisting cognitive processing (Wilson, 2002, p. 629). The viewpoint is that cognition is not merely a mind activity but instead is distributed across the mind, body, and environment. It is therefore necessary to not just study the individual, but the situation as well, as a single, unified system. According to Wilson (2002), a system is defined as a collection of elements that stand in some relation to one another, and these elements must have properties that are affected by their participation in a system. An example would be the automobile, in which the individual parts help make the whole. There can also be open systems, such as the solar system, in which a part such as the sun can be

looked at individually and as one element of a system. Therefore the definition of a system is largely dependent on one's analysis.

A system is defined by organization, or the functional relations among its elements. Systems are either *facultative* or *obligate.* Those that are facultative are temporary systems that are organized briefly and disbanded readily. Obligate systems are, for the most part, permanent systems in regards to the lifetime of their parts. If the environment is to be included in a cognitive system, then the elements of the system would change in each new situation, constituting a facultative system. New facultative systems would have to occur for each new situation that a person encounters throughout each day. The cognitive architecture of an individual mind, however, would be considered an obligate system, since the different components of the brain retain their functional roles over time. Although the mind is open in regards to its environment, it does not compromise the mind's status as a system any more than it would compromise the status of a hydrogen atom or ecosystem. Thus, according to Wilson (2002), the claim that the environment is also part of the cognitive system does not hold up.

2.2.5. Claim 5: Cognition is for Action

This claim states that the main function of the mind is to guide action, and that perception and memory must be studied in light of their contribution to situation-appropriate behavior (Wilson, 2002, p. 626). This claim has gained support from research on perception and memory. In studies on vision, the ventral visual pathway has traditionally been viewed as the "what" pathway because it generates representations of object structure. The dorsal visual pathway has been viewed as the "where" pathway traditionally, because it generates representations of spatial relationships. However, more recently it has been argued that the dorsal stream should be thought of as a "how" pathway, because its proposed function is to serve visually guided actions such as reaching and grasping (Wilson, 2002, p. 631). Some support has been found for this claim in studies that demonstrate that visual input can prime motor activity. One study by Craighero, Fadiga, Umiltà, and Rizzolatti (1996) found that viewing a rectangle of a particular orientation provided performance facilitation on a subsequent grasping task if the objects being grasped shared the same orientation[2]. The discovery of neurons in the brains of monkeys that discharge when observing tools (Rizzolatti, Fadiga, Fogassi, & Gallese, 1996) is also supportive of the claim that "vision has

[2] A priming effect was found even when the orientation of the rectangle did not predict the orientation of the object to be grasped (Wilson, 2002).

its evolutionary rationale rooted in improved motor control" (Churchland, Ramachandran, & Sjenowski, 1994, p. 25). Researchers studying the processes of memory storage have also proposed that memory should be viewed as "encoding patterns of possible physical interaction with a three-dimensional world" (Glenberg, 1997, p. 1). This viewpoint on memory may help to explain formal and informal observations that we conceptualize objects and situations in terms of their functional relevance, rather than neutrally or objectively (Wilson, 2002).

Despite these studies and observations, there are many more situations in which vision and memory do not have an obvious link to the motor system. Wilson (2002) states that visual events such as viewing sunsets, observing human faces, and reading are all examples of visual situations in which there is almost non-existent physical interaction. Some broader functions of memory are also not easily encompassed in the claim that their main function is to guide action. For example, mental concepts (such as the knowledge that a mutilated dollar bill is still a dollar bill but a counterfeit one is not) "do not always or even usually follow physical concrete properties that lend themselves to action, but instead often involve intangible properties based on folk-scientific theories or knowledge of causal history" (Wilson, 2002, p.632). Although mental representations can be incomplete and sketchy, especially when only given brief exposure to a novel object or situation, humans are able to build up strong mental representations if given time and exposure. Wilson (2002) therefore concludes that our mental representations are largely purpose-neutral, based on the fact that they tend to contain information beyond what was needed for their originally conceived purpose. This is arguably an adaptive cognitive strategy, because it provides "an enormous advantage in problem-solving flexibility over a creature that encodes purely in terms of presently foreseeable activities" (Wilson, 2002, p. 632).

2.2.6. Claim 6: Off-Line Cognition Is Body Based

The last main claim used by proponents of the theory of embodied cognition is that even with decoupling from the environment, the activity of the mind is grounded in mechanisms that evolved for interaction with the environment (Wilson, 2002). Those mechanisms are sensory processing and motor control. Wilson (2002) states that many abstract cognitive processes utilize mental structures originally evolved for perception and action. These mental structures are co-opted to run off-line, decoupled from their original purpose, to help with abstract thought. Evidence for this occurring has appeared in research

on many different aspects of higher-level cognition. Studies on mental imagery have found that mental imagery uses "analogue representations that functionally preserve spatial and other properties of the external world, rather than consisting of bundles of propositions" (Wilson, 2002, p. 633).

The use of sensory and motor control mechanisms in memory processes have been observed in studies on working memory, episodic memory, and implicit memory. In working memory, effects have been observed on phonological similarity (worse memory for words that sound alike), articulatory suppression (worse memory if the relevant articulatory muscles are kept busy with another activity such as repeating a nonsense word), and word length (worse memory for long words) (Wilson, 2002, p. 633). Some interesting studies by Wilson and Emmorey (1997, 1998) found that similar effects but with a different sensorimotor modality have been observed in deaf subjects when using sign language. They found that performance drops when participants must perform a repetitive movement with their hands while trying to remember signs, or when the signs they must remember have similar hand shapes or are temporally long. Speech perception and production areas of the brain are also involved during working memory rehearsal (Wilson, 2001). It seems, therefore, that working memory performs a form of off-loading on to the "environment" as discussed earlier in the third claim, but in these cases working memory does not off-load onto the environment itself, but instead onto systems that interact with the environment: the perceptual and motor control systems of the brain (Wilson, 2002).

Studies in episodic memory have also shown that long-term memory has links to our body's interactions with the world (Wilson, 2002). For example, episodic memories contain records of spatiotemporally localized events, as experienced by the person remembering them. When memories are fresh in one's mind, there is a quality of "reliving" in which the visual, kinesthetic, and spatial impressions are recalled. Implicit memory also seems to be embodied. Implicit memory is the way in which skills are learned, to the point that they become automatic, when previously they required attention and effort. Wilson (2002) explains that in a sense, implicit memory can be seen as off-loading some of the problems that confront the situated cognizer. Once skills are automatized, the cognitive load is reduced, circumventing the representational bottleneck. Highly automatized tasks allow for more opportunities for fine-tuned control of action, as well as more robust and stable internal representations of the situation (Wilson, 2002, p. 634).

Studies have also shown that reasoning and problem-solving heavily use sensorimotor stimulation. According to Wilson (2002), problem solving is improved with the help of

mental models. Within the field of cognitive linguistics, a new approach is emerging in contrast with the formal and abstract syntactic structures of traditional theories (e.g., Langacker, 1987, 1991; Talmy, 2000). The approach posits that syntax is deeply tied to semantics. This relationship between syntax and semantics is due in part to "*image schemas* that represent embodied knowledge of the physical world" (Wilson, 2002, p. 634). Within an image schema, perceptual principles such as attentional focus and figure/ground segregation are used as a way to encode grammatical relations between different items.

Another example of embodied cognition within reasoning and problem-solving is an embodied approach to explaining mental concepts. Although it is problematic to explain mental concepts purely by sensorimotor patterns, Wilson (2002) explains that it is possible that mental concepts have been built up out of cognitive primitives that are sensorimotor in nature (see Barsalou, 1999b; Lakoff & Johnson, 1980, 1999). Lastly, Wilson (2002) proposes that motoric simulation may play a role in representing and understanding the behavior of conspecifics. The mental simulation of something that is imitatible "can be mapped isomorphically onto one's own body" (Wilson, 2002, p. 634). This is seen in research on mirror neurons (Arbib, 2003) and is important for predicting, imitating, and understanding the behavior of other conspecifics.

These claims show that embodied cognition does not represent one viewpoint, but instead a number of different views, each with their own problems and merits. Certain claims have been readily applied to research on vision and language, both of which play an important role in this current study.

Chapter Three

Embodied Cognition in Vision and Language

3.1. Embodied Cognition Claims for Vision and Language

The theory of embodied cognition has been applied to research on vision and sensorimotor interactions. Relationships between language and the sensorimotor system have been found, providing support for the embodiment of language. These studies have supported many of the common embodied cognition claims; most commonly the first claim, that cognition is situated, and the sixth claim, that off-line cognition is body-based. Situated cognition can be observed in studies of affordance effects and motor resonance for action observation. The sixth claim, that off-line cognition is grounded in interactions with the environment, can be observed in studies of motor resonance and language comprehension. Motor resonance has also been observed in studies on lexical access. The empirical evidence for embodied cognition is mounting, and research within vision and language is revealing an overlap with the motor and premotor systems.

3.2. Mechanisms of Action Simulation

There are two candidate mechanisms involved in action simulation: the computation of affordances during object recognition and motor resonance during action observation (Fischer & Zwaan, 2008, p. 831). Studies have found an interaction between these mechanisms and language comprehension. Affordances are defined as "a feature of an object with the power to elicit some form of mental representation for action with a perceiver" (Phillips & Ward, 2002, p. 541). Phillips and Ward (2002) conducted a study to measure whether the action representation evoked by viewing a visual affordance causes a specific motor response bias for the limb that is most suited to perform the afforded action (p. 555). Participants had to respond with speeded left-right button presses in response to an imperative target superimposed onto a prime image of an object that suggested a visual affordance that was either oriented to left or right visual space. An example of a prime image used was a frying pan with the handle facing to the left or the right. They found corresponding effects between the suggested affordance of the prime and the side of response. They found little effect of modality (hands uncrossed, hands crossed, or foot response). These findings suggest that the motor system uses object information to compute

possible actions based on one's current posture in order to select favorable responses (Fischer & Zwaan, 2008, p. 831).

Flanagan and Johansson (2003) tested the hypothesis that action understanding is a result of a mechanism that maps an observed action onto motor representations of that action (p. 769). One way to test this hypothesis was to have participants observe a block stacking task and to record their gaze and hand movements. Task-specific proactive eye movements have been found to be crucial for control and planning when performing visually guided actions. The direct matching hypothesis predicts that participants will make the same eye movements when observing visually guided actions as they do when performing those actions. Flanagan and Johansson (2003) found that when participants observed block stacking, the coordination between the block-stacker's hand and their gaze was predictive rather than reactive, and it was highly similar to the gaze-hand coordination when they themselves perform the task. The results supported the direct matching hypothesis because they indicate that participants implement eye motor programs directed by motor representations of manual actions during action observation (Flanagan & Johansson, 2003, p. 769). The results are also in line with predictive coding and forward models of cognition (Friston, 2010; Grush, 2004).

3.3. Motor Processes and Language Comprehension

Fischer and Zwaan (2008) explain that there are two types of motor resonance that can occur during language comprehension. The first type, *communicative motor resonance,* occurs when the motor system responds to the communicative act itself. An example of *communicative motor resonance* would be a listener's speech motor system responding to hearing the word "kick," because the motor system is simulating the speech production of the utterance. The second type is known as *referential motor resonance,* and it occurs "when the motor system responds to the content of the communication" (Fischer & Zwaan, 2008, p. 837). An example of this type would be when the listener's leg area of the premotor cortex responds to hearing the word "kick." In this example the motor system is simulating the action described by the utterance instead of the production of the utterance itself. Fischer and Zwaan (2008) speculate that the *communicative resonance* is helpful in anticipating what the speaker is going to say next, and *referential resonance* is helpful in informing the comprehender about what is going to happen next in the described situation. Both of these forms of motor resonance play a role in language comprehension.

Communicative resonance occurs most obviously in phonological processing. A study by Fadiga, Craighero, Buccino, and Rizzolatti (2002) found that muscle evoked potentials (MEPs) measured from muscles were significantly larger for Italian participants when they listened to pseudowords that contained a tongue-trilled double-r sound than when they listened to pseudowords that contained a non-trilled double-f sound. The results showed that listening to linguistic information activates speech production motor resonances. The finding that MEPs are significantly larger when participants listen to linguistic information requiring tongue movement during production is an example of *communicative motor resonance.*

3.4. Motor Resonance and Lexical Access

The other form of motor resonance, *referential motor resonance,* is more relevant for this experiment and for the vast majority of studies on motor resonance and lexical access. Studies have shown that reading single words can evoke motor representations. Research by Gentilucci, Benuzzi, Bertolani, Daprati, and Gangitano (2000) found that visuo-motor transformation was influenced by automatic word reading. For the first two experiments, participants grasped an object that was either near or far from the participant and was labeled either the Italian word "VICINO" (near) or "LONTAN" (far). During further experiments participants grasped a small or large object labeled with the words "PICCOLO" (small) or "GRANDE" (large), and a high or low object labeled with the words "ALTO" (high) or "BASSO" (low). The meaning of the printed words affected the kinematics of the initial phase of reaching-grasping. For example, the maximum grip aperture was larger for objects with the word "GRANDE" (large) printed on them than for objects with the word "PICCOLO" (small) printed on them. Participants automatically associated the meaning of the word with the corresponding property of the object and their reach and/or grasp program was influenced by the word (Gentilucci et al., 2000, p. 468)[3].

In a further experiment they replaced the adjectives with adverbs[4]. They found that the adjectives had a larger influence on visual analysis of the target object properties, whereas adverbs had a more direct influence on the control of the action. Gentilucci et al. (2000) observed that these effects resembled the structure of a sentence in that adjectives often refer

[3] They did not find this effect in the control experiment that used word meanings that corresponded to a property of the object indirectly involved in reach control (the object's color).

[4] "ALTO" (high) and "BASSO" (low) were replaced with Italian adverbs "SOPRA" (up) and "SOTTO" (down).

to nouns, and adverbs often refer to verbs. Thus, the word class, and even in a broad sense grammar, has an influence on motor control. According to Gentilucci et al. (2000), previous neurophysiological and neuropsychological research indicates that Broca's area in the brain is involved in analysis of grammar rules. The involvement of Broca's area in both language and the mirror system for grasping could help to explain the results of the Gentilucci et al. (2000) study. Gentilucci et al. (2000) hypothesized that, during the task in their study, the process of visuo-motor transformation for reaching and/or grasping an object caused the activation of an automatic process of reading and internal repetition of the words printed on the objects. This could be represented as "simultaneous activation of processes of transformation of visual information into motor commands for both hand and mouth" (Gentilucci et al., 2000, p. 489). Then, a visual analysis of the target object could be inferred by a semantic analysis of the word.

Glover (2004) sought to further understand the effects of words on action throughout the course of movement; testing specifically the planning-control model regarding semantic effects (p. 15). The planning-control model proposed by Glover (2004) states that there are two different overlapping systems involved in the process of selecting and executing body movements. The model predicts that prior to the movement's initiation, a motor program is selected based on many cognitive factors including a "planning" system in the inferior parietal lobe. During the execution of the movement, the action becomes increasingly under the control of a different system, the "control" system, using a "limited but quickly updated visual representation in the super parietal lobe" (Glover, 2004, p. 3). According to the planning-control model, cognitive processes such as semantics should affect how a movement is planned, but not how the movement is controlled on-line. If it is the case that the effect observed by Gentilucci et al. (2000) is due to an semantic influence on planning, then one would expect to find a the largest effect early in the movement but a decrease in effect as the hand approaches the target. Glover (2004) conducted a similar study using the English words "LARGE" and "SMALL" and measured the grip aperture early in the reach for objects and later in the reach for objects. They found participants had stronger grip aperture in the reach for objects on which "LARGE" was printed compared to objects labeled "SMALL" but that these effects faded as the hand approached the object (Glover, 2004). In another experiment, Glover (2004) found that the same effect could be obtained if the participants read a word and then grasped an object. Words represented either relatively large objects such as "APPLE" or "BASEBALL" or relatively smaller objects such as "GRAPE" or "PEA." Participants had larger grip apertures after reading larger object words,

but this effect faded as the hand approached its target. These two experiments provided support for the planning-control model.

Although these studies show support for motor resonance in planning tasks, they do not show whether it still occurs in a task that is not based on planning (Fischer & Zwaan, 2008). Experiments conducted by Tucker and Ellis (2004) investigated the priming of visual objects on actions. Their experiments tested whether different types of hand postures afforded by objects became activated by exposure to associated words (Fischer & Zwaan, 2008, p.838). Participants made judgments about whether objects were natural or manmade by responding with either a precision grip or a power grasp. A response compatibility effect was found. Tucker and Ellis (2004) also found that precision grips were faster for objects that would require a precision grip and power grasps were faster for objects that would require a power grasp. They conducted a further experiment in which the pictures of the objects were replaced by words for the same objects. They found no difference in effects when using words instead of pictures.

Studies have shown that specific classes of objects such as tools differentially activate the left middle temporal gyrus, which also becomes activated by action generation tasks, and the left premotor cortex, which is also activated when a person imagines themselves grasping objects with their dominant hand (Fischer & Zwaan, 2008, p. 839). Martin, Wiggs, Ungerleider, and Haxby (1996) investigated the neural correlates of a dissociation caused by brain damage to the human brain that results in selective loss of knowledge about a specific category of objects. They used PET to map regions of the normal brain that are associated with naming animals and tools. Participants viewed drawings of animals and tools and named the objects silently during one scan and aloud during another scan[5]. The naming of pictures and tools was associated with bilateral activation of the ventral temporal lobes and Broca's area. The medial occipital lobe – a brain region involved in the earliest stages of visual processing – was also activated when participants named pictures of animals. In contrast, naming tools selectively activated a left premotor area that is also activated by imagined hand movements. An area in the left middle temporal gyrus that becomes activated by the generation of action words was also activated by tool words. Martin et al. (1996) concluded that the brain regions active when identifying objects are dependent to some degree on the intrinsic properties of the object presented (p. 649).

[5] Participants were also scanned twice while staring at visual noise patterns and twice while staring at novel nonsense objects.

Another study by Chao and Martin (2000) used functional magnetic resonance imaging (fMRI) to observe the neural response in frontal and parietal cortices associated with viewing and naming objects of different categories (p.478). They predicted that pictures of tools would elicit activity in regions of the brain that store information about motor-based properties because, in comparison to other objects, tools are highly manipulable objects associated with hand movements. The object categories used were tools, animals, faces, and houses, presented as black-and-white photographs. Chao and Martin (2000) found that the ventral premotor cortex was selectively activated when participants viewed and named pictures of tools. This area that responded selectively to tools is the homolog of the monkey canonical F5 area, an area that also discharges in the monkey when they view graspable objects, even without any subsequent motor activity. Chao and Martin (2000) concluded that there seems to be a close link between objects that can be easily manipulated and information about the actions used on these objects in both the monkey and human brain.

3.5. Canonical Neurons

Canonical neurons are different from mirror neurons, although both are present in area F5. Canonical neurons discharge during the observation of graspable objects and during the grasping of objects. It has been proposed that canonical neurons play an important role in object-to-hand movement transformations, and this effect was observed in the study by Chao and Martin (2000). Mirror neurons, on the other hand, respond both when a monkey performs an action and when a monkey observes another individual performing a similar action (Rizzolatti, Fadiga, Fogassi, & Gallese, 1996). Rizzolatti et al. (1996) proposed, based on these findings, that mirror neurons play an important role in the imitation and understanding of actions.

3.6. Category-Specific Brain Activations for Words

Category-specific brain activations have been observed not only when people view pictures of tools and animals, but also when they view tool and animal words. Chao, Haxby and Martin, (1999) found consistent, category-related activation in ventral (fusiform gyrus) and lateral (superior and middle temporal gyri) regions of the posterior temporal lobes when participants viewed and named pictures of animals and tools. Similar patterns of activity also occurred when participants read the names of, and answered questions about, animals and tools. Devlin, Rushworth, and Matthews (2005) found category-related brain activations in

the posterior fusiform gyri when participants viewed words referring to man-made and natural items, suggesting that both the "bottom-up" processing of images and the "top-down" processing of words can cause category-related activation.

Preissl, Pulvermüller, Lutzenberger, and Birbaumer (1995) recorded the electrocortical correlates of the processing of nouns and verbs of healthy participants performing lexical decisions. The data recorded found different topographies of cortical activity for nouns and verbs. They found that the differences between event-related brain potentials were due to stronger motor associations elicited by verbs. Preissl et al. (1995) concluded that the neural generators of nouns and verbs are distinct and that these generators involve areas outside of the classic language centers of Broca's and Wernicke's areas.

Pulvermüller, Lutzenberger, and Preissl (1999) also investigated the processing of concrete nouns and verbs using three different measures: (i) behavioral measures, (ii) stimulus-triggered event-related potentials and (iii) high-frequency electrocortical responses in the gamma band (p. 497). Participants performed a lexical decision task while electrocortical responses were recorded. The response times of participants were also recorded, and participants also completed questionnaires. Pulvermüller et al. (1999) found that in as little as ~200 msec after the onset of the stimulus, event-related potentials showed electrocortical differences between nouns and verbs over widespread cortical areas (p. 497). They found strong between-category differences of signals recorded above motor and visual cortices. The results from the behavioral data collected suggest that the physiological responses are related to visual or motor semantic associations elicited by the word groups. They concluded that nouns referring to objects include neurons in visual cortices, and action verbs include neurons in motor, premotor, and prefrontal cortices (Pulvermüller et al., 1999, p. 497). These studies provide evidence for differential processing of verbs and nouns in the brain, and more interestingly, differential processing of objects used by the hands. The selective activity in a premotor region of the brain when viewing tools observed in the study by Martin et al. (1996) indicate that objects that can be manipulated (e.g. tools) are processed in the context of action. The physiological differences observed in the brain between the processing of verbs in comparison to nouns provides evidence that words can also activate the same regions in the brain as visually viewing objects or performing actions.

Reading words can also cause motor resonances in parts of the body that correspond semantically to those words (Fischer & Zwaan, 2008). A study by Pulvermüller, Shtyrov, and Ilmoniemi (2005b) used high-density magnetoencephalography to record participants performing a distracter task while listening to words that denoted actions involving the leg or

face. Once words could be recognized as unique lexical items, activation was recorded in the superior temporal and inferior frontocentral areas. The superior central sites were more activated from the leg-related action words while the inferior frontocentral areas were more strongly activated by the face-related action words. These results suggest that semantic access in action word recognition is an early automatic process that can be observed in spatiotemporal signatures of word-evoked activity (Pulvermüller et al., 2005b, p. 884). Pulvermüller et al. (2005b) hypothesized that mirror neurons in different parts of the frontocentral cortex that may include the prefrontal, premotor and motor areas contribute differentially to the semantic processing of action words (p. 889). These mirror neurons are involved in both the execution of actions and in the perceptual processes triggered by action words. This study provides evidence that the mirror neurons that were observed in the monkey brain when they performed or observed actions (Rizzolatti et al., 1996) are also discharging in the human brain when they view words pertaining to actions.

If motor and premotor areas are activated merely by reading a word, is it also the case that motor and premotor areas could activate the language centers of the brain that semantically represent the corresponding action words (Fischer & Zwaan, 2008)? Is it a two-way connection? Another study by Pulvermüller, Hauk, Nikulin, and Iimoniemi (2005a) found that indeed the relationship does travel the other direction in that stimulation of the motor areas of the brain helps with lexical decisions of action words.

Pulvermüller and colleagues (2005a) measured response times when applying transcranial magnetic stimulation (TMS) to motor areas in the left language-dominant hemisphere while right-handed participants made lexical decisions on words related to actions. They found that "TMS of hand and leg areas influenced the processing of arm-related action words and leg-related action words differentially" (Pulvermüller et al., 2005a, p. 793). TMS of the arm area led to faster arm than leg word responses and TMS of the leg area led to faster lexical decisions on leg than arm words[6]. Pulvermüller et al. (2005a) concluded from their results that "left hemispheric cortical systems for language and action are linked to each other in a category-specific manner and that activation in motor and premotor areas can influence the processing of specific kinds of words semantically related to arm or leg actions" (p. 793).

[6] In the control conditions, there were no TMS-related differences. The control conditions included sham stimulation and the application of TMS to hand and leg areas in the right hemisphere.

Chapter Four

Effects of the Hands on Vision and Language

4.1. Vision and the Hands

Our hands play an important role in our visual perception. Visual processes that do not inherently involve the hands have been found to be affected by the hands (Davoli et al., 2010). Bekkering and Neggers (2002) investigated the influence of action intentions on visual selection processes within a visual search paradigm. A predefined target object that had a certain color and orientation was presented among a number of distracter objects. Participants either pointed or grasped the target object while looking at it. Bekkering and Neggers (2002) measured eye movements and found that "target selection processes prior to the first saccadic eye movement were modulated by the different action intentions" (p. 370). More specifically, the first eye movement was more accurate in selecting the correctly-orientated object in the grasping condition than in the pointing condition[7]. The results indicate that the action to be performed can enhance visual processing of action-related properties of objects, such as object orientation. Fagioli, Hommel, and Schubotz (2007) investigated whether the reverse was also true: that activating action systems primes the processing of stimuli defined on perceptual dimensions related to these actions (p. 22). In a reversal of the Bekkering and Neggers (2002) experimental paradigm, participants prepared to perform either a reaching or grasping action, and prior to carrying it out, were presented with size or location-defined stimulus events. Fagioli and colleagues (2007) found that planning a reaching action caused facilitation for detecting deviants in location sequences, while planning a grasping action caused facilitation for detecting deviants in size sequences. These results reflect an overlap between grasping actions and object properties as well as reaching actions and spatial properties, supporting the findings of Rizzolatti et al. (1988) and Hoshi and Tanji (2002) that monkeys and humans possess canonical neurons that exhibit significant activity during observation of target location and during reaching.

Reed, Grubb, and Steele (2006) investigated whether the presence of the hand in peripersonal space can modulate the distribution of visuospatial attention and, if so, which attentional mechanisms (shifting location or prioritization of space) were most affected (p. 168). The experiments used a visual covert attention paradigm and had highly predictive

[7] The number of saccades to an object of the wrong color was the same in both conditions.

cues. Participants had to detect a visual target that could appear in one of two locations[8]. Participants responded when the target appeared at either the validly cued location, or the invalidly cued location. Participants "placed either their right hand next to the right-side target location or their left hand next to the left-side target location and made their detection responses with the other hand" (Reed et al., 2006, p. 169). The first experiment explored whether there was an effect of hand presence on spatial attention. The second ruled out the possibility that any arbitrary visual anchor changes the distribution of spatial attention. The third and fourth experiments selectively minimized proprioceptive-kinesthetic information regarding hand location, and the fifth experiment explored whether there was a decrease in attentional effects when the hand was farther from the visual target.

Reed and colleagues found that participants detected targets appearing near the hand more quickly than targets appearing away from the hand, regardless of cue validity. This hand-related facilitation effect suggests that having the hand near the target prioritized the space near the hand for attentional processing. The effect was hand-specific, in that having another object in place of the hand such as a board did not cause facilitation. The positioning of a fake hand was, however, sufficient to produce a facilitation effect. Reed et al. (2006) found a stronger facilitation effect when the hands were closer to the target than away from the target, although the effect was still present when the hands were farther away[9]. The hand appeared to increase the relative saliency of targets near the hand with a cost of processing targets that were farther from the hand (Reed et al., 2006, p. 174).

Objects near the hands may be processed in an entirely different way from those farther from the hands. Abrams, Davoli, Du, Knapp, and Paull (2008) explored the relationship between hand position and visual processing. Three classic visual attention tasks were used: visual search, inhibition of return, and attentional blink. During the visual search task, participants had to identify the letters H or S among other distracter letters. The inhibition of return task involved responding to the location of a target after the presentation of a cue with varying intervals between cue and target. During the attentional blink task, participants reported the parity of the first target (odd or even) and the identity of the second target (A or B) following a stream of characters. Participants shifted their attention between stimuli more slowly when their hands were near the display, and the same results occurred when the hands were visible and invisible. Abrams et al. (2008) hypothesized that this enhancement of vision near the hands could facilitate the detailed evaluation of objects to aid

[8] A highly predictive visual cue (70%) indicated the likelihood of the target appearing at that location.
[9] The effect also did not interact with cue validity or the shifting of spatial attention.

in object manipulation, or could aid in the assessment of potentially dangerous objects (p. 1035).

Evidence from neuroscience also suggests that vision nearer to the body and specifically near the hands is processed differently. Bimodal neurons with tactile receptive fields on the hand have been found in monkeys and these neurons respond to visual stimulation from objects close to the hand (Graziano, Hu, & Gross, 1997). An fMRI study has also found regions of the human brain that generate activity when objects are close to the hand (Makin, Holmes, & Zohary, 2007).

Vision can be so powerful on the perception of one's hands that it can be used to treat patients with phantom limbs. A famous study by Ramachandran and Rogers-Ramachandran (1996) tested the effects of visual input on phantom limb sensations. A new device called a "virtual reality box" was created that used inter-sensory effects to make the phantom limb appear visually by reflecting the patient's intact hand. A vertical mirror was placed on a table so that the reflection of the patient's intact hand was "superimposed" on the felt position of the phantom (Ramachandran & Rogers-Ramachandran, 1996, p. 377). Patients reported precisely localized touch sensations in the phantom hand when the normal hand reflected in the mirror was touched.

4.2. Effects of the Hands on Semantic Processing

The evidence for altered vision near the hands could have implications for reading. Reading is typically performed by holding a piece of paper or a book in one's hands. More recently, with the advent of computers, it has become common to read off of a computer screen with one's hands farther away. Despite this change, many people prefer to print more important documents that they truly want to absorb rather than read them off of the screen (Davoli et al., 2010). According to an informal poll conducted by Davoli and colleagues (2010), the vast majority of people, rather than stating any functional advantages to printing reading material, simply state that they "just like to hold it," as if to imply that holding the text in one's hands alters reading in some fundamental way (p. 555).

4.3. The Study by Davoli et al. (2010)

To investigate the effects of the hands on reading, Davoli and colleagues (2010) conducted several experiments. Davoli et al. (2010) attempted to test the effects of the hands on *semantic* processing. Participants held different hand postures during the experiments so

that their hands were closer or farther from the screen, and therefore, the text. In the first experiment, participants read sentences and made judgments on their sensibleness. A nonsensical sentence was defined as following the conventions of English grammar but containing one word that did not belong based in the context of the sentence. For example, the sentence *Tim carried his suitcase to the car* would be a sensible sentence, but *Tim typed his suitcase to the car* would be nonsensical. Therefore, according to Davoli et al. (2010), participants had to judge the semantic content of each sentence. Two different hand posture conditions were used. In the proximal condition, participants held their hands out to the screen and rested their arms on a pillow. They entered their answers using two response buttons mounted to each side of the monitor. During the distal condition, participants held a lightweight board in their laps. Response buttons were fixed to the board and participants held one hand on each button. Participants were significantly poorer at classifying the nonsensical sentences correctly during the proximal condition than during the distal condition.

The second experiment by Davoli and colleagues (2010) employed a task to measure the Stroop interference effect (Stroop, 1935) for proximal and distal hand postures. The Stroop interference effect is a cognitive phenomenon in which a color word (e.g. RED) interferes with the color in which it appears when the color (e.g. *blue*) is incongruent with the meaning (Davoli et al., 2010, p. 558). Davoli et al. (2010) stated that this reflects the relative speed at which words are read and therefore is a good test for semantic processing. They expected to find a reduced Stroop interference effect if the hands were near the color words due to impoverished semantic processing. Results showed that the magnitude of the Stroop interference effect was dramatically reduced when the hands were near the text in the proximal condition, thus supporting their hypothesis.

Davoli and colleagues (2010) described two confounding variables. One was that instead of impoverished semantic processing, the reduced effect found when the hands were near the display could be caused by impoverished *color* processing. It was also possible that the proximal posture was less comfortable and less natural, and as a result caused slower processing. Davoli et al. (2010) conducted a third experiment to address these issues. In the third experiment, the distal posture was replaced with a different distal posture as awkward and unusual as the proximal posture. This experiment did not find any neutral trial difference between the proximal and distal conditions, suggesting that there is no impoverished color processing effect. Participants continued to have a reduced Stroop interference effect in the proximal position, despite the new awkward distal posture.

4.4. Conclusions of Davoli et al. (2010) Study

Davoli et al. (2010) provided two explanations for their results. The reduction in semantic processing could be due to the presence of a trade-off between semantic processing and spatial processing that occurs when one's hands are close to text. Perhaps visual processing near the hands is biased towards the spatial properties of objects and away from semantic ones (Davoli et al., 2010, p. 560). This bias towards spatial properties of objects could be important for object manipulation and avoidance of dangerous objects. An alternative explanation is that the differences in the tasks can be attributed to enhanced cognitive control near the hands. For example, performing the Stroop task requires the suppression of one's automatic response to read the word and instead attend to the color of the word. This process relies heavily on cognitive control. A study by Koch, Holland, Hengstler, and van Knippenberg (2009) found a large reduction in Stroop interference when participants took a step backwards before performing the task, but not when they took steps forward or to the side. Koch et al. (2009) explained that the step backwards may have induced an avoidance mindset. In an avoidance mindset it would be beneficial to have increased cognitive control. It could also be the case that the practice some people have with reading in a particular medium outweighs any effects due to hand posture. Davoli and colleagues (2010) concluded that further research is needed to determine the most appropriate explanation (p. 561).

4.5. Problems with the Davoli et al. (2010) Study

Davoli and colleagues (2010) conducted an exciting and novel study investigating the effects of hand posture on semantics. However, the tasks used to measure semantic processing were problematic. The task used in the first experiment involved judging sentences on their sensibleness. This task did not take into account that participants may have misunderstood what was implied by "sensibleness" and could have considered any sentence that was grammatically correct as being sensible, thus providing an incorrect answer.

The use of the Stroop task as a measure of semantic processing is also problematic. Despite decades of research, theoretical explanations of the Stroop interference effect are inadequate, and the cause of the effect still remains unclear (MacLeod, 1991). Without a clear theoretical understanding of the Stroop interference effect, it becomes difficult to isolate

the role of semantics. Semantic processing can be measured more directly with a semantic categorization task. In this simple task, participants must respond to whether a word fits within a given category. Semantic categorization tasks can be constructed in a variety of ways (see Ota, Hartsuiker, & Haywood, 2010; Renoult & Debruille, 2010 for some examples) for different experimental paradigms. The tasks also allow for exclusion criteria. For example, if a participant only gets 50% of the answers to the questions correct, their data can be excluded from the experiment. The Stroop task, on the other hand, lacks exclusion criteria. There may be no Stroop interference effect for one participant and a very strong Stroop interference effect found for another, but there is no way to be sure if the participant that did not have the effect had a different understanding of the word meanings. Perhaps they were distracted, or had increased cognitive control. Davoli et al. (2010) had trouble drawing conclusions from the Stroop task. It was difficult to determine if the effect was caused by impoverished color processing, increased cognitive control, or impoverished semantic processing. These confounding variables would be controlled for if a semantic categorization task was used.

Chapter Five

The Experiment

5.1. Hypotheses

In this experiment, I tested the hypothesis by Davoli et al. (2010) that that semantic processing was reduced if the hands were near text when reading. Instead of using the sensibleness task or Stroop task employed by Davoli et al. (2010), participants completed a semantic categorization task and a visual task, in a proximal and distal hand posture. The semantic categorization task assessed the effects of posture on speed of semantic processing, while the visual task acted as a control for the effects of posture on response time. There were six different word categories within the semantic categorization task: tools, animals, vegetables, fruit, flowers, and buildings.

I hypothesized that a reduction in semantic processing would occur when the hands were near the display, in line with the results of Davoli et al. (2010). If the tasks employed by Davoli et al. (2010) did indeed represent a reduction in semantic processing when the hands were near text, then participants would perform more slowly on the semantic categorization task when the hands were close to the display. If, however, Davoli and colleagues (2010) did not accurately test the effects of the hands on semantic processing, then I would expect to find no effect of the hands on semantic processing.

Following the semantic categorization task, participants completed a visual task. Participants responded to a word appearing on the screen as quickly as possible. The task did not involve semantic processing, and was used as a control task for the effects of hand posture on response times. It was predicted that if the proximal hand posture was more uncomfortable than the distal hand posture, then participants would perform more slowly in the proximal hand posture than the distal hand posture.

5.2. Methodology

5.2.1. Participants

Twenty-four participants between18 and 38 years of age were recruited through the University of Edinburgh's Student and Graduate Employment website (SAGE)[10]. The participants were compensated with £5 for participating. Half of the participants were male

[10] A total of 29 participants were recruited, but the data of five participants was not used due to technical difficulties with the game controllers.

and the other half female. Each participant filled out an ethical consent form prior to participating.

5.2.2. Materials

Six different word categories were used for the semantic categorization task. Ten words from each category were presented in the first half of the experiment and ten in the second half, totaling 20 words for each category. The categories were animals, tools, fruit, vegetables, flowers, and buildings. These category words were matched with control words for letter and syllable length. The words had an average letter length of 6.34 and an average syllable length of 2.02. The words were also matched as much as possible for Kucera-Francis number of samples frequency (Kucera & Francis, 1967) and concreteness rating (Coltheart, 1981). The category and matched control words had an average frequency of 11.24 and an average concreteness rating of 590.48. In total, there were 240 words presented in the experiment; 120 words related to a semantic category and 120 non-related matched control words (see Appendix A). The groups of 20 category words with their matched controls were randomly divided in half so that half of the words could be presented in the first half of the experiment in the first posture position and half presented in the second posture position. The words were categorized by five native British English speakers to ensure that there was consensus that the words fit into their designated category and that the control words were not classified as category words by mistake. The word categories were presented in a randomized order and the category words were pseudo-randomized with the control words so that no more than four words of the same type (category word or control word) would appear in a row. This was done to prevent any confounding effects caused by the presentation of too many category words (or control words), which could cause participants to expect a word of the other type to soon occur, influencing their responsiveness.

The computer program E-Prime was used for presenting the tasks and for recording the response times of the participants. Participants used game controllers to enter their responses. One game controller was mounted to the bottom of the computer monitor with Blu-Tack and the other was loose.

5.2.3. Apparatus

Participants sat at a desk facing a computer screen and rested their chin on a chinrest. Viewing distance was at 42.5 cm (Davoli et al., 2010). During the proximal posture the

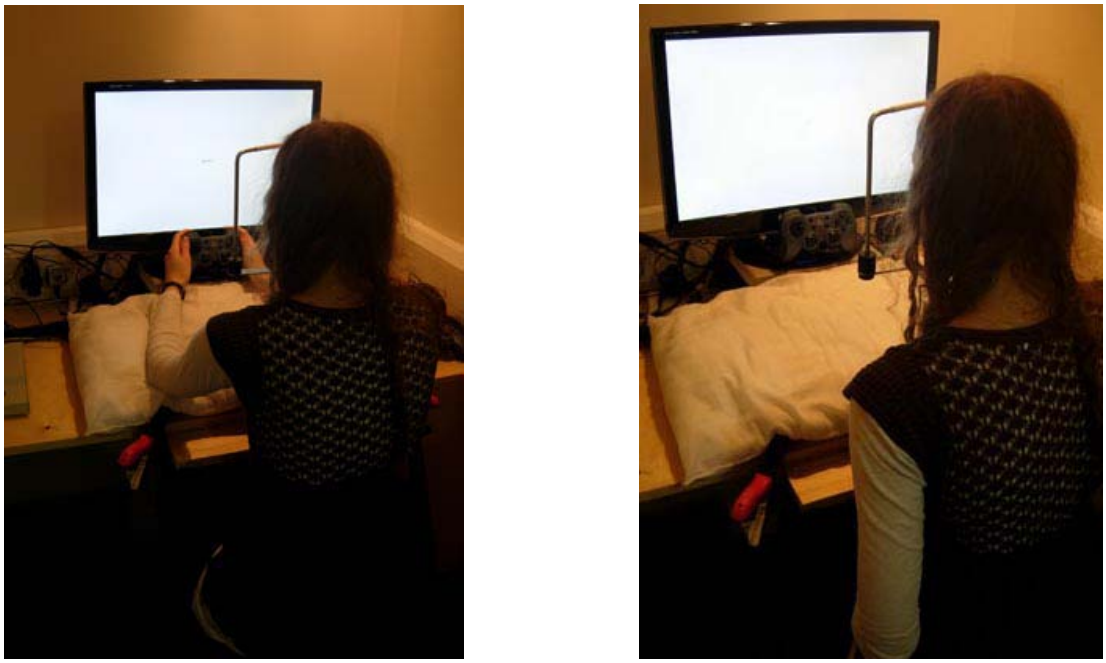

Figure 1. The picture on the left shows the proximal posture. The hands are resting on the game controller fastened to the bottom of the screen. The picture on the right shows the distal posture, in which participants held a separate game controller in their lap.

participants used the game controller fastened to the bottom of the screen and rested their arms on a pillow, and during the distal posture, participants used the loose game controller which they held in their laps (see Figure 1). Their hands and the game controller were not in their field of vision in the distal posture condition.

5.2.4. Design

This study compared the response times for participants completing a semantic categorization task and a visual task. The study used a within subjects 2 x 2 factorial design with two posture conditions and two different word lists. There were two posture conditions: the proximal posture condition in which the game counsel was held next to the screen so that the hands were near the text on the screen, and the distal posture in which the game counsel was held in the participant's lap. Participants performed half of the semantic categorization task in the proximal posture and half in the distal posture and the posture order was counterbalanced across subjects. The order of the word lists was also counterbalanced across subjects so that half of the participants received the first word list in the first half of the experiment and half received the first word list in the second half of the experiment. The visual task had the same design. Participants who performed the distal posture in the first half of the semantic categorization task also performed the distal posture in the first half of

the visual task. Halfway through the visual task participants changed to the other posture. Three male and three female participants completed each version of the experiment.

The experiment was designed to have two go/no-go tasks (Gomez, Ratcliff, & Perea, 2007) in which participants responded when a category word appeared during the semantic categorization task or when the word "press" appeared during the visual task, but did not respond when a control word or no "press" word appeared. There were practice blocks before both the semantic categorization task and the visual task so that participants could be familiarized with using the game controller and responding to the words.

5.2.5. Procedure

Participants read an information sheet explaining that they would be asked to complete a word categorization task and a visual task and enter their responses using game controllers (see Appendix B). They were also asked to fill in an informed consent form (see Appendix C). Then the experimenter adjusted the chinrest and explained how to enter responses using the game controller by demonstrating which buttons should be pressed and that they should be pressed using the pointer finger from each hand. Participants were instructed to push down with a finger from each hand at the same time to control for any hemispheric effects. The experimenter ensured that the participants were using the correct posture the first time that they were asked to perform each posture by helping them assume the correct posture at the beginning of the experiment and then asking the participant to call them back into the booth when they had to change the other posture for the first time.

The semantic categorization task was presented first. Participants were given instructions that a question word would appear and that they should press down the buttons if the following word fit into the category prompted by the question word. If the word did not fit into the prompted category, they were instructed to not press the buttons and wait for the next word to appear. The question word was the name of one of the categories, and was presented in capital letters followed by a question mark, such as "ANIMAL?" (Prévost et al., 2010). Participants had to press both buttons down on the game controller in order to start the word list. The screen was blank for 1,000 msec. A fixation cross then appeared on the screen for 500 msec and either a category word or a control word would appear for 1,500 msec. If the participant pushed down either button or both buttons with their fingers, the word would disappear immediately and the blank screen for 1,000 msec and fixation cross for 500 msec would again appear. This word would be logged as receiving a "go" response. Therefore, even if a participant did not succeed at pressing down both buttons using both

fingers, the word would still be logged as a "go" response, controlling for any difficulties the participant may have had in pressing down the buttons. If no buttons were pressed, it was logged as a "no-go" response.

Participants first completed a practice block of 24 words, four from each category (two category words and two control words). The experimental block followed. After completing 20 category and control words from each of the six categories, participants were asked to change posture and the experimenter was called in to help them with the new posture. Then they completed 20 new category and control words from each of the six categories in the new posture. After the semantic categorization task, participants were asked to complete the visual task. They changed posture once again prior to beginning the visual task. Participants were instructed to press down on both buttons on the game controller when they saw the word "press" appear. The word "press" appeared on the screen at a random time between 500 and 1,500 msec three out of every four trials, and for one out of four trials the no word appeared[11]. The order of the trials was randomized so that it was not predictable when the word "press" would not appear. Participants completed a practice block of 12 trials and then completed 32 trials in the first posture and 32 trials in the second posture. After the visual task participants were debriefed about the experiment and were given a debrief form to take home (see Appendix D). Participants were paid £5 and signed a confirmation form stating that they received the money.

[11] The word "press" only appeared three out of every four trials to keep participants from pressing the buttons out of an expectation that the word would soon appear if it had not appeared within the last ~1,400 msec.

Chapter Six

Results

The mean response time for proximal and distal hand postures for the semantic categorization task are shown in Figure 2. A 2 x 2 x 2 mixed-design analysis of variance (ANOVA) was used to compare gender (male or female), which posture participants received first (proximal or distal), and the difference in response time between the two posture conditions for the semantic categorization task (proximal and distal). No significant difference was found for posture, $F(1,20) = .375$, $p = .547$. The average response time for the proximal condition (M = 666.59 msec, SD = 21.40) was hardly different from the distal condition (M = 660.04 msec, SD = 21.09). There was a significant difference for gender, with females (M = 617.40 msec, SD = 29.08) performing slightly faster than males (M = 709.22 msec, SD = 29.08) in both posture conditions [$F(1,20) = 4.99$, $p = .037$].

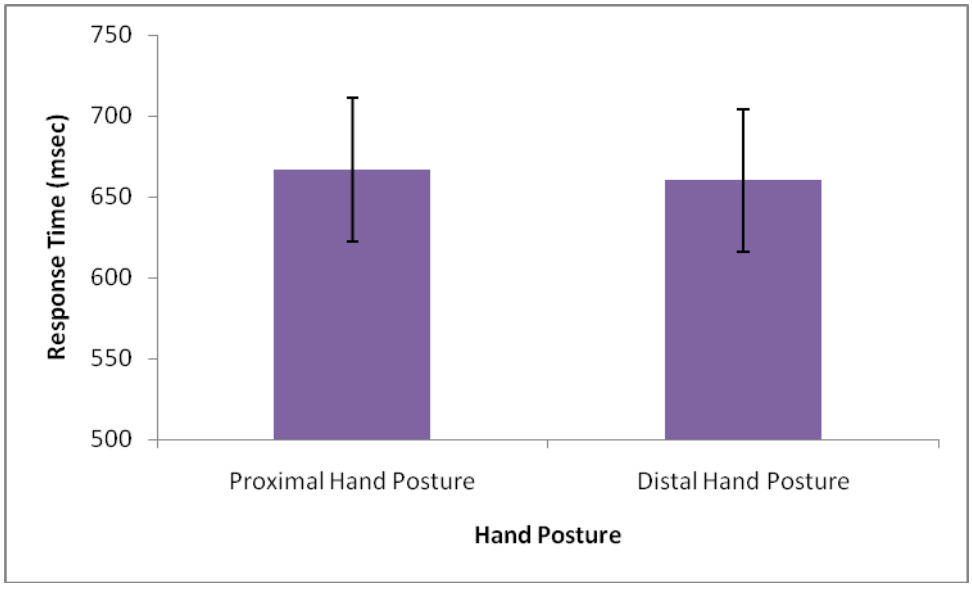

Figure 2. The mean response times (in milliseconds) for the proximal and distal hand postures for the semantic categorization task. No significant difference was found between the two posture conditions. Error bars represent the within-subjects 95% confidence intervals.

	Hand Posture			
	Proximal		Distal	
Word Category	*M*	*SD*	*M*	*SD*
Fruits	605.5	119	617.8	117.2
Animals	622.1	129.5	581.8	89.3
Tools	717.5	120.4	748.9	152.1
Vegetables	669.8	134.9	663.1	136.2
Flowers	678.7	123.7	662.8	167.9
Buildings	707.2	124.1	690.9	96.8

Table 1. The mean response times (in milliseconds) and standard deviations for each word category for the proximal and distal postures. Response times for tool words were the slowest, while response times for fruit and animal words were fastest.

A 6 x 2 repeated-measures ANOVA was conducted to compare the six different word categories (fruits, animals, tools, vegetables, flowers, and buildings) and the response times between the two posture conditions (proximal and distal). There was a strong main effect for the word categories, $F(5,20) = 28.80$, $p < .0005$ and an interaction effect between the word categories and which posture participants received first, $F(5,20) = 2.51$, $p = .035$.

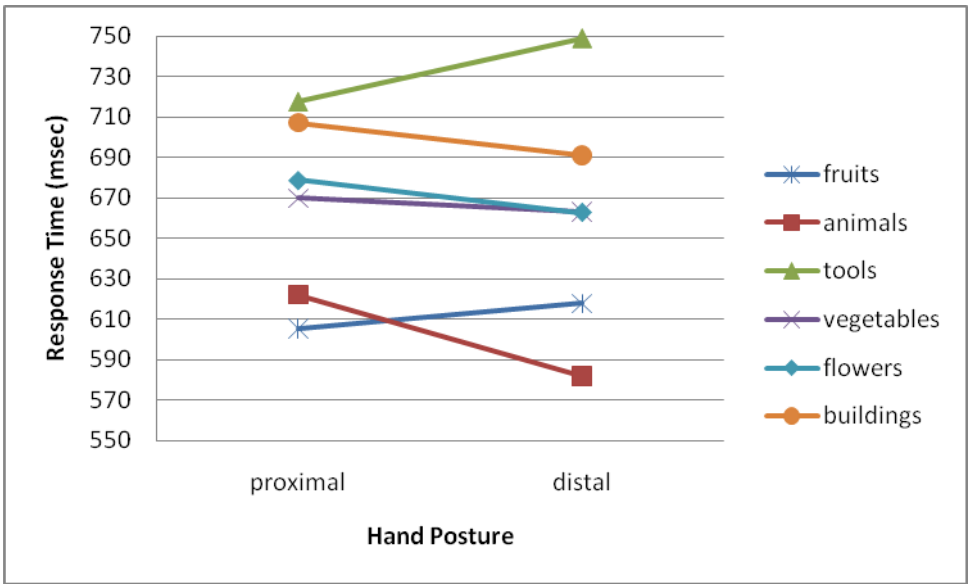

Figure 3. The mean response times (in milliseconds) for each word category in the proximal and distal postures. Response times for tool words were faster in the proximal posture than in the distal posture, but this was not significant because there was no overall significance for posture.

Post-hoc tests using the Bonferroni correction found significance for many of the categories, including: fruits and flowers ($p = .005$), fruits and vegetables ($p < .0005$), fruits and buildings ($p < .0005$), animals and vegetables ($p = .001$), animals and flowers ($p = .010$), and animals and buildings ($p < .0005$). The means and standard deviations for each category are listed in Table 1. Response times for tool words were strongly significant ($p < .0005$) in comparison to every other category except building words, which was insignificant ($p = .481$). Participants' response times for tool words were much slower than for all other word categories (see Figure 3). Participants were slightly faster when responding to the tool words when their hands were in the proximal posture ($M = 717.49$ msec, $SD = 120.43$) than in the distal posture ($M = 748.86$ msec, $SD = 152.06$), but this was not significant because the main effect for posture was not found to be significant. Response times for fruit words were slightly faster in the proximal condition ($M = 605.47$ msec, $SD = 119.00$) than the distal condition ($M = 617.75$ msec, $SD = 117.22$). Response times for animal words were slower in the proximal condition ($M = 622.06$ msec, $SD = 129.55$) than the distal condition ($M = 581.83$ msec, $SD = 89.32$), but once again, this was not significant due to no significant main effect for posture.

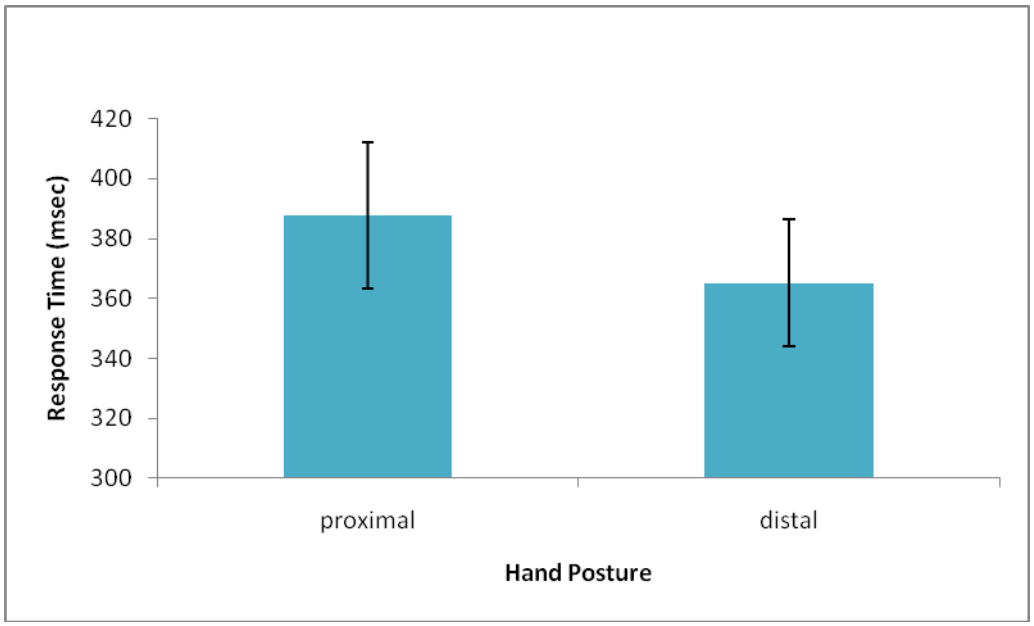

Figure 4. The mean response times (in milliseconds) for proximal and distal postures for the visual task. Response times for the proximal posture were significantly slower than for the distal posture. Error bars represent the within-subjects 95% confidence intervals.

To analyze the visual task, a 2 x 2 x 2 mixed-design ANOVA was used that compared gender (male or female), which posture participants received first (proximal or distal), and the difference in response time between the two posture conditions (proximal and distal). A significant effect was found for posture, $F(1,20) = 12.993$, $p = .002$. Participants were slightly slower at the visual task when their hands were in the proximal posture (see Figure 4).

Chapter Seven

Discussion

7.1. Findings

Contrary to Davoli et al. (2010), there was no effect from the hands on semantic processing. Participants were not slower when their hands were nearer to the display during the semantic categorization task, in fact, response times were almost exactly the same. The speed of response time for the different word categories was strongly significant. This difference in response time could be attributable to higher amounts of exposure to certain word categories over others. Participants may have been more familiar with animal and fruit words because they had more exposure to them. The concreteness of the words could also have been an influencing factor. The tool and building word categories had lower concreteness ratings than the other word categories (M = 582.03, SD = 14.96 and M = 571.92, SD = 10.11 respectively). Participants were fastest at responding to fruits and animal words, slower at responding to vegetable and flower words, and slowest at responding to building and tool words. Interestingly, response times for tool words were faster in the proximal condition, but post hoc tests could not be used due to the lack of a main effect for hand posture. Considering evidence of canonical neurons that discharge when monkeys and humans view graspable objects, and the motor resonances found by Martin et al. (1996) when participants viewed pictures of tools, there could be an effect of the hands on the speed of semantic processing for graspable objects. Four out of the six word categories used could be considered graspable objects: tools, fruits, vegetables, and flowers. Out of these word categories, tool words tend to have the strongest association with the hands. This association could have caused a facilitation effect when the hands were in the proximal position.

Response times for fruit words were slightly faster in the proximal posture than the distal posture, but little difference was found for vegetables and flowers, which could imply that fruits and tools have a stronger association with the hands in comparison to vegetables and flowers.

Participants had slower response times in the proximal condition when performing the visual task. This was likely caused by the awkwardness of the proximal posture. The fact that posture was significant for the visual task but was insignificant for the semantic categorization task seems to confirm that Davoli et al. (2010) did not measure semantic processing, and that the effect they observed may have been attributable to other factors such

as postural discomfort, an increase in cognitive control, impoverished color processing, or a misunderstanding of the sensibleness task. One would expect that if it was less comfortable to have one's hands in the proximal position, then participants would also perform more slowly with their hands near the display during the semantic categorization task as well. This was not the case, which could imply that participants benefited from their hands near the text, and that this effect was diminished because of the awkwardness of the posture. There could also be another explanation: fatigue. All participants performed the visual task at the end of the experiment. Because of this, it is possible that participants were merely more tired during the visual task, and that this fatigue effect was more pronounced in the proximal posture.

7.2. Evaluation of the Experiment

The experimental apparatus was not a replication of the apparatus used by Davoli et al. (2010). Rather than having boards with attached buttons mounted to the sides of the monitor and held in the participants' laps, game controllers were used. The use of game controllers may have given an advantage to participants familiar with video games, influencing their response time. It is also likely that the comfort of holding the game controller in one's lap, the way it is generally held when playing video games, had an influence on response times. It would have been beneficial to have replicated the experimental apparatus used by Davoli et al. (2010) in order to control for any differences in response time caused by using game controllers. With the same experimental apparatus, it would have been easier to compare the current experiment to that of Davoli et al. (2010), and gain a clearer understanding of the relationship between hand posture and semantic processing.

The visual task was always at the end of the experiment, which increased the likelihood that the results were due to fatigue. Counterbalancing the order of the two tasks would help to control for this confounding variable.

7.3. Theoretical Implications

This experiment investigated whether the hands had a facilitating effect on semantic processing, or whether semantic processing had to compete for resources because of enhanced visual processing near the hands. Generally, a facilitation effect from the use of the hands for linguistic processing has been observed in previous research. Gestures, for example, are helpful in speech production (Marangolo et al., 2010), retrieving words from

memory, and reducing cognitive burden so that effort can be focused on other tasks (Goldin-Meadow, 1999). Gestures also allow learners access to new thoughts. For example, children participating in science lessons frequently gesture to foreshadow the ideas that they later articulate into speech (Crowder, 1996). Stimulation of motor areas in the brain that correspond to body parts can facilitate action-word responses that match those body parts in a lexical decision task (Pulvermüller et al., 2005a). Getting primed with a word label on an object prior to performing an action can have an influence on the action (Gentilucci et al., 2000), and this can facilitate responses if the word and the properties of the object are congruent. The interconnectedness of language the motor system makes it highly plausible that the motor system is utilized by higher cognitive processes in a way that facilitates language processing.

It is also possible that the hands compete with linguistic processing, as proposed by Davoli et al. (2010). Gestures tend to benefit language processing, but these gestures are communicative. Having one's hands near text is not communicative, and is therefore likely to be represented differently in the brain. Studies have shown that spatial processing is enhanced near the hands (Reed et al., 2006; Abrams et al., 2008), but it is difficult to determine the effects of this enhancement on language. Alkadhi et al. (2005) recorded brain activation during motor imagery in paraplegic patients and healthy controls and found that the primary motor cortex was consistently activated, even to the same degree as the activation during movement execution in healthy controls. This finding supports the claim that regions connected and indirectly connected to the spinal cord are actively suppressed in healthy controls during motor imagery to hinder activation of the motor apparatus (Alkadhi et al., 2005, p. 138). It seems, therefore, that some processes of active suppression on the motor system occur when there is abstraction away from the production of motor movements. The active suppression of motor movements could be draining on cognition and reduce performance on other cognitive tasks. The enhancement of motor imagery found for paraplegics implies that when the motor system is not capable of interfering, other cognitive processes become enhanced. This could be extended to the results of the Davoli et al. (2010) study. In the same way that paraplegics show an enhancement of motor imagery, the absence of the hands near the display could have enhanced semantic processing because the motor system was not competing for resources.

An experiment by Boysen (1992) suggests that chimpanzees can benefit from abstract stimulus. When chimpanzees viewed a plate of candies and matched the candies with a displayed Arabic numeral, they invariably pointed to the plate with more candies, regardless

of the numeral. When the candies were replaced with marked placards symbolically representing the candies, the chimpanzees performed the task successfully. The experiment suggests that abstraction away from an action-associated stimulus can aid in performance because it limits interference from the motor system. It also highlights that there may be a very pronounced difference in the cognitive processing of real stimuli in comparison to symbolically represented stimuli. Perhaps the processing of symbolically represented stimuli (e.g. words) does not benefit from the inclusion of the motor system because it causes interference.

Facilitation from motor resonances occurs most when there is congruency between the affordance, picture, or word, and the action (Phillips & Ward, 2002; Gentilucci et al., 2000; Glover, 2004). It seems, therefore, that the motor system can facilitate symbolically represented stimuli, but that facilitation is contingent on the congruency between the stimuli and the motor response. There may be no overall effect for semantic processing when the hands are close to text, but there could be category-specific facilitation. Facilitation was found for the semantic processing of tool words when the hands were in the proximal posture, and this selective facilitation effect has been well-documented in previous studies of embodied cognition. Semantic processing may be facilitated in the same way if the words being categorized concern the hands.

7.4. Future Research

A better comparison between the Davoli et al. (2010) study and the current one could be made if the experimental apparatus used by Davoli et al. (2010) could be replicated. An experiment with the same apparatus but with a semantic categorization task would control for any differences caused by using game controllers and would provide better evidence for an effect on semantic processing.

In the third experiment by Davoli et al. (2010), they introduced an equally awkward distal hand posture. The current experiment may have benefited from the addition of an awkward distal hand posture to help control for any awkwardness of the proximal posture. If the awkwardness of posture were more controlled, it would be easier to conclude that an effect found in the proximal posture was caused by the presence of the hands near the text. It would be important to continue to include the visual task, so that the effects of posture could be measured independently of semantic processing.

The faster response times found for the categorization of tool words in the proximal posture implies that there may be an advantage to having one's hands closer to words that represent graspable objects. Chao and Martin (2000) found that viewing tools selectively activated regions of the brain that store information on motor-based properties. Studies by Chao, et al. (1999) and Devlin, et al. (2005) have found category-specific activation when participants read words, suggesting that both words and pictures cause category-specific motor area activation. Grabowski, Damasio, and Damasio (1998) found category-specific premotor activation for tool words when participants performed word retrieval tasks. This region was also activated when participants generated words for actions. These studies suggest that tool words are processed uniquely, and that they are linked to areas of the brain used for action. This connection to premotor areas associated with action could have caused the facilitation effect found for tool words when the hands were in the proximal posture. Further research is needed in order to determine if semantic processing of tool words (and possibly other graspable objects) are facilitated when one's hands are close to the text. A replication of the current experiment but with fewer categories, such as only tool and animal words, would help to isolate any category-specific facilitation effect.

It would also be interesting to investigate the effects of hand posture on a categorization task involving pictures instead of words. The unique brain activation that occurs in premotor areas when people view pictures of tools (Martin et al.,1996) suggests that the presence of the hands near pictures of tools could influence task performance. Perhaps response times would be faster for categorizing pictures of tools in the proximal hand posture because of category-specific premotor activity.

7.5. Conclusion

The hands are intrinsically tied to language, through gestures, sign language and a mirror neuron system for grasping. The connections discovered between the hands and higher level processing has led to the development of a new perspective within cognitive sciences: embodied cognition. Embodied cognition emphasizes the importance of the hands by claiming that cognition is situated in the real-world environment and inherently involves perception and action. The vast amount or research on motor resonance strengthens the evidence for this claim. Studies have found motor resonance not only when people view actions or manipulable objects, but even for nouns and verbs. The influence of the motor system extends to higher levels of cognition, and likely affects even semantic processing.

The current experiment investigated the influence of the hands on participants performing a semantic categorization task. In contrast to Davoli et al. (2010), the proximity of the hands to the text had no effect on the speed of semantic processing. It should not be concluded, therefore, that reduced semantic processing when one's hands are close to the text is a robust effect, and further research is needed to clarify that a reduction in semantic processing does in fact occur.

This study has important implications in a world in which computer screens are becoming the main medium for reading. Many people report preferring to hold their reading material in their hands. It remains unclear whether the presence of the hands causes competition for cognitive resources or provides facilitation for certain words or actions related to the hands. Further research will help to clarify the extent to which the hands influence how we read.

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Appendix A

The following words were used for the semantic categorization task.

Tool Words	Matched Control Words	Vegetable Words	Matched Control Words
axe	bin	bean	cart
drill	aisle	cabbage	blister
pliers	cavern	carrot	helmet
rake	stew	onion	linen
clamp	feast	potato	violin
hacksaw	glacier	spinach	platter
shears	breeze	broccoli	clarinet
mallet	liquor	lettuce	whistle
grinder	stomach	cucumber	ornament
scraper	costume	radish	piston
spanner	pasture	celery	cavity
clipper	typhoon	pea	ink
shovel	velvet	cauliflower	caterpillar
pickaxe	bagpipe	beetroot	windmill
spade	stain	leek	cube
tongs	flute	asparagus	ballerina
screwdriver	grandmother	shallot	cyclist
crowbar	trailer	artichoke	parachute
chisel	manure	pumpkin	butcher
hammer	circus	parsnip	settler

Flower Words	Matched Control Words	Fruit Words	Matched Control Words
bluebell	mountain	apple	ankle
daffodil	revolver	apricot	tornado
daisy	piano	banana	mosaic
orchid	kettle	cherry	wallet
rose	club	grape	brook
tulip	canoe	lemon	belly
dandelion	infirmary	orange	driver
sunflower	projector	peach	trunk
lily	dial	pear	sock
primrose	graphite	pineapple	performer
crocus	turban	plum	kite
geranium	motorist	raspberry	accordion

buttercup	orphanage	strawberry	typewriter
foxglove	bookcase	blackberry	roundabout
poppy	harem	currant	nostril
petunia	referee	lime	vest
chrysanthemum	advertisement	melon	digit
pansy	robot	mango	cigar
honeysuckle	commentator	tangerine	saxophone
snowdrop	basement	cranberry	passenger

Animal Words	Matched Control Words	Building Words	Matched Control Words
cat	fan	skyscraper	nutcracker
dog	ice	hotel	river
horse	train	farmhouse	scripture
monkey	button	warehouse	craftsmen
elephant	overcoat	bank	band
pig	pie	school	street
lion	riot	theatre	plastic
bear	hill	palace	cotton
zebra	jewel	prison	target
camel	carol	factory	pioneer
tiger	ferry	castle	carbon
cow	pan	church	spring
sheep	steam	mosque	blouse
deer	doll	hospital	director
rabbit	pillow	stadium	whiskey
giraffe	slipper	house	night
wolf	limb	barn	bell
rat	jar	cinema	pirate
squirrel	carriage	bungalow	retailer
goat	foam	cottage	missile

Appendix B

PARTICIPANT INFORMATION

Project Title: Semantic Categorization Task and Visual Task

Principal Investigator: Nicole Miles (Masters student)

Investigator contact details: s1055988@sms.ed.ac.uk

Payment: £5

What is the purpose of the project?

I am investigating how people comprehend and categorize words. There will first be a word categorization task, and then a short visual task.

What will I have to do?

There will be two tasks, a word categorization task and a visual task. The first task will be the word categorization task. A question word will appear and then a list of words will follow, appearing one after another. You will be asked to press buttons on the front of a game controller when you see a word that fits into the category of the question word.

For example, a question word such as "PLANT?" may appear. Following this question word, plant words and non-plant words will appear, and you will be instructed to press the buttons on the game controller when you see a plant word. If a non-plant word appears, you will be instructed to not press any buttons and wait until the next word appears. For example, if the word "ivy" appears, you should press the buttons, but if the word "duck" appears, you should not.

The second task is a visual task. When the word "press" appears you will be asked to press both buttons on the front of the game controller.

There will be several opportunities to take a break during the experiment. The experiment will take 50 minutes or less, and you will be paid £5.

If you have any questions then please ask the experimenter now, or during one of the breaks in the experiment.

Appendix C

INFORMED CONSENT FORM

Project Title: Semantic Categorization Task and Visual Task

Principal Investigator: Nicole Miles (Masters student)

Participant Number: _____

Session Number: _____

	please tick where applicable
I have read and understood the Participant Information Sheet.	☐
I have had an opportunity to ask questions and discuss this study, and if I asked any questions I have received satisfactory answers.	☐
I understand I am free to withdraw from the study at any time, without having to give a reason for withdrawing, and without prejudice.	☐
I agree to take part in this study.	☐
I would like to receive feedback on the overall results of the study at the email address given below. I understand that I will not receive individual feedback on my own performance.	☐

Email address…….

Signature of participant..... Date.....……..

Age (in years) .....

(NAME IN BLOCK LETTERS).....……

Signature of researcher..... Date.....……..

(NAME IN BLOCK LETTERS) ……

Appendix D

PARTICIPANT DEBRIEF

Project Title: Semantic Categorization Task and Visual Task

Principal Investigator: Nicole Miles (Masters student)

Investigator contact details: Email: s1055988@sms.ed.ac.uk

Participant Number: _____

Session Number:_____

1. What was the purpose of the project?

I would ask you not to discuss the experiment with friends who might take part in it, at least till after they have completed the experiment – if you tell them about the task it may interfere with the results, as explained below.

In this experiment I am investigating if having one's hands near text influences semantic processing of words (our understanding of the meaning of words). Previous research that used a different task found that having one's hands near text causes a reduction in the speed of semantic processing. I am testing to see if the same effect is found when doing a word categorization task. I will compare the reaction times of participants holding their hands near the screen to holding their hands in their laps.

This research could have interesting implications now that it is more common for people to read information off of a screen rather than on paper.

2. How will I find out about the results?

A summary of the results will be emailed to you within a few weeks of completion of the study, if you provided your email address.

3. What will happen to the information I have provided?

Your data will be stored safely, it will remain confidential and it will be destroyed after at most 3 years. Only members of the research team will have access to your data during that time.

4. How will the results be disseminated?

The results of the study may be presented at conferences or published in academic journals but that data will be generalised – your personal information or data will not be identifiable, just the general patterns of performance across all our participants.

5. Have I been deceived in any way during the project?

Yes, in a very minor way. You were not told about changing hand postures until necessary and you were not told exactly what was being measured in order to avoid any extra focus on your hands near the text.

6. If I change my mind and wish to withdraw the information I have provided, how do I do this?

You can either speak directly to the experimenter now, or contact Nicole Miles, Madeleine Beveridge or Richard Shillcock at any point quoting your Participant Number or your full name.

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