UNDERSTANDING THE NEUROPHYSIOLOGICAL REPRESENTATION PATTERNS OF NON-VERIFIABLE MENTAL ACTION VERBS: AN ERP INVESTIGATION

by

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Abstract

Imaging has revealed that brain activation of verbs with verifiable products ('throw, kick') activate language areas as well as the motor cortex responsible for the performance of the action described. An exploratory comparison of eye related verbs with no verifiable products ('observe') to mouth related verbs with verifiable products ('shout') has revealed a similar activation pattern. Thus in order to further study mental action verbs with no verifiable products, the present two-part study used words that were suitable across two modalities (e.g. you can 'perceive' both through vision and audition) and compare them to themselves under differing contexts of auditory and visual verbs so as to eliminate any word characteristics differences, as well as explored the two modalities directly. The primary purpose was to delineate whether associative learning or the mirror systems theory might better account for the acquisition of this unique subclass of verbs. Results suggest that Mirror systems theory more likely accounts for the observed cognitive processing differences between the two verbs.

Keywords: Verbs, language, Event-related potentials, abstract, associative learning theory, mirror systems theory.

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1 Introduction

'Nitwit, Blubber, Oddment, Tweak.'

In the absence of any context, what do these words mean? What do they symbolize? Where in the brain do we store the semantic meaning of these verbs and how are they retrieved? Most importantly, is your understanding of the meaning of these words the same as mine? Consider now, the following excerpt from 'Harry Potter and the Philosopher's stone' by J.K. Rowling (1997):

Albus Dumbledore got to his feet. He was beaming at his students; his arms opened wide as if nothing could have pleased him more than to see them all there. 'Welcome,' he said. 'Welcome to a new year at Hogwarts. Before we begin our banquet, I would like to say a few words. Here they are: Nitwit, blubber, oddment, tweak. Thank you'. He sat back down. Everybody clapped and jeered. Harry didn't know whether to laugh or not. 'Is he a bit mad?' he asked Percy uncertainly. 'Mad?' said Percy airily. 'He's a genius. Best wizard in the world. But he's a bit mad, yes. Potatoes, Harry?' Harry's mouth fell open. The dishes in front of him were now piled with food….

Presumably, the words 'nitwit, blubber, oddment and tweak' are part of an incantation that conjured up the food on the house tables in Hogwarts school of Witchcraft and Wizardry. How does this change your perception of the meaning of the words? Given a context with which to associate the meaning of the verbs, does it make your understanding of the verbs similar to mine? And most importantly do we store the semantic meanings of these verbs in a similar location in the brain given our knowledge of its meaning? From a neurobiological and psycholinguistic point of view, these are extremely important questions we must ask ourselves in an attempt to understand the languages we speak and how our cognition in and around these words are shaped by ambiguity, context, acquisition, etc. This is particularly important in the case of mental action verbs, that retain a fair amount of ambiguity in meaning, and are easily influenced by context and have remained relatively unexplored (Dickinson & Szeligo, 2008).

The evolution of language has been such that some words have come to mean several different things depending on their context (Storkel & Maekawa, 2005). For instance, the English word 'mad' can either refer to a state of mental illness or anger. Conversely, the opposite is also true, wherein several different words exist to describe similar phenomenon. For example, in the Inuit language, over 95 words exist to describe the sole English word, 'snow' (Martin, 1986). Linguistic exploration of this phenomenon in the Inuit language has revealed that there is a common understanding among the Inuit people about the differences in meaning between the different words used for snow (Martin, 1986). Each word is selected for the differences in characteristics they represent.

In the English language as well as others mental action verbs display a similar characterization wherein action verbs with overlapping definitions are consistently differentiated in meaning despite their overall similarities. For example, participants are able to groups specific sets of verbs on a multidimensional scale as input processes (e.g.

see and recognize) whereas others as words that have more cognitive function associated with them (Cacciari & Levorato, 2000; Dickinson & Szeligo, 2008). Additionally, 199 mental verbs relating to intelligence exist in the Dutch language (Hoskens & DeBoeck, 1991). Despite this, native speakers of Dutch can consistently categorize these words differently from one another regardless of the overlaps in definition. In a similar study done in Italian, Cacciari and Levorato (2001) assembled a list of 37 Italian verbs related to the process of vision and found again that participants consistently differentiated these words from one another in terms of dimensions such as the duration of the mental process that they describe and in terms of their cognitive function (e.g. distinguish). Overall, their results showed that the different words reflect separate mental actions or cognitive states and more importantly, that there seems to be a common understanding among the people about their interpretation as well as usage (Dickinson & Szeligo, 2008).

In the English language also, there are a number of verbs associated with visual processes that exist with considerable overlap in their definitions (e.g., view, peer, and gaze) (Naigles, 2000). This raises the question: does our common understanding of these verbs manifest behaviorally in a common fashion based on varying instructions and if so, where do these differences stem from? Specifically, as in the case of the Inuit words for snow, do the various visual verbs describe different characteristics of the same process? Some research attempting to answer these pressing questions has thus far been done.

While neuroimaging research on language processing has typically focused on language as a whole, in more recent years the focus has shifted to specific categories (Pulvermüller, Harle & Hummel, 2001). Using modern imaging techniques such as Electroencephalography (EEG), Event-Related Potentials (ERP), Magnetic Encephalography (MEG), and functional Magnetic Resonance Imaging (fMRI), it has been widely recognized that the classical view of language as being controlled by the two language areas of Broca and Wernicke, is incomplete (Pulvermuller et. al., 2001). The present research outlines the present stance on a specific subcategory of language, namely action verbs and more specifically mental action verbs and attempts to provide an overview and elaboration of the cognitive models that may assist in describing them.

1.1 Mental Action Verbs

In an attempt to answer the question as to whether or not people behave in a consistent manner in response to mental action verbs, a simple visual discrimination task was used by Dickinson and Szeligo (2008) who discovered that when perceptual action words were embedded in the instructions for a visual discrimination task, the response times (but not accuracy) for discrimination were dependent on the action that participants were asked to perform. When reporting whether two triangles were of the same size or of a different size, participants responded significantly faster if they had been asked to ‘see’ these triangles than if they had been asked to either ‘perceive’ or ‘become conscious’ of them (Dickinson & Szeligo, 2008). The triangles presented were in the format of textual stimuli, pictorial stimuli or part of a discriminatory task between pictorial stimuli for multiple levels of processing and to ensure a focus on the mental action (Dickinson & Szeligo, 2008). Although the response times were different, it was found that between the three instructions, no accuracy differences existed, which as per the speed/accuracy tradeoff is an unexpected finding (Wickelgren, 1977). The participants were then presented with rating scales to rate their own performance and perception. Within subject analyses indicated that participant response times differed depending on the task.

To delineate precisely where the differences originated from, be it instruction characteristics or instructional strategies, experiment 2 was designed to examine more thoroughly the relationship amongst words that describe mental action verbs. Using the Mental operations: ratings of sameness scale and analyzing it with multidimensional scaling, 45 participants were given a list of 14 words/phrases which represented mental action verbs performable and were told to rate them according to how similar each of the words listed were to each other in terms of meaning. It was found overall that the words were positioned along a single dimension consistent with previous research (Dickinson & Szeligo, 2008).

Experiment 3 was designed to take into account the finding of the differences in meaning identified on the MDS analysis. Thus a signal detection paradigm was used, employing different mental verbs, namely *see*, *are conscious of*, *distinguish* & *recognize*. Participants were told to respond immediately after they perceive/ are conscious of/

distinguish/ recognize that the triangles are the same; pressing a left mouse key if they were same and right mouse key if they were different. Upon analysis it was found that there were no differences in the accuracy whereas differences in response time were found to be significant as expected since the words were on different ends of the scale (Dickinson & Szeligo, 2008). As in experiment 1, participants seemed to be aware of the differences between instructions, having significant differences in ratings on certainty, difficulty and time it would take to perform. The authors argue that length, familiarity or frequency are likely not the contributors to the given differences, given that the participants weren't responding to the word itself, but rather to the instruction (Dickinson & Szeligo, 2008). The authors postulated based on a paper published in 2001 by Pulvermüller and his colleagues that similar to his findings perhaps the differences in verb processing occurs at the neural level and perhaps even in a similar fashion.

On the other hand, it was hypothesized that the reaction time differences found in this study were the result of word length differences. However, this hypothesis was not supported in a study done by Cirelli and Dickinson (2013) in French using different words with different word lengths in the same visual discrimination task. The results of this study indicated that neither word length nor word frequency could be used to explain the reaction time differences. However, these studies were aimed at gauging behavioral differences in processing these mental action verbs rather than retrieval of the verbs themselves. In more recent times the focus has shifted to brain processing and activation patterns during semantic processing.

1.2 Action verb processing: through the eyes of the neurophysiologist

In 2001, Pulvermüller put forth a model to explain the storage and retrieval of action verbs related to the face, arms and legs in the brain for which he provided support using the aforementioned ERP research in conjunction with fMRI. The principal advantages of using ERPs are that each component reflects brain activation associated with one or more mental operations. Thus ERPs can be used to distinguish as well as identify psychological and neural sub-processes involved in complex cognitive, motor or perceptual tasks (Luck, 2005).

Three word types: face-related action verbs, arm-related action verbs and leg-related action verbs were studied. The experiment consisted of a lexical decision task in which the participants were presented with either real words or pseudo words for a duration of 100ms and asked to respond by pressing a button if they saw a real word and do nothing if they saw a pseudo word. Pulvermüller et al. (2001) used 32 words in each category, and controlled word length as well as normative lexical frequency as taken from Baayen et al. (1993). All words were bi-syllabic and as such, bi-syllabic pseudo words were generated by exchanging letters within and between the words and were therefore matched to the actual words by number of letters. All of the pseudo words were carefully created to be in accordance with the phonological and orthographic rules of the German language. Between each stimulus there was an inter-stimulus interval that varied between 3.5-4.5 seconds to avoid any anticipatory or expectancy effects. Pulvermüller et al. (2001) found that, on average, the lexical decisions were fastest with face-related words (676ms post stimulus onset), slower for arm-related verbs (688ms) and slowest for leg-related verbs (708ms). The differences were found to be significant. A rationale for the differences was provided in the form of parallel topography studies performed, the results of which are seen in figure 1.

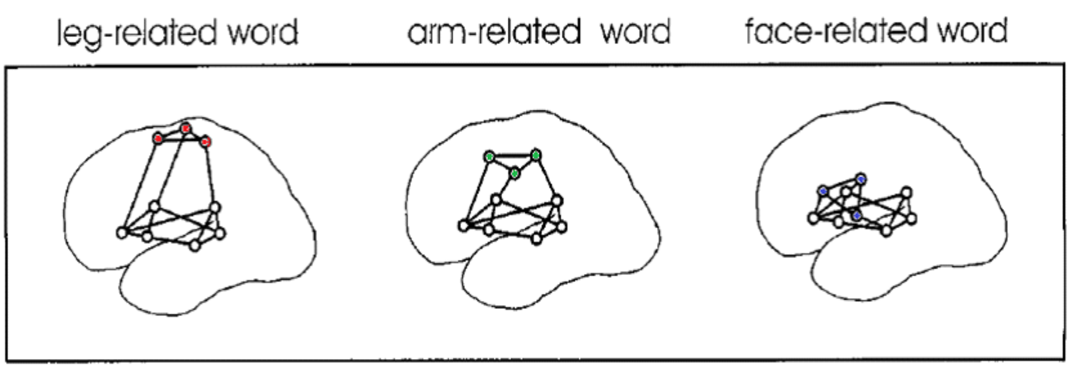

Figure 1: A diagram of the brain activation patterns discovered by Pulvermuller et al., (2001) in response to leg-related, arm-related and face-related verbs from an fMRI study.

Pulvermüller et al. (2001) proposed that the differences in response times probably occurred as a result of the topography (location and dispersion of activation) associated with the word processing. As seen in figure 1, the word webs that were activated by each verb type to represent their corresponding meanings are not the same. It was believed that the reasoning for the delay in response times for leg-related words compared to the arm-related and face-related words lies in the dispersion of the neurons for each word type. The leg-related words are more widely dispersed than the arm-related words, which in turn are more dispersed than the face-related words. Interestingly, the dispersion in each word type corresponds to the general area in which action processing of the word takes place within the motor cortex.

The authors also found a main effect of word category, with the highest peaks for face-related items (Pulvermuller et al., 2001). It was thought that the amplitude differences were a result of the efficiencies of the synaptic connections for each word type, i.e. less activation would be required to process words that have been used more often. All of these results together were used to support the associative learning theory as the mode for the learning of these verbs (Pulvermüller et al., 2001).

1.3 Pulvermüller's model of action verb processing through associative learning

According to the associative learning theory, constant neural pairing of word activation with physical actions is the reason for the creation of complex neural webs in response to these words. For instance, during language learning, every time the person semantically processes the word 'kick', it is usually accompanied by the action of kicking. Thus, neurons involved in the activation of the kicking action are co-activated alongside the neurons involved in its word processing. In the end, as seen by Pulvermüller et al. (2001), reading the word 'kick' activates a complex neural web which includes both areas for word processing as well as areas for the processing of the physical actions. James and Maouene (2009), studied the neural activation patterns during verb processing in children. Consistent with Pulvermüller's findings, they found that different types of verbs activated different regions in the motor cortex. For instance, James and Maouene (2009) found that auditory verb perception elicits activation in the motor regions involved in performing the specific actions during the processing of verbs that refer to those actions, identical to what Pulvermuller et al (2001) discovered.

Thus the model for action verb processing used by Pulvermüller was a neurobiological one according to which brain activation would include two regions: a cell assembly distributed over language areas, and additional areas related specifically to the word's meaning (Pulvermüller, 2001). In the case of action verbs, the specific region includes areas of the motor cortex associated with the processing of those body-part related actions. The connection between the two regions is thought to be built as a result of constant neural pairing which strengthens the connection as described in Hebbian theory ("Neurons that fire together, wire together." -Hebb's law) (Pulvermuller, 2001).

Due to the non-verifiability of the mental action verbs, one would expect variations in the activation pattern which needs to be explicitly explored because as described shortly, understanding the brain activation patterns during the semantic processing of these verbs will help us make better predictions as to the modes of acquisition and possible effects of decline with disease. In the case of mental action verbs which have no verifiable external actions represented by their semantics, a second theory which is thought to more accurately describe their acquisition exists based on the mirror neuron system.

1.4 Mirror systems theory

The mirror neuron system, first discovered in monkeys and recently in human beings, is a group of specialized neurons that mirrors the actions and behaviours of others and is implicated in a wide variety of neurocognitive functions (language, social cognition, etc.) (Rajmohan & Mohandas, 2007; Rizzolatti & Craighero, 2004; Rizzolatti, Fadiga, Gallese & fogassi, 1996b). Initial discovery of this system was provided by Gastaut and Bert, (1954) who discovered desynchronization of an EEG rhythm recorded from central regions of the head which occurred during active movements by the participants and also when those movements were observed in others. Since then a wide variety of studies using more sophisticated imaging techniques has confirmed the presence of motor neurons forming complex networks comprising occipital, temporal and parietal visual areas as well as two cortical regions whose function is predominantly motor (Buccino et al., 2001; Grezes, Armony, Rowe & Passingham, 2003; Nishitani & Hari, 2000, 2002; Rizzolatti & Craighero, 2004; Rizzolatti et al., 1996b). With regards to strength of association in other individuals, Buccino et al. (2004) did an fMRI study in which they presented participants with video clips showing silent mouth actions performed by humans, monkeys and dogs. The two types of actions shown were biting and oral communicative actions with static images of the same as controls (Buccino et al., 2004). Their findings indicated mirror system activation for the biting, less activation for lip smacking (thought to be a predominantly monkey action) and no frontal lobe activation for barking (Buccino et al., 2004). This suggests that actions which are performable by us as individuals will result in motor neuron mapping whereas those not performable are recognized solely on a visual basis without motor involvement.

With regard to the mental action verbs, this suggests that the subtle differences suggested by the semantics of the verbs will result in activation of the respective motor regions based on mirror neuron activation (i.e. occipital lobe for visual actions and parietal lobe for auditory verbs). For instance, with regards to the learning of the verbs ‘view’ and ‘perceive’, theoretically, first one internalizes the definitions of the words to their own perception of what they assume the definition implies. This self-implied definition would then be modified based on one’s perception of how other people’s definition of the word varies from their own.

In summary, Pulvermüller (2001) proposed a model of neural representation in the brain for action verbs with verifiable products (i.e. verbs with consistent motor associations), based on the associative learning theory which purported that when we semantically process verbs with verifiable products it activates a general language processing web in the brain as well as specific regions in the motor cortex which coincidentally are involved in the performance of the actions represented by the verbs. This is thought to result from constant neuronal pairing between verb semantics and the physical action. In contrast the mirror systems theory purports a similar activation pattern involving semantic areas of the brain and the motor cortex region. However in this case, it is thought to result from mapping the perceived actions of others onto oneself. In the case of the mental action verbs being studied, (i.e., verbs that have no verifiable products), the formation of neural webs through associative learning is thought to be unlikely to form due to the non-verifiability of the verbs. Thus improved cortical activity is thought to provide support for the mirror systems theory as the mode of acquisition for the given neural representation patterns. However, before delineating which, if either is involved in the semantics of mental action verbs, it is imperative to first determine the actual activation patterns involved in the semantic processing of these verbs. Subsequently, the second aim of this research is to determine which more accurately represents the actual mode of acquisition of mental action words.

In fact, more importantly why is it important to have this knowledge? The usefulness of such knowledge about verbs with verifiable products is demonstrated in the applications in which they are used. Specifically, knowledge about the activation patterns of these verbs can assist other researchers in the understanding of cognitive decline in individuals with brain-related disorders or diseases (Yi, Moore & Grossman, 2007).

1.5 Verb decline in patients with Alzheimer's Disease and Semantic Dementia

Yi and colleagues studied the comprehension of carefully matched classes of words by manipulating grammatical subcategories (nouns and verbs) and semantic characteristics (concrete and abstract) for participants with semantic dementia (SD) or Alzheimer's disease (AD). The study was designed to exploit the concreteness effect, whereby a superior performance in responding has been observed for concrete words compared to abstract ones (Yi et al., 2007). It is believed that this is the result of a more thorough coding system for concrete verbs involving both the verbal propositional system and a visual-perceptual system, whereas abstract words utilize only the verbal propositional system (Yi et al., 2007). The participants were asked to select a word that best illustrated the given description. Although the participants with AD and SD varied in terms of their demonstration of the concreteness effect, both participants with SD and AD, showed more difficulty with verbs compared to nouns (Yi et al., 2007). Yet there was a distinctly different impairment pattern observed for the participants with SD and AD, wherein the participants with SD showed a more severe impairment on motion verbs than cognition verbs but not for nouns, whereas participants with AD showed equal difficulty with both.

Research investigating the speech impairments in individuals with brain damage has generally revealed increased difficulty in processing of verbs (Berndt, Haendiges, Mitchum & Sandson, 1996a; Joanisse & Seidenberg, 1999; Perani et al, 1998). Thus it was hypothesized that the reason for increased impairment for the verbs was due to this extensive neural networks involved in the semantics of these verbs.

Interestingly, similar verbs were studied by Boulenger and Nazir (2010) in patients with Parkinson's disease. Among other things, they analyzed the effects of congruent priming in patients taking L-Dopa medication and those not taking the medication. The authors used a masked priming task with the understanding that masked priming effects are thought to reflect automatic and rapid access to lexico-semantic information about words as studied in the context of spreading-activation theories (Davis, 2003; Boulenger & Nazir, 2010). L-Dopa is thought to restore functioning to the motor cortex regions of the brain. Their findings showed that patients not on medication with impaired functioning of the premotor and motor regions revealed no priming effect, where in contrast patients with L-Dopa intake, which restored the functioning of the premotor and motor regions via the fronto-striatal loop, showed restored priming effects for the action verbs (Boulenger & Nazir, 2010). Similar to previous studies this provides further evidence for the role of specific cell assemblies in language processing and consistent with the other research involving action verbs, with verifiable products.

The authors propose that there are two interpretations which could account for the functional link between language and action. The first one is based on the assumption that word related motor activation occurs because of the links between an action and its verbal description that is formed during language acquisition as proposed by Pulvermüller (2001; 2005). The second is based on the mirror system theory which proposes that actions are understood by reflecting one's own motor actions and mapping it to perceived actions of others (Boulenger & Nazir, 2010; Rizolatti & Craighero, 2004).

Other studies in recent times have examined these cognitive deficits in disease states in relation to mirror system dysfunction (Alegre, Guridi & Artieda, 2011). Alegre et al., (2011) examined theory of mind (TOM), which is the ability to infer our own, or more frequently other people's mental states, and their deficits in Parkinson's disease (PD). Their study showed that basal ganglia which are involved in the mirror neuron system as well as TOM may be affected in PD which suggests that TOM deficits in PD might be at least partially mediated by mirror system dysfunction (Alegre et al., 2011). This further validates the need to study the neural representation pattern of mental action verbs and the need to determine their mode of acquisition.

Insofar as mental action verbs with no verifiable products are concerned, research delineating their neural representation within the brain has yet to be done. Prior research done on these verbs indicates that people tend to have a similar understanding of these verbs and respond behaviorally in a similar fashion too (Dickinson & Szeligo, 2008). The important question then becomes how are they represented in the brain? As already demonstrated, this knowledge would greatly further our understanding regarding their acquisition and more importantly provide us insight on possible effects regarding decline under disease states.

Verbs with verifiable products are a relatively broad class of verbs whose neural representations have been well studied and whose acquisition had been proposed to be largely based on associative learning (Pulvermuller, et al., 2001). However, with the advancement of age, and particularly the onset of neurological disease such as Alzheimer's a decline in cognitive access to these verbs has been observed which is thought to be the result of more wide-spread neurological damage as opposed to specific area damage (Yi et al., 2007). Generally this decline has been studied in terms of differences between nouns and verbs whereas the distinction between different types of verbs has not been fully characterized. There still remains the large void regarding verbs with no verifiable products.

Most importantly, how are these verbs stored in the brain and neurologically represented? Once that is determined, future research might be able to gauge cognitive deficits in the face of disease states and better inform the negative consequences of decline in patients with diseases such as AD and SD. The first step to gauging the neural representation of verbs with no verifiable products was to compare verbs with verifiable products to verbs with no verifiable products. Since the following research employs the use of event-related potentials (ERPs), it is imperative to provide a brief background on what ERPs are and what they represent as well as how they are used in studies.

1.6 Event-Related Potentials

Event-related brain potentials (ERPs) reflect voltage changes in the ongoing electroencephalography (EEG) measured at the scalp in response to specific stimuli (Luck, 2005). Since ERPs reflect very small changes in EEG activity, signal averaging is necessary in order to remove excess "noise" in the signal. For instance, when you are told to press a button upon seeing the letter 'x' on a screen, your response elicits specific waveforms. However contained in that waveform is other activity, typically referred to as 'noise'. This could be in the form of an itch or sneeze. Thus since it is unlikely that you feel the same type of itch in every instance of the presentation of the letter 'x', by averaging the EEG data in response to the stimuli, we are left with a characteristic ERP waveform for each type of stimulus for each participant (Luck, 2005). The grand average waveform is the average across all participants for one type of stimulus, which is then used for analysis.

A typical waveform consists of specialized peaks referred to as components which are defined based on their polarity and latency (Luck, 2005). The first known attempt at ERP research began in 1939 when Pauline and Davis used a very simple averaging technique to try and extract useful information from EEG. However it was Walter (1964) who discovered the first ERP cognitive component known as the readiness potential or contingent negative variation (CNV) (Luck 2005). In essence it was a negative spike of electrical activity that appeared in the brain half a second prior to a person becoming consciously aware of movements that he or she is about to perform. In his study, participants were presented with a warning signal followed by a target stimulus either 500 or 1000ms later. Whenever the participants were required to press a button, the CNV would appear (Luck, 2005).

The next component to be discovered and perhaps the most well known and well characterized of all ERP components was the P300 by Sutton, Braren, Zubin and John (1965). The P300 is a cognitive component of the ERP wave shown to be elicited in response to novel stimuli. For example if a participant is shown an ‘x’ 75% of the time and 25% of the time they see a ‘y’, it will result in a large P300 component every time they see the ‘y’ because the ‘y’ in the given context would be a novel stimulus (Luck, 2005). In the beginning ERPs were known as evoked potentials because they were electrical potentials evoked by specific stimuli. However in a chapter published in 1969, Herb Vaughan explained how the term was no longer sufficiently general to apply to all EEG phenomena and so proposed the term event related potentials which in his words designate the general class of potentials that display stable time relationships to a definable reference event (Vaughan, 1969, p46; Luck, 2005).

Since then a whole array or ERP components have been discovered and characterized, the results of which have been included in table 1 (Luck, 2005). Modern day ERPs utilize either 128 electrode or 64 electrode HydroCel nets which use baby shampoo, salt and water to build the electrical conductivity to silver chloride electrodes padded with sponges. 4 electrodes are placed above and below the eyes to capture ocular activity and thereafter remove it during the analysis phase (Luck, 2005). During the cleaning of the raw EEG to form ERPs, all data are filtered and ocular as well as other artifacts are removed to yield characteristic ERP waves that are devoid of noise and contain only the response to the event (Luck, 2005). While research using ERPs has been churning over 3500 papers these past few years, the areas of research have varied from emotional discrimination, to sequence recognition to language processing and on (PubMed, 2012).

Table 1: Commonly studied ERP components (Luck, 2005)

Component	Duration (ms)	Assignment
P50		Attend to salient information and ignore trivial information
C1	80-100 ms	+ve/-ve, Evoked with visual stimuli
P1	100-130 ms	State of arousal and direction of spatial attention
N1	90-200 ms	Reflects discriminative processing
P2	100-250 ms	Little known.
N2	200 ms	Changes (deviants) in repetitive auditory stimulation
P3	250-400 ms	Unusual, unexpected, or surprising stimuli

The principle advantage of using ERPs is that they are a relatively non-invasive cheap procedure compared to other neuroimaging techniques such as PET and fMRI (Luck, 2005). Moreover their maintenance requires less effort, and compared with other behavioral procedures, it provides a continuous measure of processing between a stimulus and response with an excellent temporal resolution of 1ms or better which allows for determining which stages are affected based on specific experimental manipulations (Luck, 2005). Another key advantage of using ERPs is their ability to provide a measure of processing of stimuli even in the absence of behavioral changes (Luck, 2005). Although the high temporal resolution and other advantages make ERPs the choice of methodology in most cognitive health laboratories, ERP research lacks the spatial resolution capabilities typical of other procedures such as fMRI and PET (Luck, 2005). Still so far as mm range resolution is not required to answer the given research question, ERPs prove to be an excellent measure of cognitive processes and neural representation patterns.

1.7 Verifiable verbs vs. non-verifiable verbs

Using ERPs to measure brain activation patterns, a lexical decision task was employed on 28 undergraduate students to compare mouth related verbs with verifiable products to eye-related verbs with no verifiable products (Thomas & Dickinson, 2012). The 14 mouth related verbs with verifiable products were chosen from Pulvermüller's original list of 32 mouth related verbs and were matched for frequency, familiarity, word length and syllabicity with 14 eye-related verbs. Significant ERP differences in the early components were found. However, the early components are generally thought to reflect selective attention to stimulus characteristics of initial discrimination processing (Luck, 2005). In the later components such as the N4 where semantic differences are typically discovered (Luck, 2005), no ERP differences achieved significance between the two categories. Thus there is initial evidence suggesting that non-verifiable verbs are categorized differently to verifiable verbs. Moreover response time differences indicate faster response times for mouth-related verifiable verbs than eye-related non-verifiable verbs, a finding consistent with Pulvermuller's finding regarding RT differences according to associative learning theory.

Given the indication that verbs with no verifiable products seem to exhibit a similar activation pattern to verbs with verifiable products, it was determined that perhaps these differences are the result of the lexical categorical differences as opposed to semantic factor differences between the two which necessitates the further exploration of these mental action verbs.

2 Experiment one

The purpose of the present study was to further investigate verbs with no verifiable products and more importantly to examine their neural representation patterns during semantic processing with the aim to delineate whether Pulvermuller's theory of associative learning or the Mirror systems theory can more accurately account for the observed neural representation pattern during the semantic processing of these verbs. Research done by Pulvermüller et al, (2001) suggests that action verbs' semantic representation within the brain incorporates neural cell assemblies that encompass the motor cortical regions involved in the performance of the respective actions. They proposed that associative learning is likely the mechanism through which these verbs are learnt.

The verbs Pulvermüller studied represent a sub-category of verbs with verifiable products (i.e., more concrete verbs that you can see other people perform). Due to the non-verifiability of the verbs, the strength of association is expected to be less for mental action verbs. Thus if indeed motor region activation is observed in the semantic processing of these mental action verbs, it is thought to be more likely formed through mirror systems theory through imitated activation of the mirror neurons during the mapping of perceived actions of others onto oneself. However, since the neural representation patterns of mental action verbs with no verifiable products has not been explicitly studied, it is necessary to characterize the neural representation patterns of these verbs first with the aim in the future to be able to hopefully find a link between what we know of the acquisition of language and the progressive degeneration of it under disease states.

In order to do so, using event related potentials to gauge cognitive processing of these verbs, a lexical decision task was employed to directly compare visual verbs with no verifiable products to auditory verbs with no verifiable products so as to further validate the findings of the previous research into non-verifiable verbs and extend it to the realm of a wider selection of mental action verbs. However due to possible word characteristic differences and the shortage, in terms of the number of verbs usable, a second experiment was designed in which we used modality non-specific verbs such as perceive, distinguish, etc. which make sense in the auditory as well as visual contexts.

In this second experiment, the modality non-specific verbs are then embedded in both contexts and compared to themselves, thereby eliminating all possible word characteristic confounds which may or may not affect the first experiment. The principal advantage of doing so is that it allows us to make multiple comparisons. First between the specific word lists, secondly between the modality non-specific verbs under each context, and lastly even a comparison across context with grouped results of the specific and non-specific in each category. The hypothesis being tested is:

1) Consistent with the activation pattern of verbs with verifiable products, if processing of verbs with no verifiable products results in the co-activation of

motor cortex regions involved in the performance of those actions (i.e. eye occipital and ear parietal), then acquisition of those verbs is likely through mirror systems theory. If indeed this is the case we expect ERP differences across conditions driven mainly by the occipital lobe and parietal lobe specifically for components in the post 150ms to 500ms range as seen by Pulvermuller Components such as the P3 and N4 which would typically be elicited in the 150-500ms time windows are thought to be more involved in semantic processing than in response to attention processes involving stimulus characteristics.

2.1 Methods

2.1.1 Participants

A total of 20 participants (3 male and 17 female) were included in the analysis for this experiment. Four were left handed. Their ages ranged from 18 to 32 (mean= 21.1 years; SD= 4.1 years). Three participants were removed from the experiment for taking medication or having a medical condition that may have affected their data. And 3 participants were removed during the ERP cleaning procedure due to low number of correctly responded to trials. All participants spoke English as a first language, but the degree of bilingualism was not gauged which is a limitation of the study. Informed consent was obtained from all participants and those eligible received extra course credit for their participation.

2.1.2 Materials

A lexical decision task was used for the duration of the experiment. All stimuli were visually presented to the participants using E-prime software (v. 20). The target words consisted of visually presented English words and pseudo words. In experiment 1, these consisted of visual verbs and auditory verbs. All words were one to three syllables long but matched across condition. Word length did not differ significantly between the two categories (average values = 5.80 letters for visual verbs and 5.83 letters for auditory verbs). The frequencies and imageability of the words were analyzed using the MRC database (Wilson, 1988) with no significant differences found across conditions. Mono/bi/tri-syllabic pseudo words were generated by exchanging letters within and between the words and were thus matched to the words by number of letters and syllabicity (See table 2 for a list of all stimuli used and table 3 for word characteristics as per the MRC database). A limitation in this analysis of psycholinguistic properties is the lack of data for some of the words.

Table 2: Stimuli used

Modal Non-Specific Verbs	Pseudo words	Visual Modal Specific Verbs	Pseudo words	Auditory Modal Specific Verbs	Pseudo words
Perceive	Snees	View	Rapheever	Hark	Gistee
Distinguish	Centted	Gaze	Haseen	Heed	Simpties
Notice	Credin	Peer	Levorse	Hear	Blane
Recognize	Prestidgous	Witness	Wize	Listen	Rark
Identify	Mediny	Glimpse	Veep	Overhear	Hoves
Detect	Ditentize	Observe	Graw	Eavesdrop	Hodered
Sense	Vicerniser	-	-	-	-
Discern	Cheifigee	-	-	-	-

Table 3: Word characteristics from MRC data base

Word	*BFRQ*	*CBC*	*CPOS*	*IMG*	*KFFRG*	*NLET*	*NSYL*
HEAR	*34*	*394*	*V*	*425*	*153*	*4*	*1*
EAVESDROP	-	-	*V*	-	-	*9*	*2*
LISTEN	*13*	*408*	*V*	*378*	*51*	*6*	*2*
OVERHEAR	-	-	*V*	-	-	*8*	*3*
HARK	-	-	*V*	-	*3*	*4*	*1*
HEED	-	-	*V*	-	*8*	*4*	*1*
PEER	*1*	*406*	*V*	*376*	*8*	*4*	*1*
VIEW	*43*	*379*	-	*430*	*186*	*4*	*1*
WITNESS	*1*	*459*	-	*467*	*28*	*7*	*2*
GAZE	-	-	*V*	-	*12*	*4*	*1*
GLIMPSE	*1*	*372*	-	*422*	*16*	*7*	*1*

No *significant differences in frequency or word length p>.64*

Bfrq = frequency, CBC =concreteness, CPOS = common parts of speech, IMG = imageability, KFFRG =Kucera-French written freq., NLET = number of letters, NSYL = number of syllables

2.1.3 Procedure

Participants were tested individually in a sound attenuated booth where they were seated approximately 25 inches from the screen and were presented with a general instruction screen upon which the procedure was outlined for them. Each session lasted about 45-60 minutes. Participants were instructed to press a button whenever they saw a real word and do nothing when they saw a pseudo word. Presentation of the stimuli was done in 4 blocks containing 72 stimuli each (each set of audio and visual verbs was shown thrice). The stimuli were presented for 100ms in random order with an inter-stimulus time interval that varied between 1500 ms and 2500 ms so as to avoid expectancy effects. Before stimulus presentation, the participants focused on a fixation cross appearing in the center of the screen. Participants were instructed to keep their eye-blinking to a minimum.

2.1.4 ERP cleaning

Event-related potentials were recorded from a 64-electrode HydroCel Geodesic Sensor Net (Electrical Geodesics, Inc., Eugene, OR). Data acquisition was done using NetStation software, version 4.4.1 (Electrical Geodesics, Inc., Eugene, OR) and digitized with a sampling rate of 250 Hz, using the vertex as reference electrode. Data were re-referenced off-line to the average mastoid reference. EEG data was filtered on-line using a 0.1 Hz high pass filter and stored on a computer for off-line analysis.

ERP data were filtered off-line using a 0.1-30 Hz band pass filter and segmented into 1200 ms epochs that were sorted by condition. Epochs began 200 ms before stimulus onset and extended 1000 ms after the appearance of the stimulus. Using NetStation v.4.4.1 (Electrical Geodesics, Inc., Eugene, OR), data were examined for artifacts using an eye-blink threshold of 100μV and a threshold of 5μV for horizontal eye movements, and were visually checked afterwards. An average was calculated for each subject and epochs were baseline-corrected using the 200 ms interval before stimulus onset. A grand average across all participants was then calculated.

2.1.5 Data analysis

Behavioral dependent measures included means for reaction time (Ruddell & Hu, 2001) and accuracy of performance (percentage of correct responses). Individual response times were analyzed and all trials with a response time greater than 3 standard deviations were removed. Also response times of less than a 100ms, which are thought to be impulsive or inattentive in nature, were removed from the analysis (Luck, 2005). Less than 10% of trials in all conditions were removed.

Electro-cortical dependent measure consisted of adaptive mean amplitude measures within specific temporal windows across 4 region-of-interest (ROI) channel groups which were chosen to broadly gauge at the 4 main lobes of the brain. In experiment one, each ROI contained a set of at least 4 electrodes (listed numbers represent electrode numbers on the 64 electrode HydroCel Geodesic Sensor Net) (Frontal-6(3, 6, 8, 9), Left parietal-8 (14, 15, 16, 19, 20), Right parietal-8(50, 51, 53, 56,

57) and Occipital-9 (33, 34, 36, 37, 38) and the same electrodes were selected for the ROIs for experiment two. Four separate time ranges were defined for statistical analysis of possible differences chosen based on the grand averages: N1(90-150ms), P2(150-300ms), N4(300-500ms) and Late positive peaks (LPP)(700-1000ms) for experiment 1 and N1 (90-190 ms), P2(190-300ms), N4(300-550ms), and LPP(700-1000ms) for experiment 2. Variations are the result of peak shifts between experiments. In all analyses, the Greenhouse-Geisser corrections was employed whenever the assumption of sphericity was violated, but the corrected degrees of freedom have not been reported unless the results were affected accordingly (Greenhouse & Geisser, 1959) and the alpha level was set at .05. The analysis were run in the absence of the left-handers, and though the ERP results changed, the interpretation of the results did not, thus all participants were included in the presented analysis. In each experiment, the statistical analyses were performed separately for each ERP component. To follow-up on ROI differences, pair-wise comparisons of means were utilized.

2.2 Results

Each time window epoch was subjected to a 2 (Verb: visual, auditory) x 4 (ROI: frontal, left parietal, right parietal, occipital) repeated measures ANOVA for experiment 1. Within the General Linear Model, the Least Significant Differences (LSD) were used for the post hoc comparisons. Behavioral data were analyzed using a simple dependent samples t test.

2.2.1 Behavioral Data

Participants responded significantly faster to auditory verbs (584.54ms) compared to the visual verbs (601.75ms). $F(1,19)=4.48$, $p<.05$, $\eta^2= .19$. These reaction times are for only accurately responded to trials. When analyzing the accuracy in responses, it was found that participants generally responded to visual verbs with high accuracy (89.9%) whereas had more difficulty when semantically processing the auditory verbs (71.1%). This difference was significant. $t(19)=6.23$, $p<.001$. Individual word latencies along with percent accuracies are shown in table 4

Table 4: Word latencies and accuracy for experiment 1

	Mean RT	**Std Error**	**Accuracy rate %**
Eavesdrop	669.73	16.31	79
Fixate	790.01	24.77	79
Gaze	740.29	23.46	86
Glimpse	631.51	12.84	91
Hark	847.09	42.05	38
Heed	776.10	34.94	39
Hear	574.41	11.67	89
Listen	556.66	9.54	90
Observe	618.36	22.13	93
Overhear	631.98	13.64	82
Peer	636.02	17.02	87
View	574.29	16.79	90
Witness	589.46	13.64	89

2.2.2 ERP Data

The ERP data analysis was performed separately for each time window. The results of the major components analyzed are presented.

N1

There was no main effect of verb. $F(1,19)=1.34$, $p>.05$. The verb x ROI interaction also emerged non-significant. $F(3,57)=.30$, $p>.05$.

P2

There was no main effect of verb. $F(1,19)=2.41$, $p>.05$. The verb x ROI interaction emerged non-significant. $F(3,57)=.65$, $p>.05$.

N**4**

The main effect of verb was significant only at $p=.051$. $F(1,19)=4.34$, $p=.051$, $\eta^2=.19$. However there was no verb x ROI interaction. $F(3,57)=.60$, $p>.05$.

LPP

There was no significant main effect of verb $F(1,19)=.96$, $p>.05$ nor any significant interaction of verb x ROI $F(3,57)=.75$, $p>.05$.

2.3 Discussion

In experiment one, six auditory verbs were directly compared against six visual verbs, matched for imageability, frequency, number of letters as well as number of syllables. However, the low number of words used in the study, is a major limitation which was nevertheless explored to examine the behavioural and ERP differences if any elicited by them.

2.3.1 Behavioural analysis

An analysis of the behavioural data revealed that participants responded faster to auditory verbs than visual verbs. With regards to the study done by Pulvermuller et al (2001), this is not an unexpected finding given the location of the parietal lobe compared to the occipital lobe. However, further exploration revealed that participants responded with significantly poorer accuracy to the auditory verbs. Although it was hypothesized that unfamiliarity with the auditory verb list might have contributed to this poorer accuracy, lack of significance with regards to word frequency suggests this is not the case. Although the aforementioned parameters were controlled for across word lists (imageability, frequency, word length & syllabicity), it is possible that other word characteristics confound might be modulating this response time difference. Thus experiment two may shed more light on these observed differences. Additionally lack of frequency data for the words heed and hark might be contributors to the lack of frequency effects.

2.3.2 ERP analysis

ERP research over the years has garnered an unprecedented seat of importance in the study of cognition in psychology and increasingly researchers tend to ignore caution in interpretation of results obtained from such research. The fundamental problems of ERP research, namely signal-noise ratio, the necessity of averages, influence of artifacts and choice of points for the electrical references are common issues that researchers have attempted to address over the years (Kotchoubey, 2006). However, there is no standard practice in place and though there are gold standards as guidelines to follow, some are always violated (Luck, 2005). Thus the interpretations described must be treated with the caution due such research. In an effort to avoid the fallacy of the research methodologies, the ROIs were chosen to reflect broader regions of the cranium as opposed to smaller regions with at least 4 electrodes per area. Additionally, stringent ERP cleaning procedures were utilized to minimize the adverse effects of averaging, artifacts and signal-noise ratio anomalies. With that in mind, let us examine the findings of this study in greater detail.

The early components, N1 and P2 are thought to be elicited in response to differences in the physical characteristics of stimuli (Luck, 2005). Thus it was hypothesized that although word length and syllabicity were controlled for, other unaccounted for differences in physical characteristics might result in significant differences for the auditory and visual verbs. However, no significant differences emerged in the ERP analysis. Furthermore, the early components are also thought to reflect attentional differences (Luck, 2005). In the context of experiment one, no significant differences emerged, so the implications of these are discussed later.

The N4 is an ERP component thought to be elicited in direct response to semantics associated with the words (Hillyard & Kutas, 1998; Luck, 2005). The main effect of verb type was significant only at p=.051. It was expected that the N4 difference would emerge significant in the interaction across regions, since motor cortical region coactivation was expected regardless of the theory to back up the activation patterns. With regards to the N4 component, increased semantic incongruence has been shown to elicit higher N4 amplitudes (Luck, 2005). In experiment one, the visual verbs showed higher N4 amplitude (figure 2), which suggests that participants view visual verbs as incongruent. Experiment one employed the use of a small subset of all visual verbs in the English language in order to be able to compare to the same number of auditory verbs. However, a limitation of doing so, might be possible within list variability that might manifest in the lack of significance at the verb by region interaction. Thus future research needs to explore the characteristics of the entire visual verb list.

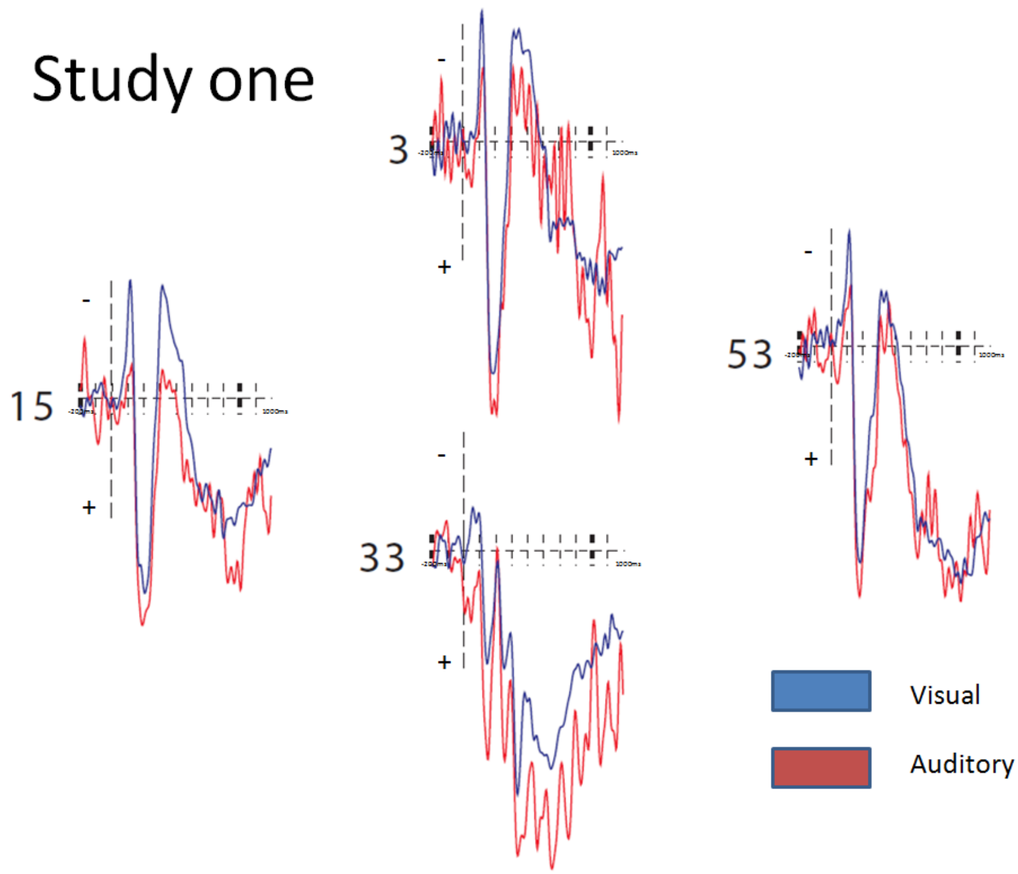

Figure 2: Grand-average event-related potentials in response to visual verbs and auditory verbs across the four regions of interest. Representative electrodes of each region have been shown. The time course of the ERPs extends for 1000ms following a 200ms baseline

3 Experiment 2

In experiment 1, a subset of visual verbs was compared directly to the auditory verbs using ERPs and a lexical decision task. In order to control for possible confounds typical of language research, in experiment two, modality non-specific verbs were embedded among the visual and auditory specific verbs and compared to themselves, thereby eliminating all word characteristic differences and allowing for the gauging of contextual effects on semantic processing within the brain.

Language studies revolving around verbs have generally pooled the different kinds without addressing the issues surrounding separate types of verbs. This study explores a specific subset of verbs namely verbs with no verifiable products in order to better inform us on possible differences in characterization patterns compared to the more researched verbs with verifiable products (Dickinson & Szeligo, 2008; Pulvermuller et al., 2001). A major complication in the researching of mental action verbs has been the enormous diversity in subclasses based on modality, meaning, concreteness, etc. (Dickinson & Szeligo, 2008). The present research attempts to address this issue by examining the effectiveness of embedding modality non specific verbs among modality specific verbs, thereby eliminating all word characteristics confounds since the same words are being compared to themselves.

3.1 Methods

3.1.1 Participants

A total of 23 participants (5 male and 18 female) were included in the analysis for this experiment. Three were left-handed. Without the left-handers, the results and interpretations remained the same, so all participants were included in the final analysis. Their ages ranged from 18 to 47 (mean= 22.6 years; SD= 7.9 years). Four participants were removed from the experiment for taking medication that may have affected their data. Four additional participants were removed during the ERP cleaning procedure due to poor performance. Informed consent was obtained from all participants and those eligible received extra course credit for their participation.

3.1.2 Materials

In experiment 2, the words being compared across conditions were the same so the word characteristic differences are non-existent. However the modality- specific verbs used to set context were taken from experiment 1 and thus matched for the same parameters as experiment 1. For both experiments, mono/bi/tri-syllabic pseudo words were generated by exchanging letters within and between the words and were thus matched to the words by number of letters and syllabicity.

Presentation parameters were kept constant between experiment 1 and 2. For this experiment, participants were presented with modality non-specific verbs embedded within the modality specific verbs in two separate blocks in order to hopefully eliminate the word characteristic differences characteristic of the modality-specific list. Thus participants were shown all 8 stimuli in random order 4 times in each block with the positions of the modality non-specific verbs being controlled for across blocks. Within each block, to ensure the setting of the context, the participants were first shown all six modality specific verbs before the onset of the pseudorandom sequential presentation of all stimuli. Each block consisted solely of auditory or visual verbs among the modality non-specific verbs to ensure proper setting of the context and was counterbalanced for participants.

3.2 Results

In experiment two, the ERP data were subjected to a 2 (specificity: modality specific, modality non-specific) x 2 (Context: visual, auditory) x 4 (ROI: frontal, left parietal, right parietal, occipital) repeated measures ANOVA for each epoch. Again LSD within the GLM were used for post-hoc comparisons. A 2(verb: visual, auditory) x 2(specificity: modality specific vs. modality non-specific) repeated measures ANOVA was used to analyze the behavioral data.

3.2.1 Behavioral data

The 2 (context: visual, auditory) x 2 (specificity: modality specific, modality non specific) repeated measures ANOVA revealed a significant main effect of response time for context. Regardless of specificity, people responded significantly faster to the verbs associated with vision (576.82ms) when compared to those associated with audition (605.45ms). $F(1,22)=4.71$, $p<.05$, $\eta^2=.18$. This difference was driven by the modality specific visual verbs compared to the auditory verbs ($p=.019$) as in experiment one. There was no significant difference between the modality non-specific verbs under the two contexts ($p=.23$). Also, the participants responded significantly faster to the modality specific verbs (565.29ms) compared to the modality non-specific verbs (616.98 ms). $F(1,22)=52.97$, $p<.001$, $\eta^2= .71$. In all comparisons between modality specific verbs and non-specific verbs, note the uneven number of stimuli (6 vs. 8) which may have impacted the data. The interaction between context and specificity emerged non-significant, ($p=.12$). An analysis of the accuracy in responses revealed a significant main effect of context $F(1,22)=20.24$, $p<.001$, $\eta^2=.48$, as well as specificity $F(1,22)=23.01$, $p<.001$, $\eta^2=.51$. However the interaction was also revealed to be significant $F(1,22)=32.14$, $p<.001$, $\eta^2.=.59$. Further exploration revealed that the interaction was driven by the auditory specific verb category which had already been shown to be responded to poorly in experiment one. Between the modality non specific verbs, there was no difference in accuracy ($p=.15$). Response time data and accuracy rates on a per word basis are presented in table 5 and 6.

Table 5: Latencies and Accuracy rates for the Visual context verbs

	Mean RT	**Std. Error**	**Accuracy Rate %**
Detect	643.47	21.77	96
Discern	773.42	33.19	78
Distinguish	705.20	32.27	98
Gaze	601.09	13.47	97
Glimpse	600.72	12.69	95
Identify	577.53	15.55	100
Notice	599.14	15.83	99
Observe	589.44	14.25	98
Peer	595.59	14.04	93
Perceive	639.34	28.31	99
Recognize	633.82	22.99	97
Sense	587.32	18.85	95
View	558.38	12.04	98
Witness	590.74	12.61	98

Table 6: Latencies and Accuracy rates for the Auditory context verbs

	Mean RT	**Std. Error**	**Accuracy Rate %**
Detect	624.84	19.31	97
Discern	758.15	38.01	66
Distinguish	691.61	22.63	97
Eavesdrop	647.11	14.78	75
Hark	664.75	25.47	45
Heed	679.59	21.04	42
Hear	597.87	11.95	96
identify	608.02	16.22	96
Listen	571.97	12.25	97
Notice	573.99	14.36	95
Overhear	644.63	13.69	90
Perceive	711.99	28.48	96
Recognize	655.43	637.10	99
Sense	637.10	25.61	93

3.2.2 ERP data

The ERP data analysis was performed separately for each time window. The results of the major components analyzed are presented.

N1

There was no main effect of specificity, $F(1,22)=3.92$. $p=.06$, nor a main effect of context, $F(1,22)=1.05$, $p>.05$. The interaction between specificity and context emerged non-significant, $F(1, 22)=.33$, $p>.05$. However the specificity x ROI interaction was found to be significant, $F(3,66)=3.54$, $p<.05$, $\eta^2=.14$. Post hocs revealed this to be driven by the three ROIs: frontal ($p=.047$), left ($p=.025$) and right parietal ($p=.013$) lobes. Also the context x ROI interaction was significant, $F(3,66)=3.14$, $p<.05$, $\eta^2= .13$. This was revealed in the post hoc analysis to be driven by the frontal lobe ($p=.06$). The specificity x context x ROI interaction was not significant. $F(3,66)=1.26$, $p>.05$.

P2

The main effect of specificity was found to be non-significant, $F(1,22)=1.76$, $p>.05$. So was the main effect of context, $F(1,22)=.21$, $p>.05$. The specificity x context interaction remained non-significant, $F(1,22)=.96$, $p>.05$. Also the specificity x ROI interaction was non-significant, $F(3,66)=1.18$, $p>.05$. However the context x ROI interaction did achieve significance, $F(3,66)=3.61$, $p<.05$. $\eta^2=.14$.Upon running the post hocs, the occipital lobe was shown to be the driving force behind the interaction (p=.053). The specificity x context x ROI interaction was not significant, F(3,66)=.72, p>.05.

N4

The analysis of the N4 showed no significant main effect of specificity (F(1,22)=.67, p>.05) nor context (F(1,22)=.23, p>.05). The specificity x context interaction also was not significant, F(1,22)=1.39, p>.05. However, the specificity x ROI interaction emerged significant, F(3,66)=3.98, p<.05, η^2=.15. This was revealed to be driven by the frontal lobe (p=.102). Also the context x ROI interaction emerged significant, F(3,66)=3.53, p<.05, η^2=.14. The context x ROI interaction was driven by the occipital lobe (p=.12). The specificity x context x ROI interaction was not significant, F(3,66)=1.02, p>.05.

LPP

The LPP analysis revealed no significant main effect of specificity, F(1,22)=.01, p>.05. Also there was no significant main effect of context, F(1,22)=1.13, p>.05. All four interaction of specificity x context (F(1,22)=.07, p>.05), specificity x ROI (F(3,66)=1.82, p>.05), context x ROI (F(3,66)=.64, p>.05) and specificity x context x ROI (F(3,66)=1.25, p>.05) emerged non-significant.

3.3 Discussion

The principle objective of this study was to examine the neural representation pattern of mental action verbs by embedding modality non-specific verbs in two specific modalities, namely vision and audition, with the aim to delineate whether Pulvermüller's theory of associative learning or the mirror systems theory could more accurately account for the observed neural representation patterns.

3.3.1 Behavioural analysis

An analysis of response time in the processing of modality nonspecific verbs in the visual context compared to in the auditory context revealed no significant response time differences. Although significant response time differences for the modality specific verbs emerged, it was found that auditory verbs were responded to with a significantly lower accuracy rate compared to the visual ones. The task given to the students was not a speeded lexical decision task in which participants were asked to respond as quickly as possible, but rather participants were informed to simply do their best to follow the instructions which informed them to press a button whenever they saw a real word, as compared to a pseudo word. Interestingly, the results do correspond to the speed accuracy tradeoff typical of such literatures, whereby decreased accuracy seems typically to be associated with increased speed (Van der maas, Dolan & Molenaar, 2002). Alternatively lowered attention to the auditory verbs may also account for this observed difference. Thus stems the usefulness of ERPs which complement behavioral measures, allowing us to test these hypotheses. For the former, the appearance of P300 component would be observed while the latter would produce differences in the earlier component, namely N1 and P2. Each is described more fully in the ERP section of the discussion.

Of interest, Pulvermüller et al. (2001) described the collection of behavioral data as essential for testing the predictions of the neurobiological model of action processing. Specifically, they proposed that wider cortical distributions (as discovered for the leg-related verbs) and narrow distributions (as discovered in the face-related items) would result in a difference in processing times because the longer cortico-cortical connections imply longer travelling times for action potentials upon ignition of the networks (Pulvermüller et al., 2001). The primary purpose of the behavioral analysis in this study was to test this prediction with regards to visual verbs compared to auditory verbs for which the expectation is longer response time for visual verbs due to wider cortical distribution (occipital lobe) compared to auditory verbs (temporal verbs). However while methods such as fMRI provide sufficient resolutions to pinpoint the origin of activation and thereby make such comparisons, the relatively poorer spatial resolution of ERPs means that this aspect of the hypothesis is marginally more difficult to test. However, as mentioned before, a key advantage of using the ERP technique is its ability to provide a measure of processing of stimuli independent of behavioral changes (Luck, 2005).

3.3.2 ERP analysis

Prior language research incorporating ERPs has led to the assumption that early components are elicited in responses to differences in the physical characteristics of the stimuli and may rely on factors of the stimuli rather than an individual's processing of its meaning whereas the later components are thought to be more sensitive to changes in the meanings of stimuli (Luck, 2005). Thus with regards to experiment two, no ERP differences were expected in the early components. However due to the differences observed in the grand average waveforms, they were analyzed. Each epoch was chosen to reflect the component in its entirety. As mentioned earlier, the waveforms reflect grand averages and may thus not reflect latent components but rather averaged differences. The electrodes for each ROI are chosen for the differences they exhibit between categories. The purpose of testing interactions with ROIs across epochs is to gauge whether cognitive processing differences are region specific, which would lend further support to associative learning theory or the mirror system theory in relation to the verbs based on the findings. All ERP analysis of the data from experiment one revealed a lack of significance except for the effect of context which approached significance. Thus the discussion shall focus on experiment two unless otherwise specified.

N1

The N1 is generally assumed to reflect selective attention to basic stimulus characteristics, initial selection for later pattern recognition, and initial discrimination processing (Key, Dove & Maguire, 2005; Luck, 2000; Mangun & Hillyard, 1990; Vogel &). This is typically attributed to enhanced processing of the attended location (Coull, 1998; Luck 1995). Using a combination of imaging techniques, researchers have localized the origin of visual N1 sources in the inferior occipital lobe and the occipito-temporal junction as well as the inferior temporal lobe (Bokura, Yamaguchi & Kobayashi, 2001; Hopf et al., 2002). Pulvermüller's study of 2001 found no significant differences in the early components <200ms. Thus none were originally proposed for this experiment. However the study done by Thomas and Dickinson, (2012) comparing visual verbs with no verifiable verbs to mouth related verbs with verifiable products did find an N1 difference based on which the possibility of an N1 difference was hypothesized.

Within experiment 2, we discovered a context by ROI interaction as well as a specificity x ROI interaction for this N1 component. Both were driven in part by the frontal lobe. Comparing the modality specific verbs to the modality non-specific verbs as seen in the figure 3, we see that the interaction is driven by the modality non-specific verbs and not the modality specific verbs, a finding consistent with the non-significance in experiment one. This is largely a surprising finding because as mentioned before, the N1 is thought to reflect selective attention to basic stimulus characteristics such as spatial location, color, motion, etc. (King & Kutas, 1995). However in the case of the modality non-specific verbs, it was the same verbs being compared to themselves, thereby rendering the basic stimulus characteristics exactly the same. The only variable thus, is the context within which the verbs are set and evidence suggests that participants are able to discriminate the two as early as 90 ms.

An early study done in 1987 by Besson and Macar comparing congruent stimuli to incongruent stimuli was done to examine the effect of expectancy in non-linguistic stimuli on the N4 component. However, they stumbled instead upon an N1 difference which was shown to be larger for incongruent stimuli than congruent stimuli. Albeit a possible explanation for the N1 difference observed, an alternate and more likely explanation given our behavioral results, involves the role of attention.

Subsequent research on the N1 found that its amplitude varies according to the levels of attention. Thus using a paradigm known as the filtering paradigm to assess how attention influences perception of the same stimuli, Luck et al (2000) discovered that a larger N1 is elicited for attended targets compared to unattended targets. In the case of our study which is a linguistic study as opposed to the visuo-spatial task employed by Luck et al., 2000, the auditory verbs elicited smaller N1 in the three regions of interest except the occipital lobe which had higher N1 amplitude. This appears to be consistent with the obtained behavioral results wherein participants displayed lowered accuracy for the auditory specific verbs. It would appear that the reduction in accuracy is the result of lowered attention rates to the auditory verbs. Prinzmetal, McCool and Park (2005) studied the effects of voluntary and involuntary attention on reaction time and accuracy in a spatial cuing paradigm. They found that response time is affected by inattention, voluntary or not (Prinzmetal et al., 2005).

It is important to note that the context effects on the modality non-specific verbs are regulated by the modality specific verb list since they set the context within the experiment. Thus it is possible for residual effects of the modality specific lists to affect the outcomes on the modality non-specific list, even if it is at a reduced rate. However due to the lack of literature surrounding such a previously unseen phenomenon, further research is required to successfully delineate it. Of key importance with regards to the finding is the actual presence of the difference between the two conditions. It suggests that our manipulation of context did actually work and that participants were able to make that distinction between the two contexts within the modality non-specific list.

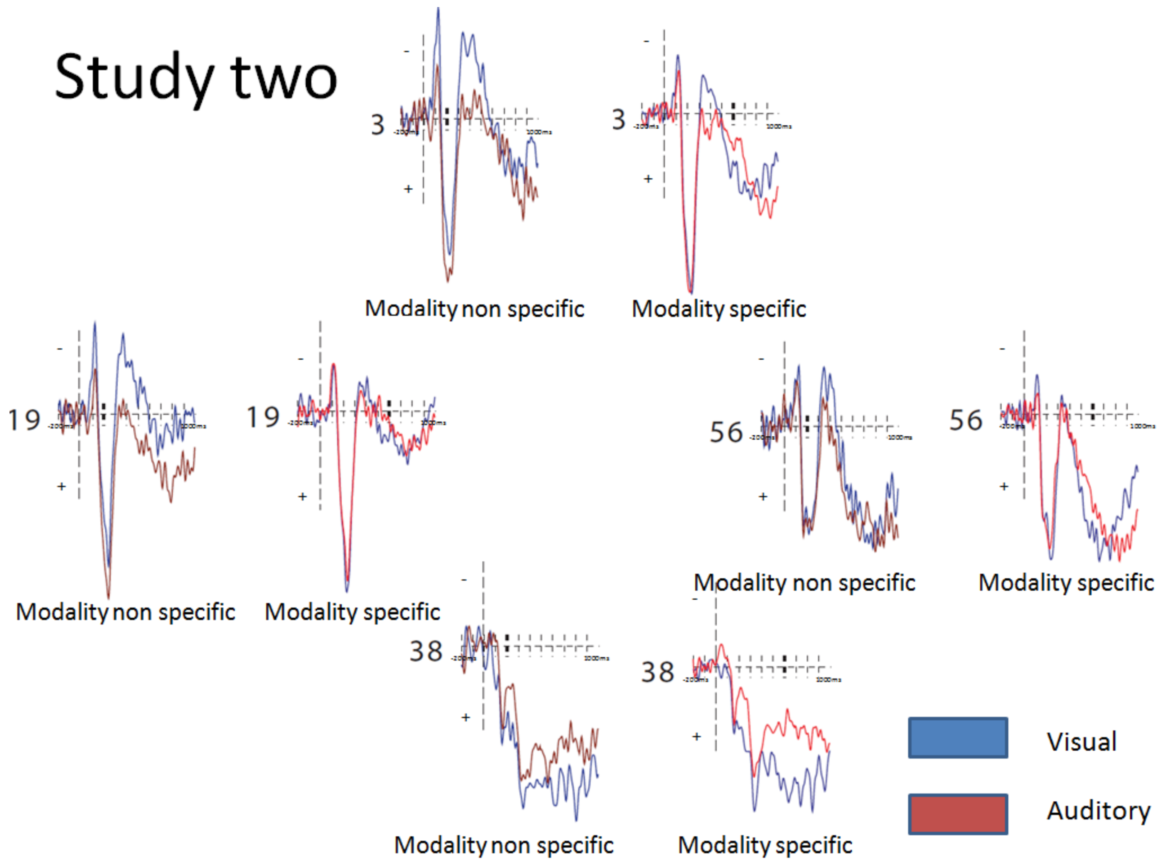

Figure 3: Grand-average event-related potentials in response to visual verbs and auditory verbs across the four regions of interest in the modality non-specific and modality specific conditions. Representative electrodes of each region have been shown. The time course of the ERPs extends for 1000ms following a 200ms baseline

P2

The P2 component is often thought to be the first component of lexical access and is elicited by frequency differences or attention (Luck, 2005). As opposed to the N1 difference which existed for the context x ROI interaction as well as the specificity x ROI interaction, the P2 achieved significance only for the context x ROI interaction driven by the occipital lobe. A comparison of the waveforms clearly shows a similar effect across specificity for the two contexts. A major complication in clearly characterizing the P2 is that evidence suggests that it is modulated by a large and diverse number of cognitive tasks (Luck, 2005).

Two studies by Peters, Suchan Zhang and Daum (2005a & b) have helped characterize the role of the P2 component with regards to visual spatial attention and visuo-verbal interactions. The first study sought to end the debate as to the time course involved in updating processes during saccadic eye movements. Fifteen participants were subjected to a saccadic double-step task which required them to perform two successive saccades to flashed targets. To ensure updating of the visual space, the saccade targets would disappear before the execution of the first saccade. Interestingly a significantly larger slow P2 wave was observed compared to the control condition which suggests that visual updating occurs no earlier than 150 ms post stimulus presentation. A second study sought to investigate the interactions between modality specific storage systems in working memory (Peters et al., 2005). For this, a modified 2-back paradigm was used in which participants were asked to make same/different judgments with respect to the 2-back item (i.e. the stimulus presented 2 stimuli previously). Their findings suggest the modulation of the P2 reflects reduced allocation of attention resources towards the eliciting stimulus. The role of the P2 as implicated in attentional processing has also been established in other studies (Mangun & Hillyard, 1995; Woldorff & Hillyard, 1991).

Interestingly as seen from figure 3, while the amplitude differences across contexts vary across regions for the modality non-specific verbs, there appears to consistently lower P2 amplitude for the auditory verbs which as per the above mentioned studies reflects lower allocation of resources towards the semantic processing of these verbs. When gauged in conjunction with the behavioral data we see that the auditory modality non-specific verbs had the highest error rates a finding consistent with the observed ERP data which provides further support for the view that perhaps attentional differences among the verb categories are driving the context x ROI interaction. This suggests that we inherently allocate fewer resources towards semantically attending to auditory verbs compared to visual verbs. It would be interesting in future research to examine if this is the result of the task type by using an auditory task as opposed to a visual one to examine if it affects attention in the opposite reaction.

N4

The N4 component is the most widely studied of components in ERP research involving language studies (Luck, 2005). Originally reported by Kutas and Hillyard, (1980) the N4 is a negative-going wave component that is typically seen in response to violations of semantic expectancies (Luck, 2005). N4 amplitude is thought to increase in response to infrequent words compared to frequent ones and for inconsistent primes compared to consistent one (Luck, 2005).

The effect of context in experiment 1 between auditory verbs and visual verbs approached significance. The η^2 value of 0.19 suggests that this may be a power-related issue. Within the N4, for experiment 2, two interactions emerged significant: the specificity x ROI interaction driven by the frontal lobe and the context x ROI interaction driven by the occipital lobe. In essence experiment two is a priming study with the modality specific verbs used to prime the context for the modality non-specific verbs. Overall, the evidence thus far suggests higher amplitudes for the auditory verbs than the visual verbs, a finding which suggests that participants perceive auditory stimuli as being semantically, morphologically or orthographically related to the modality non-specific verbs (Kutas and Federmeier, 2000; Kutas & Hillyard, 1980a, b). Nevertheless, the context x ROI interaction provides evidence that the two categories are processed differently across regions of the brain which is the primary hypothesis being tested. Further exploration of this reveals higher N4 amplitude for the visual verbs in the left parietal region for the modality non-specific verbs and higher N4 amplitude for the auditory verbs in the occipital lobe, suggesting that within each region, the amplitude is modulated differently In the occipital lobe which controls visual activity, the semantic incongruence of visual verbs was lower compared to the auditory verbs whereas in the parietal region where audition is controlled, we see the opposite. This provides further evidence that the activation pattern observed by Pulvermüller et al. (2001) appears to be followed by mental action verbs with no verifiable products.

Holcomb (1993) did a study to test the implications of semantic priming and stimulus degradation on the N4 component. It was found that the N4 component was larger for unrelated than related targets. More importantly, the evidence suggests that the behavioral and ERP measures reported in the study appear to be tapping into different components of the processes involved in semantic priming (Holcomb, 1993). From the ERP results of experiment two, it is apparent that visual verbs in the modality-non-specific context have the higher amplitude across regions except in the occipital region. In contrast, in the specific category both verbs have similar amplitudes consistent with the findings of experiment one. This would suggest greater incongruence between the modality non-specific auditory verbs than the modality non-specific visual verbs. One likely explanation for this phenomenon is the apparent reduced attention in response to the auditory verbs as gauged by the P2 results. Reduced attention to the auditory verbs likely led to an overall reduced priming effect of the auditory verbs. The results of this study appear to have been successful in tapping into the processes gauged by ERP measures involved in semantic priming but not so in the case of the behavioral measures. It is believed that this could be the result of interference at some semantic level during the recognition of the modality non-specific verbs or as gauged by the attentional modulation afforded by the P2, an issue of inattentiveness.

Further research is required to further pinpoint the source. In an attempt to do so, future research could likely employ a subjective measure of attention by incorporating a confidence questionnaire either within or after the task. Alternatively, the absence of N4 effects for the modality specific verbs could be the result of within list variance. i.e. within list variability for either category may be modulating the differences. Thus a second avenue of future research would be to examine within list variability by examining ERP effects across subclasses of the verbs as gauged by a subjective measure such as multidimensional scaling (Dickinson & Szeligo, 2008).

LPP

No significant main effects or interactions emerged in the analyses of the late positive peaks which are thought to tap into post-lexical access (Luck, 2005). Largely this is a surprising finding. It is thought that within list variability may possibly be the cause of this lack of difference, particularly so in the case of the modality specific verbs. Future research may aim to look at within list variability to see if it is a mitigating factor in the analysis of ERP data.

4 General Discussion

Mental action verbs in the English language, due to their non-verifiability in terms of behavioral output, represent a distinct class of verbs whose brain activation pattern and characterization needed investigation so as to better inform us on their possible mode of acquisition and more importantly how they may or may not be affected by cognitive decline in the face of disease states such as AD and SD. The present study investigated these mental action verbs using event-related potentials.

This study led to a number of unexpected results about mental action verbs with no verifiable products. First the response time differences between responding to auditory and visual action verbs was significant. The auditory verbs were responded to faster than the visual verbs consistent with the proposed hypotheses of acquisition through associative learning or mirror systems theory however, a significant accuracy difference in the two verb types was found suggesting that these response time differences are the result of the speed accuracy tradeoff commonly found in the literature (Wickelgreen, 1977). In the direct analyses between the two verbs no significant ERP differences emerged that would lend support to the acquisition of these verbs through associative learning or mirror systems theory. However, a second unexpected finding was the lack of accuracy in responding to the modality specific auditory verbs, consistent across participants through both experiments.

The results of the ERP portion of the study suggest that this is perhaps the result of reduced attentional resources allocated to the auditory verbs. However, through the use of a priming study to set the context of modality non-specific verbs in the two specific modalities, it was possible to gauge at the semantic processing differences between the two. The embedding of the same modality non-specific verbs under the two contexts appears to be a novel fix for the issue of confounds characteristic of language studies. By manipulating the context on the same words it is possible to gauge semantic processing related to the verb category without directly comparing the words, a feat shown clearly to be a hassle by the serious lack of modality specific verbs and the word characteristic confounds between the different kinds (Dickinson & Szeligo, 2008). It is thought that the lack of ERP differences between the specific verbs is due to the low number of modality specific verbs available for use in the study. Future studies may attempt to address this issue by doing the study in an alternate language with a wider selection of words. That these differences were picked up on as early as 100ms is to the author's knowledge a hitherto unseen phenomenon, and of great importance in furthering our understanding of N1 differences in ERP studies. Research examining the N1 with regards to attention has generally found greater N1 mean amplitude for increased attention to stimuli. In the case of the modality non-specific verbs, the N1 amplitude was found to be higher for the visual context as opposed to the auditory context. Interestingly a similar N1 difference between verifiable verbs and non-verifiable verbs was found in the earlier study by

Thomas and Dickinson (2012) with greater N1 amplitude for visual verbs with no verifiable products compared to the mouth-related verbs with verifiable products.

The P2 context X ROI interaction appears to be modulated by reduced attention to the auditory verbs compared to the visual verbs which may explain the significantly reduced accuracy in response to these verbs. Albeit experiment two was designed to prevent the fallacy of these issues, evidence suggests that a result of the lowered attention is a reduced priming effect for the modality non-specific verbs from the auditory verbs which would explain the reduced N4 amplitude in the auditory condition for the modality non-specific verbs. Alternatively, the reduced amplitude in the auditory condition may be the result of subjective incongruence between visual verbs and the used modality non-specific verbs list. Future research may attempt to delineate the source by incorporating subjective ratings of the congruence by the participants.

Thus far, both N1 and P2 differences suggest reduced attention for the auditory verbs however, the modality non-specific verbs were the same in both cases thus supporting the notion that context is manipulating this ERP differences in a similar manner to attention. In addition context x ROI and specificity x ROI interactions in most significant epochs were driven in part by the frontal lobe or occipital lobes. The frontal activation is likely the result of having to consciously sort the modality non-specific verbs within the two contexts (Tortora & Derrickson, 2008). The context x ROI interactions driven by the occipital lobe however lends support to the notion that the activation pattern of non-verifiable verbs is consistent with Hebbian associative learning. In particular the mean amplitude differences across the two contexts in the modality non-specific list between the left parietal and occipital lobes provide strong evidence for the differential activation patterns according to verb type. In the case of verbs with verifiable products the observed neural representation patterns are thought to form through continuous motor action activation and semantic processing activation (Pulvermüller et al., 2001).

In the case of mental action verbs with no verifiable products to be coactivated during semantic processing, if a similar activation is found, it is thought to be the result of association formation through the mirror systems theory. The results of this study suggest that the mirror system theory is more likely to explain the acquisition, given the non-verifiability of the verbs (Boulenger and Nazir, 2010; Pulvermüller, 2001, 2005; Rizolatti & Craighero, 2004). It was hypothesized that that these early ERP differences may likely reflect task difficulty as a result of the accuracy differences between the auditory and visual verbs. Given the emergence, of the N4 difference however, it would appear that semantic processing differences are responsible for some of the variance. However future research using longitudinal studies will likely be required to confirm this. Also future research may attempt to create better spatial resolution by doing the study using fMRI. Lastly it was hypothesized that perhaps the lack of differences in study one are modulated by within list variability. Thus future research may also choose to explore this by recording ERPs for each and then studying the within group variability. Thus the principal objectives of discovering possible differences in semantic processing based on brain location between the two verb types has been achieved and hopefully future research may further characterize these differences with the hope to help us better understand comprehension of language and its decline in the face of brain damaging diseases such as AD, SD, etc.

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