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Parkinson's Patients' Upper and Lower Limb Motor Impairments Differentially Influence Action Verb Processing

Peter Nguyen, *The University of Western Ontario*

Supervisor: Ken McRae, *The University of Western Ontario*
A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Neuroscience

PARKINSON'S PATIENTS' UPPER AND LOWER LIMB MOTOR IMPAIRMENTS DIFFERENTIALLY INFLUENCE ACTION VERB PROCESSING

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by

Peter Nguyen

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The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

Abstract

Theories of grounded cognition emphasize the role of sensorimotor simulation in conceptual knowledge. With regard to action concepts, the motor system is hypothesized to play a central role in their representation and processing. The present study investigates whether patients with Parkinson's disease (PD) who have greater upper versus greater lower limb impairments show different patterns of performance when processing action verbs. Patients and matched controls made action decisions on upper-limb (*reach*), lower-limb (*kick*), and psych verbs (*think*). The most important result was an interaction between PD dominance (PD upper vs. lower limb motor impairments) and verb type (upper- vs. lower-limb verbs). PD patients with greater upper limb impairment were slower in processing upper-limb versus lower-limb verbs, whereas those with greater lower limb impairment performed similarly on these verb types. The results support a relatively fine-grained functional role of the motor system in the conceptual representation of action verbs.

Keywords: Grounded cognition, Action verbs, Motor system, Parkinson's disease

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Parkinson's Patients' Upper and Lower Limb Motor Impairments Differentially Influence Action Verb Processing

During the past couple of decades, a great deal of research in cognitive neuroscience has focused on the theoretical and empirical issues surrounding the neural and conceptual representation of word meaning. Although it is well established that the left inferior frontal and superior temporal cortices, Broca's and Wernicke's areas, respectively, play a major role in language processing, the role of sensory and motor systems in semantic processing in the brain remains controversial. There have been two main approaches to conceptual representation, amodal and modality-specific theories. In amodal theories, concepts such as *apple* or *truck* are represented in the brain in an abstract and symbolic form, stored independently of perceptual (e.g., visual, auditory) and motor (e.g., movement, proprioceptive) modalities that are used during experience (Barsalou, 2008). That is, perceptual and motor experiences are assumed to be important for learning, but these experiences are transduced into amodal symbols, resulting in memory representations that are distinct from the modal systems. In contrast, in modality-specific theories, concepts are represented, at least in part, by the brain's perceptual and motor systems (Barsalou, Simmons, Barbey, & Wilson, 2003). That is, the perceptual and motor experiences that are important during learning are also involved in the representation of the learned concept.

There has been a great deal of debate among proponents of these views. As part of this controversy, researchers have investigated concepts and their relationships with perceptual and motor systems of the brain. For example, Goldberg, Perfetti, and Schneider (2006) investigated the neuroanatomical correlates of the perceptual processing of object concepts. In an fMRI experiment, participants were presented with words denoting concrete concepts (e.g. *apple*, *feather*) and were asked to verify whether the item possessed a feature from one of four sensory modalities: colour (*red*), sound (*loud*), touch (*soft*), or taste (*sweet*). Goldberg et al. found activation of related modality-specific sensory areas of the brain during feature verification. For example, when a participant verified that a pillow is soft, tactile-related areas of the brain would be selectively activated. Goldberg et al.'s results suggest that modality-specific systems are part of how the brain represents and computes concepts.

In addition to object concepts, another intensely researched area is action concepts and their relationship with the motor system. This is the focus of my thesis. Although the concept of action is typically regarded as physical movement, for the purpose of this thesis, it includes verbs that refer to both physical and mental actions, as in *kick* and *think*. Most of the research in this domain has been limited to physical action concepts (e.g., *grasp*, *kick*, and *smile*) because they can be relatively easily mapped along the body and have corresponding somatotopic representations in the brain. This enables fine-grained hypotheses to be derived from amodal and modality-specific theories.

The motor system involves areas of the central nervous system that are responsible for movement. This includes cortical – primary, premotor, and supplementary motor cortex – and subcortical structures – basal ganglia. To study the parallels between physical action concepts and the motor system, researchers have explored how impairments in motor functioning such as those observed in amyotrophic lateral sclerosis (ALS), Huntington's disease, and progressive supranuclear palsy, affect conceptual representation of physical actions during language processing (Cotelli et al., 2006; Grossman et al., 2008; Teichmann et al., 2008).

The goal of the current study is to explore how Parkinson's disease (PD), a movement disorder, influences linguistic processing of action concepts. Specifically, I tested whether PD patients with either greater upper or greater lower limb impairment differentially process hand-related (*reach*) and leg-related verbs (*run*). In addition, I explored how processing of mental action words such as *think* and *admire* are affected in PD. I found that arm-related action words are processed more slowly than leg-related action words in PD patients with greater upper limb impairment, whereas there was no difference in PD patients with greater lower limb impairment. Surprisingly, processing of physical and mental action words were not impaired in PD patients relative to controls. I interpret these results in terms of a functional and selective role of the motor system in language comprehension of body-part-specific action concepts. The results provide support for the view that conceptual representations are grounded in modality-specific experiences.

The remainder of the Introduction is structured as follows. I begin by discussing a dominant view in conceptual knowledge, grounded cognition. Next, I discuss the relationship between the motor system and action concepts in language by presenting findings from neuroimaging (fMRI), transcranial magnetic stimulation, and motor-lesion patient studies. I then introduce Parkinson's disease and discuss the PD literature regarding verb processing. Finally, I present some shortcomings from verb studies with PD patients that lead to the present study.

Grounded Cognition

In grounded cognition theories, concepts are represented and processed using sensory and motor experiences both with the world and within the body. That is, conceptual representations are 'grounded' in these modal experiences. Accounts of grounded cognition emphasize the role of simulation in cognition (Barsalou, 2008). Simulation involves the partial re-enactment of perceptual and motor states acquired during experience with the external environment, as well as bodily states. As experience is gained (e.g., playing with a soccer ball), the brain retains perceptual and motor states, which are then integrated to form a multimodal representation (e.g., how to kick a ball, the way a ball looks and feels). Later when the concept (e.g. soccer ball) is brought to mind, a multimodal representation of the experience is simulated.

With regard to action concepts, the functioning and integrity of the motor system is expected to play a crucial role in their representation. Because of the somatotopic representation in the motor cortex, examining the parallels between action concepts and the motor system has played a central role in grounded cognition studies.

Neuroimaging Evidence

Neuroimaging techniques have been used to assess the involvement of the motor cortex during language processing. For example, Hauk, Johnsrude, and Pulvermüller (2004) investigated the activity of cortical motor areas during processing of physical action words. Healthy individuals, while in an fMRI scanner, passively read single words such as *lick*, *pick*, and *kick* that denote actions of specific body parts. Consistent with grounded cognition theories, they predicted that when people read such words, the motor system should be activated. More specifically, when people read action verbs relating to the legs, hands, or face, then motor areas of the brain corresponding to those body parts should become active. First, Hauk et al. found that the motor cortex was activated from action words. Second, and more importantly, activity of neural regions responsible for movements of the foot, hand, and tongue overlapped with those involved in reading corresponding action verbs. Hauk et al. interpreted these results in terms of the motor system being directly involved in the neural representation of physical action concepts.

Tettamanti et al. (2005) used fMRI to investigate whether selective cortical motor areas become active when people listen to sentences that denote bodily action. To locate somatotopic ‘mirror neuron areas’ in the motor cortex, the researchers had participants observe actions of the leg, hand, and mouth. Participants then listened to sentences expressing actions of related body parts. In the left motor cortex, areas activated during observation of bodily action overlapped with those activated by sentences describing related actions. Tettamanti et al.'s results suggest that language comprehension of physical action at the sentence level involves selective neural activity in the motor regions.

In a similar fMRI study, Aziz-Zadeh, Wilson, Rizzolatti and Iacoboni (2006) investigated whether reading sentences describing body-part-specific actions involves motor areas crucial for executing and observing actions. Participants observed actions of the foot, hand, and mouth. They then read sentences describing actions of the same body parts. Aziz-Zadeh et al. found that in the left pre-motor cortex there was a clear congruence between areas that were active in action observation and those that were active when reading body-part-specific actions. The authors concluded that a key role of 'mirror neuron areas' was the re-enactment of sensory-motor representations during comprehension of language describing physical actions.

Although selective cortical motor areas have been shown to be activated during linguistic processing of physical action concepts, such findings do not specify whether the role of the motor system is functional- or ancillary-related (Mahon & Caramazza, 2008). In other words, at least according to some researchers, activation of these cortical motor areas may be an intrinsic part of physical action concepts, or instead it may be a consequence of understanding the action concept, so that activation of these cortical areas is not part of the concept per se.

TMS and Motor-Lesion Evidence

To elucidate the role of the motor system in language processing, transcranial magnetic stimulation (TMS) and motor-lesion patient studies have been conducted. Pulvermüller, Hauk, Nikulim, and Ilmoniemi (2005) investigated how depolarization of motor cortical activity affects processing of physical action words. Single-pulse TMS was applied to hand and leg motor areas while participants performed a lexical decision (word/nonword) task on arm-related and leg-related verbs. TMS applied to the hand area of the motor cortex led to shorter lexical decision latencies to arm-related than to leg-related action words, whereas stimulation over the leg area produced opposite results. Similarly, Papeo, Vallesi, Isaja, and Rumiati (2009) investigated whether the left primary motor cortical areas are automatically and necessarily involved in language comprehension of physical action verbs. They applied TMS to hand and non-hand areas of the motor cortex while participants performed a lexical decision task. TMS applied to the hand area resulted in shorter lexical decision latencies for hand-related action verbs over non-hand-related action verbs. These results suggest that there is an interaction between language and motor areas, and that this dialogue is fast and automatic.

Neininger and Pulvermüller (2003) tested for word-category deficits in patients suffering from right hemisphere lesions. Two groups of patients with right frontal and right tempor-occipital lesions were assessed on their ability to process verbs and nouns using a lexical decision task. Patients with right frontal lesions showed the most severe deficits in processing action verbs (*grasp*), whereas patients with right tempor-occipital lesions showed the most severe deficits in processing of concrete nouns (*table*). This double dissociation suggests that frontal cortical areas are more involved in action processing, whereas temporal cortical areas are more involved in noun processing.

Grossman, Anderson, Avants, Elman, and McCluskey (2008) studied a group of amyotrophic lateral sclerosis patients with cortical atrophy to investigate their ability to process verbs and nouns. Voxel-based morphometry was used to assess the degree of cortical atrophy. Performance on verb and noun processing was measured using a word-description matching task. In this task, participants were presented with a phrase describing an action or object and then were asked to select the best of four available action verbs or object nouns that matched the description. Grossman et al. found that the degree of motor cortical atrophy was correlated with performance on the action verb judgements.

The results from the studies presented in this section suggest at least a partly functional role of cortical motor areas in processing of physical action denoted by words. That is, the cortical motor areas appear to be crucial in the conceptual representation of physical actions.

The importance of the motor system's integrity in language processing has been emphasized (Fisher & Zwaan, 2008). However, the motor system is complex and involves more than just cortical motor areas (primary, pre-, supplementary motor cortex). It is well known that the basal ganglia, a group of subcortical nuclei, play a major role in the motor system, particularly in voluntary movement and learning of routine behaviour (Marsden & Obeso, 1994). It is well established that parts of the basal ganglia, in particular, the striatum, form circuits with the frontal lobe, and these circuits are instrumental in the functioning of cortical motor areas (Cardona et al., 2013). To assess the role of subcortical motor structures in linguistic processing of action concepts, researchers have studied patients with Parkinson's disease.

Parkinson's Disease

Parkinson's disease (PD) is a disorder characterized by degeneration of dopaminergic cells in the central nervous system, specifically in the substantia niga, which leads to progressive impairments in motor function. The four cardinal symptoms of PD are tremor, rigidity, slowness of movement, and postural instability. It is well known that dementia can develop in later stages of PD. With regard to disease progression, the disease emanates from the brain stem and projects superiorly to the basal ganglia during the early stages, and to the cerebral cortex in the later stages (Braak et al., 2003).

For a long time, PD was defined as a disorder presenting with motor deficits only, and very little was known about how early stages of the disease affect cognition, particularly language comprehension. However, it is now well established that language impairments develop in early PD (Cummings, Darkins, Hill, & Benson, 1988; Grossman et al., 1991).

Numerous studies have investigated the relationships between PD and verb processing (Bertella et al., 2002; Péran et al., 2003; Cotelli et al., 2007; Boulenger et al., 2008; Péran et al., 2009). Péran et al. (2003) assessed language production of action and object concepts in PD. In a word generation task, PD patients were presented with a verb or noun and were required to generate a semantically related verb or noun. In the intracategory task, noun-to-noun and verb-to-verb generations were made. In the intercategory task, noun-to-verb and verb-to-noun generations were made. Compared to controls, PD patients were impaired in verb generation tasks, regardless of whether the cue word was a noun or verb. However, performance of PD patients was similar to that of controls in the noun-generation task. This finding illustrates a selective verb retrieval deficit in PD patients.

Boulenger et al. (2008) investigated the processing of nouns and verbs in PD patients ‘on’ and ‘off’ medication using a priming paradigm. In priming experiments, it is expected that when the presented prime is closely associated with the target, response latency is shorter than when the prime is not associated with the target. This is called the priming effect. Priming effects were found in all conditions except when PD patients ‘off’ medication were presented with primes and targets that were verbs. Thus, a verb processing impairment was found again in PD patients. Note that PD patients ‘on’ medication showed priming effects in the verb condition, suggesting that replenishing dopamine in the central nervous system can potentially alleviate verb processing effects in PD. However, this conclusion remains controversial.

Cotelli et al. (2007) assessed action-verb and object-noun production in Parkinson's disease using a picture naming task. The expected verb and noun responses were equated on lexical length and frequency. PD patients were presented with pictures and cued to name either the presented action or object. Compared with controls, patients showed a deficit in both action and object naming. In addition, PD patients, but not controls, made significantly more errors in action than object naming.

These studies illustrate the main and recurring results in the literature concerning PD and verb processing. Thus, there exists a strong empirical case that the motor system, specifically at the subcortical level, plays a functional role in the conceptual representation of verbs.

However, one shortcoming of these PD verb studies is that they compared processing of physical action verbs (e.g., *kick*, *reach*, and *smile*) to that of nouns. Thus, given these studies, it is unclear whether the subcortical motor area's conceptual role can be generalized to all verbs, or is specific to certain semantic categories of verbs.

Very recently, researchers have begun investigating PD patients' processing of types of verbs (Herrera, Rodriguez-Ferreiro, & Cuetos, 2011; Fernandino et al., 2012; Kemmerer et al., 2013). For example, in Herrera et al. (2011), PD patients were more impaired in naming action-verbs with high motor content (*dig*) compared to those with low motor content (*sleep*). This finding suggests that the conceptual role of the motor system is not uniformly generalized to all verbs, but rather is specific to one aspect of verb semantics, particularly motion. However, these results may be more precisely explained by a somatotopic functional role of the motor system in the conceptual representation of physical action verbs. In other words, lesions to areas of the motor system that result in deficits to hand movements may also lead to impaired conceptual processing of hand-related action concepts. This rationale would add depth to Herrera et al.'s results. Thus, it may be more precise to argue that the impaired performance on high motion verbs, such as *swim* and *dance*, was observed because these actions involve motor recruitment corresponding to impaired body parts, leading to verb processing difficulty.

Cotelli et al. (2007) performed a post hoc analysis on the impact of the semantic variable of manipulability on naming performance. After finding a verb retrieval deficit in PD using an object and action picture naming task, they re-categorized the object and action stimuli into those which do or do not involve fine hand movements. The manipulable items included nouns and verbs such as *screwdriver* and *squeeze,* whereas the non-manipulable items included words such as *tree* and *fly*. Cotelli et al. found no significant difference between the two conditions and concluded that manipulability does not influence picture naming in PD patients. This finding suggests that the motor system in language processing is not selective to concepts that involve fine hand movements.

It is important to note that although many studies on verb processing in PD typically group patients into a single category, patients with PD display an array of phenotypic presentations, exhibiting motor symptom differences in rigidity and tremor, extent of unilateral and bilateral impairments, and extent of impairments in upper and lower limbs. Because all PD verb studies have grouped PD patients into a single category, very little is known about how the varying phenotypic disorders contribute to the verb processing impairment. With regard to Cotelli et al.'s (2007) findings, it may have been the case that poorer naming performance in the manipulable compared to the non-manipulable condition was not found because the PD group consisted of patients with varying phenotypic motor symptoms. If the effect of the central nervous system on selective motor control is, in part, crucial to the processing of body-part-specific action verbs, then patients who have poor motor control in their hands and arms would be predicted to show impaired processing of hand-related action words. Thus, an effect in fine hand movement condition may have been observed if PD patients with greater upper limb impairments were tested selectively.

In summary, a major motivation for the present study is the assumption that treating PD patients as a homogeneous group potentially obscures important differences among individuals with PD with respect to their patterns of performance when processing specific types of verbs. That is, it remains unclear whether aspects of the varying phenotypic expression in PD differentially influence verb processing. In combination, it is possible that subtypes of PD patients may vary in their ability to process verbs that differ in important ways, such as those referring to upper-limb movement (*reach*), lower limb movement (*kick*), and abstract verbs of cognition ("psych" verbs such as *think* and *consider*).

The Present Study

The goal of the current study is to investigate how PD may differentially affect the processing of physical and mental action verbs. Physical action verbs have a clear bodily referent, and in this study consist of hand- and arm-related, and feet- and leg-related verbs (*reach* and *kick*, respectively). Mental action verbs are abstract, and do not have clear bodily referents; in this study, they consist of psych verbs (*consider*). The vast majority of past research on verb processing in PD has focused on differences between verbs and nouns. The present study instead assesses whether PD patients with varying motor symptoms along the upper and lower limbs show different patterns in their comprehension of hand-related, leg-related, and psych verbs.

If the integrity of the motor system is important in the representation of bodily action concepts in language, then early PD patients without dementia, a clinical population with degeneration mainly to subcortical motor structures, should show greater impairments in processing physical action words (*kick*) compared to mental action words (*believe*). On the other hand, if the subcortical motor structures play a more uniform and generalized role in the conceptual representation of verbs, then early PD patients should process physical and mental action words relatively the same.

According to grounded cognition, motor simulation is at least partly crucial for processing action verbs. Therefore, deficits in physical motor control should impair processing of bodily motor verbs. More specifically, greater impairments to motor control of upper limbs than lower limbs should lead to greater deficits in processing hand- and arm-related compared to feet- and leg-related action verbs. Likewise, greater impairments to motor control of lower limbs than upper limbs should lead to greater deficits in processing of feet- and leg-related compared to hand- and arm-related action verbs. However, it may be the case that modality-specific theories, as they relate to bodily action concepts, are limited to cortical motor areas only. As such, early PD patients, who presumably have damage mainly, or only, to subcortical areas will not show selective impairments in verb processing related to their specific motor symptoms. This would suggest a limitation to the scope of modality-specific theories particularly as they relate to action concepts. That is, motor simulation alone may not be what is particularly important in the conceptual representation of concepts, but rather the deficit must occur at a particular level in the central nervous system for language impairments of action concepts to be observable.

Experiment 1: Limb-Relatedness Norming Study

The purpose of this study was to determine the degree to which people believe that various physical action verbs (e.g., *kick, punch,* and *dance*) are related to the upper limbs (hands/arms) and the lower limbs (legs/feet). Participants were presented with a series of verbs and rated, on two scales, the extent to which each verb denotes actions of the upper and lower limbs. These results were used to select two sets of verbs that were as polarized as possible with respect to these ratings. These sets of verbs were then used as targets for Experiment 2.

Method

Participants

Forty-two undergraduate students enrolled in an introductory psychology course at the University of Western Ontario participated for course credit. Each participant completed the study in one sitting on a computer with internet access. Seven participants gave random survey ratings and were therefore excluded from all analyses. Note that no participants took part in more than one of the experiments in this thesis.

Materials

Using lexical databases and a thesaurus, two sets of verbs involving actions of either the upper limbs or the lower limbs were constructed. There were 80 verbs that were assumed to be biased toward involving the upper limbs. These included verbs such as *reach, grasp,* and *clap*. Because there are far fewer English words describing actions of the lower limbs, there were only 41 verbs that were assumed to be biased toward involving the lower limbs. These included verbs such as *kick, run,* and *jump*.

To distinguish between participants who provided random ratings and those who provided informative ratings, 29 psych verbs were added (e.g. *consider, believe,* and *admire*).

These are mental action words with no bodily referent and therefore they should receive low relatedness ratings.

The survey consisted of two 7 point-Likert scales, upper-limb relatedness and lower-limb relatedness. On the upper-limb relatedness scale, a rating of “1” indicated that the “upper limbs (arms/hands) are not involved in this action”, whereas a rating of “7” indicated that the “upper limbs (arms/hands) are critical for this action”. On the lower-limb relatedness scale, a rating of “1” indicated that the “lower limbs (legs/feet) are not involved in this action”, whereas a rating of “7” indicated that the “lower limbs (legs/feet) are critical for this action”.

Procedure

Participants completed the survey on a computer with internet access. The survey was administered online via Survey Gizmo. Both upper- and lower-limb relatedness scales were presented to each participant. The order in which the scales were presented was counterbalanced and the order in which the items were presented in each scale was randomly fixed and different for each scale. Participants were instructed to click a radio button corresponding to the appropriate relatedness rating for each item. The study took less than half an hour.

Results

Seven participants who produced average relatedness ratings for the psych verbs of over 2 on either upper-limb or lower-limb 7-point scales were removed from all analyses. The goal was to select verbs that had high upper-limb or lower-limb relatedness ratings, and to remove those that had similar ratings on both scales. The specific criteria for choosing items was established post hoc because of the need to set criteria that were sufficient to establish that the verbs actually involved the upper or lower limbs, while maintaining a sufficient number of items in each set.

Average relatedness ratings for each of the 150 verbs were calculated. For the upper limb verbs, an average upper-limb relatedness score of at least 6 and an absolute difference between upper- and lower-limb ratings of 2 or greater were designated as appropriate relatedness cut-offs for experimental stimuli. Of the original 80 upper limb verbs, 56 were selected, with an average upper-limb relatedness rating of 6.37 (*SD* = 0.20) and an average absolute difference between ratings of 4.11 (*SD* = 1.08). For the lower limb verbs, an average lower-limb relatedness score of at least 4.85 and an absolute difference between ratings of 1.5 or greater were designated as appropriate cut-offs for experimental stimuli. Of the original 41 lower limb verbs, 32 were selected, with an average lower-limb relatedness rating of 6.02 (*SD* = 0.46) and an average absolute difference between ratings of 2.77 (*SD* = 0.82). Therefore, overall, because of the differences in both types of actions and numbers of English verbs, the upper-limb set was stronger.

Experiment 2: Action Decision Norming Study

The purpose of this study was to take a large group of undergraduate participants and collect decision latencies for upper-limb, lower-limb, and psych verbs using a semantic task. The upper- and lower-limb verbs were taken from Experiment 1. Using lexical databases and a thesaurus, a set of over 400 psych verbs was constructed. Words without a dominant psych verb meaning were removed (e.g., *monitor*, *anger*, and *mirror*). Using the British National Corpus (available online at: http://www.natcorp.ox.ac.uk/) and the English Lexicon Project (available online at: http://elexicon.wustl.edu/), lexical features (frequency and number of letters, phonemes, and syllables) of all verbs were retrieved. A set of psych verbs generally equated on lexical features of the upper and lower limb verbs was selected.

The following is my rationale for developing the implemented task and collecting decision latencies from a large group of undergraduate participants. In developing the task to assess word processing in PD patients, there were two major considerations. First, because two aims of the study included assessing processing of psych verbs and studying language comprehension at the semantic level, standard picture naming and lexical decision tasks were not used. In a picture naming task, participants are presented with a picture and asked to name the depicted object or action. Generating pictures that depict psych verbs would be extremely difficult. In a lexical decision task, participants are presented with a series of words and non-words and must distinguish between the two. The task necessarily requires word processing at the orthographic level (and most likely the phonological level as well), but does not necessarily require the use of word meaning. In contrast, action decisions in a go/no-go task in which participants respond to targets that denote a mental or physical action ("go" trials) and refrain from responding on filler "no-go" trials, featuring adjectives (e.g., *green*) or noun targets referring to concrete objects (e.g., *chair*), accomplishes these two aims. By using printed words as stimuli and having participants respond only when presented items denote a mental or physical action, psych verbs can be tested, and responses unambiguously require processing of word meaning. Second, because PD patients with greater upper and greater lower limb impairment were to be tested, responses that required movements of the arms and hands or the legs and feet would create a potential confound. Thus, participants responded verbally. Furthermore, to minimize inconsistent voice onset time among target words, a single verbal response was selected. Specifically, a verbal response of "go" was used because it begins with a hard consonant sound, making it easier for the microphone to detect, and the word is consistent with the concept of 'action'. The task was named the *action decision go/no-go task*.

Collecting decision latencies with undergraduate participants was important for several reasons. First, because the action decision go/no-go task has not been used in published studies, it was necessary to examine whether a group in the general population could successfully complete the task. Second, target and filler items appropriate for the task needed to be identified. That is, Experiment 2 provided data regarding target and filler items to which participants consistently responded correctly. Finally, the results were used to select sets of items from the three verb groups equated on decision latencies for Experiment 3.

Method

Participants

Forty undergraduate students from the University of Western Ontario participated for monetary compensation ($5). Each participant was tested individually in the lab. Three participants scored below chance and were removed from all analyses. The study took less than half an hour.

Materials

There were 160 target and 160 filler items. Target items consisted of 56 upper-limb, 32 lower-limb, and 72 psych verbs. Filler items were non-verbs (e.g. nouns and adjectives such as *rice* and *green*) that did not denote a mental or physical action. Care was taken to avoid fillers that could potentially have a meaning denoting an action. The items were presented in the action decision go/no-go task.

Procedure

Participants were seated comfortably in front of a computer and microphone. The action decision go/no-go task was presented using E-prime v2.1 on a PC with a 15-inch colour monitor that has a 1 ms refresh rate. Letter strings were displayed in 24 Arial font and centered on a white screen. Participants responded using a Psychological Software Tools serial-response box (Model 200A), which provided millisecond accuracy. Instructions were read aloud by the experimenter and were also presented on the monitor for participants to read (see Appendix A). Participants were asked to either make the verbal response, “GO”, if the presented word (e.g., *swim, enjoy*) refers to either a physical or mental action, or make no response at all, if the presented word (e.g., *kitten*, *short*) does not refer to either a physical or mental action.

Participants began with 20 practice trials which contained feedback after each trial. If participants made an error, the trial would continue to repeat until the participant made the correct response. Participants then completed the experimental trials, for which no feedback was provided. Participants were given short breaks after every 40 trials. The experiment took less than 30 minutes.

On each trial, participants were presented with a fixation cross for 500 ms followed by a word stimulus for up to 3000 ms. When a participant made a verbal response, the microphone detected the onset of the verbal response, and the presented item immediately disappeared from the screen. If a participant did not respond, the item remained on the screen for 3000 ms. There was a 500 ms inter-trial interval blank screen after every trial, and then a new trial commenced with the fixation cross.

Results

The dependent variables were accuracy, as well as decision latency for correct trials only. I chose sets of upper-limb, lower-limb, and psych verbs that were equated as closely as possible on decision latency, and had as low error rates as possible. There were a sufficient number of items to allow 30 upper-limb, 29 lower-limb, and 30 psych verbs. Table 1 presents the characteristics of these item sets, and the verbs themselves can be found in Appendix B. Mean

Table 1. Mean Performance Scores, Lexical Features, and Relatedness Ratings of the Selected Sets of Verbs Established in Experiment 2 (standard error in parentheses).

	Verb Groups		
	Upper-limb	Lower-limb	Psych
N	30	29	30
Action Decision Go/No-go Task			
Error Rate (%)	1.1 (0.3)	4.0 (0.8)	2.1 (0.4)
Decision Latency (ms)	876 (16)	877 (20)	880 (7)
Lexical features			
Number of Letters	4.7 (0.2)	4.9 (0.2)	5.9 (0.2)
BNC Frequency	3654 (1377)	2811 (1010)	2872 (799)
Number of Phonemes	3.87 (0.15)	4.28 (0.23)	4.73 (0.21)
Number of Syllables	1.13 (0.06)	1.17 (0.07)	1.87 (0.10)
Relatedness Ratings			
Upper-Limb Relatedness Rating	6.48 (0.04)	3.20 (0.14)	
Lower-Limb Relatedness Rating	2.40 (0.20)	6.43 (0.08)	
|Upper – Lower| Limb Relatedness Rating	4.08	3.23	

decision latencies for the three groups did not differ by greater than 4 ms. Mean percent errors were slightly greater for the lower-limb verbs because there were fewer from which to choose, limiting the degrees of freedom in the selection process. Sets of upper and lower limb verbs chosen were better matched on both respective limb relatedness ratings and difference between ratings than the sets established from Experiment 1. These 89 verbs were used as the target items in Experiment 3.

Experiment 3 – Parkinson's Disease Verb Study

Method

Participants

Eighteen PD patients (6 females) and 16 healthy adult controls (9 females) participated. PD patients ranged in age from 36 to 86 years (*M* = 64.6, *SD* = 10.8), and controls ranged in age from 48 to 76 (*M* = 62.9, *SD* = 6.1). PD patients attended school for an average of 15.7 years (*SD* = 2.0 years) and controls for an average of 16.6 years (*SD* = 3.2 years). Thus, the two groups were well matched on age and years of education. Matching for gender was not a primary concern because there is neither reason nor evidence to suggest that gender affects verb processing. PD patients were recruited from the Movement Disorder Clinic at University Hospital in London, Ontario, Canada. Healthy older adults were recruited either as spouses of PD patients, or as members of the London community.

At their time of participation in the study, the average number of years since the patients' PD diagnosis was 6.8 (*SD* = 5.6). Because I was particularly interested in patients with greater motor impairment in either the upper or lower limbs, scores from items (tremor at rest and rigidity) relating to both upper and lower limb motor symptoms were collected by the neurologist using the Unified Parkinson's Disease Rating Scale (UPDRS; Fahn and Elton, 1987). Hoehn and

Yahr (1967) scores were collected to classify disease severity (*M* = 2.08, *SD* = 0.54). This scale ranges from 1 (unilateral involvement only usually with minimal or no functional disability) to 5 (confinement to bed or wheelchair unless aided). To ensure that all participants were not demented and their cognitive functioning was adequate to complete the action decision go/no-go task, the Dementia Rating Scale (DRS; Brown et al., 1999) was administered. The cut-off for the PD patients was 127 and controls was 133 or below, out of 144. One patient that was categorized as having a mild cognitive impairment was excluded from the study (this patient is not part of the 18 patients referred to above). The remaining 18 PD patients scored a minimum of 127 on the DRS (*M* = 139.3, range = 127 to 144). No controls were excluded based on the DRS. Although one control scored 127, which was below the control cut-off of 133, the participant was not excluded for two reasons. First, the participant was known to have hearing difficulties and the DRS is administered orally. Thus, errors made on the DRS were most likely not due exclusively to cognitive impairment, but rather were related to auditory deficits. Second, on the action decision go/no-go task, which was administered visually, the control had perfect accuracy with short decision latencies (*M* = 790 ms). With the exception of the one control, all controls scored a minimum of 133 on the DRS (including all controls: *M* = 139.6, range = 127 to 144).

All PD patients were optimally medicated when completing the study. That is, PD patients were on their normal medication regimen when they participated. Of the 18 PD patients, 17 were on medication and one had not yet begun taking medication. All participants were tested in the morning because general cognitive functioning has been shown to be better during this time of day (Bruguerolle & Simon, 2002; Factor et al., 1990; Struck, Rodnitzky, & Dobson, 1990). All participants were native English speakers, attended school through at least grade 10, and had no neurological or psychiatric disorders other than PD. Each participant was compensated $15 for taking part in the study.

Materials

The action decision go/no-go task used 89 target verbs and 99 filler non-verbs (i.e., nouns and adjectives). There was a slightly greater number of no-go fillers due to an experimenter error, but presumably using 53% rather than 50% no-go trials did not influence the results in any manner. The target verbs consisted of 30 upper-limb, 29 lower-limb, and 30 psych verbs. The groups of verbs were equated on action decision go/no-go latencies and produced low error rates when undergraduate were used as participants, as shown in Experiment 2. Table 1 presents the Experiment 2 latencies and error rates, as well as other important measures for the stimuli. Finally, filler non-verbs with low error rates were chosen from Experiment 2 (M = 1.3%, SD = 1.9%). There are no latencies for these items because they are no-go trials.

Procedure

During a clinical visit, the neurologist assessed each PD patient's motor impairments using the UPDRS. Patients deemed as greater upper or greater lower limb impaired were invited to take part in the study. The study date was set to be within one month of the clinical visit.

During the study, patients completed the Dementia Rating Scale and the action decision go/no-go task, with a short break in between. Task order was counterbalanced. All aspects of the action decision go/no-go task itself were identical to Experiment 2. The study took less than one hour.

Finally, after all PD patients had been tested, they were called on average 8 weeks later and given a self-report motor impairment questionnaire. This questionnaire was administered over the phone and patients were asked to rate, on a 10-point Likert scale, their subjective experiences with respect to motor impairments for each of their limbs (right hand/arm, left hand/arm, right leg/foot, and left leg/foot). A rating of “1” indicated that the “motor control in that limb was normal; similar to motor function before PD diagnosis”, whereas a rating of “10” indicated that the “motor control in that limb was extremely poor”. The questionnaire took less than 5 minutes.

Results

Two PD patients and three controls were removed from all analyses. Group descriptive statistics in the Participants section do not include these individuals. One PD patient was removed because their accuracy for target trials was 52%, which is essentially chance performance. A second PD patient’s accuracy for target trials was 73%. I removed this participant because there was a substantial break in the distribution of accuracy rates given that all other PD patients scored at least 92% correct. Thus, the data of 18 PD patients with accuracy for target trials of 92% or greater were analyzed. All 18 PD patients were at least 86% accurate on the no-go trials.

Two controls’ accuracies for target trials were 76% and 75%. Parallel to the PD patients, they were both removed because all other controls scored at least 92% correct. One control scored an accuracy on target trials of 97%, but did so presumably because this participant had a strong tendency to respond “go”, given their 73% accuracy on fillers. That is, this control participant responded “go” on 27% of the non-verb filler items. Therefore, this participant was removed. Thus, the data of 16 controls with accuracy for target trials of 92% or greater were analyzed. All 16 controls were at least 86% accurate on the no-go trials.

Decision latency data includes only correct trials. Decision latencies greater than three standard deviations above the group mean were replaced with those values (2.1% of PD patient trials, 1.7% of control trials). For all analyses, the data were analyzed using participants (F_1) and items (F_2) as random variables.

There are three analyses sections. The first includes group (PD patients and controls) and verb type with three levels (upper-limb, lower-limb, and psych). The second includes group and verb type with two levels (physical verbs using upper-limb and lower-limb combined, and psych verbs). Results from the first two analysis sections do not indicate anything particularly interesting because group and verb type do not interact, although, somewhat surprisingly, the PD patients and controls differ nonsignificantly. The final analyses, which are the most important given the goals of the study, use dominance of limb impairment (upper vs. lower dominant PD patients) and the two types of physical action verbs (upper-limb vs. lower-limb). Note that there is no basis for predicting differences in performance on psych verbs for upper versus lower limb dominant PD patients. The results of these analyses do show that PD patients' performance on upper- versus lower-limb verbs differ in interesting ways. Decision latencies and error rates for all conditions are presented in Table 2.

Analysis 1: Group (PD, controls) x Verb type (upper-limb, lower-limb, psych)

Mixed analyses of variance were conducted. The independent variables were group (PD patients, controls) and verb type (upper-limb, lower-limb, psych). Group was between participants, but within items, whereas verb type was within participants, but between items. The dependent variables were decision latency and square root of the number of errors (Myers, 1979).

For decision latencies, the group by verb type interaction was not significant, $F_1(2,64) < 1$, $F_2(2, 86) < 1$. I conducted pairwise comparisons to explore differences among conditions. For upper limb verbs, decision latencies were 18 ms longer for PD patients than for controls, which

Table 2. Mean Decision Latency and Percent Errors in Experiment 3 Action Decision Go/No-go Task (standard error in parentheses)

	PD upper	PD lower	PD	Controls	All Participants
Decision Latency (ms)					
Physical-Action	897 (39)	849 (44)	875 (33)	866 (35)	871 (29)
Upper-Limb	924 (41)	850 (46)	891 (35)	873 (37)	882 (25)
Lower-Limb	869 (39)	847 (44)	859 (32)	859 (33)	859 (23)
Psych	973 (52)	922 (48)	950 (40)	964 (43)	957 (29)
All Verbs	922 (41)	873 (45)	900 (34)	899 (36)	
Error Percentages (%)					
Physical-Action	1.4 (0.8)	0.6 (0.6)	1.0 (0.4)	1.8 (0.6)	1.3 (0.4)
Upper-Limb	1.3 (0.7)	0.4 (0.4)	0.9 (0.5)	1.9 (0.8)	1.3 (0.5)
Lower-Limb	1.4 (0.8)	0.9 (0.9)	1.1 (0.6)	1.7 (0.6)	1.4 (0.4)
Psych	3.3(1.3)	4.7(3.0)	3.9 (1.5)	5 (1.5)	4.5 (1.0)
All Verbs	2.0 (0.9)	2.0 (1.4)	2.0 (0.6)	2.9 (0.6)	

was significant by items, $F_2(1, 86) = 5.62$, $p < .03$, but not by participants, $F_1(1, 39) < 1$. There were no group differences for the lower-limb, both *F*'s < 1, or psych verbs, both *F'*s < 1. For PD patients, decision latencies for psych verbs were 59 ms longer than for upper-limb verbs, $F_1(1,64) = 9.60$, $p < .003$, $F_2(1,116) = 4.73$, $p < .04$, and 91 ms longer than for lower-limb verbs, $F_1(1,64) = 22.83$, $p < .0001$, $F_2(1,116) = 10.58$, $p < .002$. PD patients' decision latencies were nonsignificantly 32 ms longer for upper than for lower limb verbs, $F_1(1,64) = 2.82$, $p > .09$, $F_2(1,116) = 1.20$, $p > .2$. For controls, decision latencies for psych verbs were 91 ms longer than for upper-limb verbs, $F_1(1,64) = 20.30$, $p < .0001$, $F_2(1,116) = 9.62$, $p < .003$, and 105 ms longer than for lower-limb verbs, $F_1(1,64) = 27.02$, $p < .0001$, $F_2(1,116) = 10.81$, $p < .002$. Finally, there was no difference between upper- and lower-limb verbs, both *F'*s < 1.

Overall, PD patients (*M* = 900 ms, *SE* = 34 ms**)** were 1 ms slower than controls (*M* = 899 ms, *SE* = 36 ms), which was significant by items, $F_2(1, 86) = 5.00$, $p < .03$, but not by participants, $F_1(1, 32) < 1$. There was a main effect of verb type, $F_1(2, 64) = 27.17$, $p < .001$, $F_2(2, 86) = 7.15$, $p < .002$, with lower-limb verbs having numerically the shortest latencies (*M* = 859 ms, *SE* = 23 ms), followed by upper-limb (*M* = 882 ms, *SE* = 25 ms) and psych verbs (*M* = 957 ms, *SE* = 29 ms).

For error rates, the group by verb type interaction was not significant, $F_1(2, 64) < 1$, $F_2(2, 86) < 1$. There was not a significant difference between PD patients (*M* = 2.0%, *SE* = 0.6%) and controls (*M* = 2.9%, *SE* = 0.6%), $F_1(1, 32) = 1.22$, $p > .2$, $F_2(1, 86) < 1$. There was a main effect of verb type, $F_1(2, 64) = 7.91$, $p < .001$, $F_2(2, 86) = 8.11$, $p < .0007$, with psych verbs having numerically the highest error rate (*M* = 4.5%, *SE* = 1.0%), whereas upper-limb (*M* = 1.3%, *SE* = 0.5%) and lower-limb verbs (*M* = 1.4%, *SE* = 0.4%) were almost equal.

Analysis 2: Group (PD, controls) x Verb type (physical-action, psych)

Mixed analyses of variance were conducted. The independent variables were group (PD patients, controls) and verb type (physical-action, psych). Group was between participants, but within items, whereas verb type was within participants, but between items. The dependent variables were decision latency and square root of the number of errors (Myers, 1979).

For decision latencies, the group by verb type interaction was not significant, $F_1(1, 32) < 1$, $F_2(1, 87) < 1$. Pairwise comparisons again were conducted. For physical-action verbs, the 9 ms advantage for controls was significant by items, $F_2(1, 87) = 5.03$, $p < .03$, but not by participants, $F_1 < 1$. The 14 ms advantage for PD patients for psych verbs was nonsignificant, both *F'*s < 1. Decision latencies were 75 ms longer for psych verbs for PD patients, $F_1(1, 32) = 22.44$, $p < .0001$, $F_2(1, 118) = 9.78$, $p < .003$, and 98 ms longer for controls, $F_1(1, 32) = 22.15$, $p < .0001$, $F_2(1, 118) = 13.72$, $p < .0004$.

Overall, PD patients (919 ms, *SE* = 11 ms) were 18 ms slower than controls (*M* = 901 ms, *SE* = 13 ms), which was marginally significant by items, $F_2(1, 87) = 3.52$, $p < .07$, and not significant by participants, $F_1(1, 32) < 1$. Decision latencies for physical action verbs (*M* = 871 ms, *SE* = 24 ms) were 86 ms shorter than for psych verbs (*M* = 957 ms, *SE* = 29 ms), $F_1(1, 32) = 36.27$, $p < .001$, $F_2(1, 87) = 13.89$, $p < .001$.

For error rates, the group by verb type interaction was not significant, $F_1(1, 32) < 1$, $F_2(1, 87) < 1$. There was no significant difference between PD patients (*M* = 1.8%, *SE* = 0.5%) and controls (*M* = 2.6%, *SE* = 0.6%), $F_1(1, 32) = 1.05$, $p > .3$, $F_2(1, 87) < 1$. There were 3.2% more errors for psych verbs (*M* = 4.5%, *SE* = 1.0%) than for physical-action verbs (*M* = 1.3%, *SE* = 0.4%), $F_1(1, 32) = 8.35$, $p < .008$, $F_2(1, 33) = 16.40$, $p < .001$.

Analysis 3: PD dominance (PD upper, PD lower) x Verb type (upper-, lower-limb)

PD patients were categorized into either greater upper or greater lower limb impairment using the UPDRS and self-reported motor impairment questionnaire. Although there are a number of items on the UPDRS that measure severity of motor symptoms in the upper and/or lower limbs, I was interested only in the items that equally assessed both upper and lower limbs. These were items 20, tremor at rest, and 22, rigidity. All other items either do not provide a score specific to the limbs, or provide scores for the upper or lower limbs, but not both.

The tremor at rest and rigidity items each provide 4 motor severity scores: for the right and left upper limb, and right and left lower limb. Motor symptom severity on each limb is rated along a 5-point Likert scale. A rating of “0” indicates that tremor or rigidity is “absent”. A rating of “4” indicates that the tremor is “marked in amplitude; present most of the time” and the rigidity is “severe, range of motion achieved with difficulty” (note that physicians also typically use 0.5 increments in their ratings). Thus, upper and lower limb scores were calculated as a proportion out of 16 from 4 scores for the upper limb and 4 scores for the lower limb. PD patients with greater upper limb proportion scores were categorized as having greater upper limb impairment and those with greater lower limb proportion scores were categorized as having greater lower limb impairment. Because only two items from the UPDRS were used and almost all scores were between 0 and 2.5 with increments of 0.5, the measure was not sensitive enough to dichotomize some patients with closer upper and lower motor impairment scores. Using the UPDRS, 12 patients were categorized into either greater upper or greater lower limb motor impairment. Six patients had the same proportion scores. Instead of using other items from the UPDRS which did not equally provide scores for both upper and lower limb motor impairments, I used a self-report motor impairment questionnaire to dichotomize the remaining 6 patients. The self-report motor impairment questionnaire provided two functions. First, I wanted to ensure that the binary categorization from the UPDRS rigidity and tremor scores were fairly consistent with patient's subjective experience of motor control. Second, the self-reported motor impairment scores allowed me to dichotomize with certainty any situations in which patients had very close upper and lower limb proportion scores.

Using the UPDRS and self-report motor impairment scale, 10 PD patients were categorized as having greater upper limb impairment and 8 as having greater lower limb impairment. UPDRS proportion scores for upper and lower limb impairments consisted of respective limb-related ratings from tremor at rest and rigidity items. Upper dominance PD patients had a mean upper-limb proportion score of 0.28 (SE = 0.03) and a mean lower-limb score of 0.14 (SE = 0.03), whereas lower dominance PD patients had a mean upper-limb proportion score of 0.16 (SE = 0.04) and a mean lower-limb score of 0.23 (SE = 0.02).

From the self-report motor impairment questionnaire, upper and lower limb impairment scores were calculated as sums of right and left upper limb ratings, and right and left lower limb ratings, respectively. Each upper and lower limb score ranges from 2 to 20. Upper dominance PD patients had a mean upper-limb score of 8.0 (SE = 1.2) and a mean lower-limb score of 6.4 (SE = 1.3), whereas lower dominance PD patients had a mean upper-limb score of 5.0 (SE = 0.7) and a mean lower-limb score of 7.5 (SE = 1.3).

A bivariate correlation analysis showed that the tremor-and-ridigity UPDRS scores and self-report motor impairment scores were positively correlated, although nonsignificant for both upper, $r = .43$, $p < .08$, and lower limbs, $r = .42$, $p = .08$. These results show that the motor clinical test and subjective experience of motor control move in the same direction. It also shows that the two measures are not providing completely redundant information, otherwise, the correlations would have been higher. Therefore, using both sources of information to classify the patients was advantageous.

Mixed analyses of variance were conducted on decision latency and square root of the number of errors. The independent variables were PD dominance (greater upper and greater lower limb impairment) and verb type (upper-limb, lower-limb). PD dominance was between participants, but within items, whereas verb type was within participants, but between items.

For decision latency, the PD dominance by verb type interaction was significant by items, $F_2(1, 57) = 7.25$, $p < .01$, and marginally significant by participants, $F_1(1, 16) = 3.64$, $p < .08$. Planned comparisons revealed that for PD patients with greater motor impairments in their upper limbs, decision latencies were 74 ms longer for upper-limb than for lower-limb verbs, which is significant by items, $F_2(1, 57) = 11.10$, p < .002, but not by participants, $F_1(1, 18) < 1$. In contrast, for PD patients with greater motor impairments in their lower limbs, the difference was only 3 ms, both F’s < 1.

Overall, due primarily to differences in the upper-limb verbs, decision latencies for PD patients with greater upper limb impairment (*M* = 897 ms, *SE* = 39 ms) were 48 ms faster than PD patients with greater lower limb impairment (*M* = 849 ms, *SE* = 44 ms), which was significant by items, $F_2(1, 57) = 15.20$, $p < .001$, but not by participants, $F_1(1, 16) < 1$. Decision latencies for upper limb verbs (*M* = 887 ms, *SE* = 31 ms) were 29 ms longer than for lower limb verbs (*M* = 858 ms, *SE* = 29 ms), which was marginally significant by participants, $F_1(1, 16) = 4.23$, $p < .06$, and not significant by items, $F_2(1, 57) = 1.04$, $p > .3$.

Error rates were similar and quite low in all conditions. The PD dominance by verb type interaction was not significant, $F_1(1, 16) < 1$, $F_2(1, 57) < 1$. Error rates did not differ between PD patients with greater upper (*M* = 1.4%, *SE* = 0.7%) and greater lower limb impairment (*M* =

0.6%, *SE* = 0.7%), $F_1(1, 16) = 1.08$, $p > .3$, $F_2(1, 57) = 2.27$, $p > .1$. They also did not differ between upper limb (*M* = 0.9%, *SE* = 0.5%) and lower limb verbs (*M* = 1.1%, *SE* = 0.6%), $F_1(1, 16) < 1$, $F_2(1, 57) < 1$.

Discussion

There were three main findings in Experiment 3. First, and most importantly, there was an interaction between PD dominance (upper dominance, lower dominance) and verb type (upper-limb, lower-limb). That is, PD patients with greater upper and greater lower limb motor impairments showed different patterns in language processing for upper- and lower-limb verbs. Second, surprisingly, verb decision latencies of PD patients and controls differed nonsignificantly. Third, psych verbs had significantly longer decision latencies than both types of physical-action verbs in both PD patients and controls.

Most accounts of grounded cognition emphasize the role of simulation in cognition (Barsalou, 2008). With respect to physical action concepts, the motor system is expected to play a crucial role in their representation. I tested PD patients with greater upper and greater lower limb impairments. My goal was to determine whether these subsets of patients showed different patterns in their processing of upper- and lower-limb verbs. Consistent with theories of grounded cognition, I hypothesized that if motor simulation is fundamental to comprehending bodily action concepts, then PD patients with greater upper limb impairment might take longer to process words that denote actions of the arms and hands relative to those denoting actions of the legs and feet. Likewise, PD patients with greater lower limb impairment might take longer to process words that denote actions of the legs and feet relative to those denoting actions of the arms and hands.

PD dominance and verb type interacted in that PD patients with greater upper limb impairments had significantly longer decision latencies for upper-limb than lower-limb verbs, whereas those with greater lower limb impairments had a difference of only 3 ms. Results from PD patients with greater upper limb impairments were consistent with the hypothesis derived from grounded cognition theories. This provides evidence that motor impairments in arms and hands influence processing of upper-limb verbs. However, results from PD patients with greater lower limb impairments were not consistent with my hypothesis. One potential reason for this may relate to differences between bodily motor involvement in the upper and lower limb verbs.

Obviously, upper and lower limb verbs denote actions of mainly different body parts. In addition, the physical actions that are described by upper- and lower-limb verbs differ in their motor distribution along the body. In essence, upper limb verbs such as *reach* and *grasp* are thought of as requiring movements almost exclusively of the arms and hands. In other words, to perform a reach or a grasp, the entire body is often quite still while the arm and hand perform the action. That is, a person often performs a reach while sitting, with their lower body completely still, as in reaching for a glass while sitting at a table. In contrast, although lower limb verbs such as *run, jump* and even *kick* can be considered as requiring mostly the legs and feet, the arms and torso are also typically involved. That is, running or jumping without moving one’s arms is almost impossible, although the primary movements involve the legs and feet. Thus, upper- and lower-limb verbs can be viewed as differing in their motor distributions along the body; whereas upper-limb verbs denote movements that can easily be executed exclusively using the hands and arms, lower-limb verbs denote movements that are often more distributed along the body.

Evidence of this verb type difference can be observed in the relatedness ratings of upper- and lower-limb verbs in Table 1. Although the upper- and lower-limb verbs both have high biased upper- and lower-limb-relatedness ratings, respectively, they are not equally biased. There is a larger difference between ratings for upper- than for lower-limb verbs, which indicates that people are sensitive to the fact that upper limb verbs require less of the legs and feet than the lower limb verbs require of the hands and arms.

With respect to this upper- and lower-limb verb difference, it may be the case that actions denoted by lower limb verbs are not only subserved by leg and feet areas of the motor system, but also, to an extent, subserved by arm, hand, and torso areas. Thus, damage to leg and feet areas of the motor system does not lead to an observable deficit in processing of lower-limb relative to upper-limb verbs. In contrast, actions denoted by upper limb verbs are more likely to be subserved by mostly, if not entirely, arm and hand areas of the motor system. Thus, damage to arm and hand areas leads to an observable deficit in upper-limb verb processing.

One issue concerns the fact that language processing of hand- and leg-related action concepts does differentially activate corresponding brain areas in neuroimaging studies (Hauk, Johnsrude, & Pulvermüller, 2004; Tettamanti et al., 2005; Aziz-Zadeh et al. 2006). It is important to note that many of these studies use sentences or phrases to depict actions, which allow for fine tuning of the involvement of specific body-parts. For example, verbs such as *kick* can denote actions of just the legs and feet, or may involve a greater motor distribution along the body. Phrases such as “the boy kicks the ball” and “the athlete kicks the ball”, can affect the motor distribution involved; where the former would more likely involve just the legs and feet and the latter would more likely involve a greater motor distribution along the body. Thus, the use of sentences and phrases can refine the localization of motor areas required during language processing of physical action concepts.

In one neuroimaging study, single verbs were used to denote actions of body parts (Hauk, Johnsrude, & Pulvermüller, 2004). The researchers indicated that the areas important in physical leg movements are also involved when reading leg-related verbs. However, the fMRI results show that areas activated during reading of leg-related words did not only activate parts of leg motor areas, but surrounding motor regions were activated as well. This suggests that processing of lower-limb verbs in isolation may evoke a greater motor distribution along the body than previously thought. In addition, studies such as Hauk et al. mainly reported results concerning the areas of the brain that are most activated by a type of verb, relative to other types. Finding differential activations does not mean that other areas are not involved. Involvement of other brain regions can have different consequences for a patient study than for an imaging study using normal participants.

Past studies on verb processing have consistently demonstrated that overall, PD patients process verbs more slowly than do controls (Péran et al., 2003; Cotelli et al., 2007; Boulenger et al., 2008; Fernandino et al., 2012; Kemmerer et al. 2013). However, this group effect was not observed in the present study. There are two potential reasons as to why this may have occurred. First, there may simply be a great deal of variability in the performance of older adults in the action decision go/no-go task. There was substantial variability in the controls' mean decision latencies, which ranged from 678 ms to 1211 ms. And thus, by random chance, I may have happened to recruit a number of controls who were on the slower end of the distribution.

Second, due to the manner in which controls were recruited, there may have been essentially two control populations. As mentioned in the Participants section, controls were recruited either as spouses of PD patients, or as members of the community. I first tested the spousal controls and then community-member controls. After testing the community-member controls, there was a substantial decrease in mean decision latencies. When comparing these groups, spousal controls (*M* = 980 ms, *SE* = 65 ms) were 164 ms slower than community-member controls (*M* = 816 ms, *SE* = 31 ms), and this trend was consistent across all verb types. This difference suggests that the two control populations may very well be different. It is possible that this difference is related to the burden and demands on spousal controls due to caring for their partner. Such emotional pressures and changes to daily routines may potentially result in subtle changes in cognitive functioning. Regardless of the potential causes of the underlying differences between spouses and general community members, their performance differed substantially in this experiment.

Recently, two PD studies have compared the processing of psych and physical action verbs. Although motor-deficit based explanations of PD patients would appear to predict faster processing of psych verbs because they do not describe physical actions, Fernandino et al. (2012) and Kemmerer et al. (2013) found that psych verbs were processed more slowly than physical action verbs in PD patients, and this difference was comparable in controls. In the present study, although the three sets of verbs were equated on undergraduate participants' decision latencies collected in Experiment 2, decision latencies for psych verbs were also significantly longer than for physical-action verbs in both PD patients and controls. In addition to equating the three verb sets on decision latency, I also tried as much as possible to equate them on lexical variables (frequency and number of letters, phonemes, and syllables; see Table 1). However, in the English language, psych verbs tend to be longer than upper- and lower-limb verbs, and they were in this experiment. Therefore, one potential reason for the longer decision latencies for psych verbs is word length. Consistent with this hypothesis, it has been shown that word length influences reading latencies more strongly for older than for younger adults. For example, Allen, Maddem, Weber, and Groth (1993) found an interaction between age and word length in a lexical decision task such that word length increased older adults' decision latencies more substantially than it did for younger adults. Thus, longer latencies for psych verbs in both groups of older adults may have been due, at least in part, to the psych verbs being longer than the physical-action verbs.

General Discussion

The present study was novel in two major ways. It was the first to investigate verb processing in Parkinson's patients who were divided into groups based on whether their motor functioning was biased toward their upper versus lower limbs. In addition, it was the first study to investigate upper- and lower-limb verbs separately. The verbs were selected carefully using ratings and a preliminary experiment that incorporated the same procedure as the PD experiment, but with undergraduates as participants. These innovations led to the novel result that action decision latencies for PD patients with predominantly upper-limb motor impairments were longer for upper-limb verbs, whereas there was no difference in upper- versus lower-limb verb decision latencies for PD patients with predominantly lower-limb motor impairments.

In the remainder of this thesis, I first discuss implications of past research on verb processing impairments in PD in terms of the neural connectivity between the basal ganglia and cortical regions. Next, I discuss how my main results may add to ideas regarding the organization of these basal ganglia connections. Finally, I provide a few speculations regarding the manner in which psych verbs may be represented in the brain.

For a long time, the basal ganglia were viewed as a secondary component of the motor system (Penfield & Rasmusen, 1950). It was believed that the basal ganglia played a role only in motor function in terms of voluntary movement, as well as selection and inhibition of competing motor templates (Mink & Thach, 1992). Given this view, damage to the basal ganglia, as in Parkinson's disease, led only to motor control impairments. However, it has now been established that the basal ganglia are involved in non-motor functions including implicit learning, habit formation, and reward processing (Yin & Knowlton, 2006). Furthermore, researchers have found that the basal ganglia are involved in higher cognitive functions underlying language comprehension (Kotz et al., 2009; Cardona et al., 2013). For example, studies have demonstrated the role of the basal ganglia in syntactic and semantic processing (Friederici et al., 2003; Kotz et al., 2009).

It is now known that the basal ganglia have profuse connections with the cerebral cortex, as established by studies that used diffusion tensor imaging (DTI) with human participants (Saur et al., 2008). Co-activation of the basal ganglia and motor cortical regions during action-semantic tasks have led researchers to suggest that these two areas work together to integrate motor-semantic information (Crosson et al., 2003).

To explain the recurring finding of action verb processing impairment in PD (Péran et al., 2003; Cotelli et al., 2007), Cardona et al. (2013) proposed a model in which the motor and language areas of the brain interact to process action concepts. The circuits between the basal ganglia and cerebral cortex are thought to interact with language processing areas. Specifically, this circuitry modulates the motor-language integration observed in action verb processing. Relevant to semantic processing of actions, there are two main areas in which the basal ganglia interact with the cerebral cortex: frontal (inferior frontal gyrus, primary motor cortex, and supplementary motor areas) and temporal lobes (anterior temporal lobes and superior temporal sulcus). The basal ganglia's connections with the frontal areas are involved in the processing of motor simulation and action patterns. Specifically, the basal ganglia play a role in the automatic selection (and inhibition) of motor templates, which are then processed by cortical motor regions.

The basal ganglia's interaction with temporal areas are involved in processing abstract conceptual information. It is thought that the basal ganglia's role in implicit learning and action selection modulates and directly influences semantic processing in those temporal areas. In addition, connections exist between the frontal and temporal regions (Saur et al., 2008). These connections allow temporal areas to directly access action-semantic knowledge in frontal regions during semantic processing. Thus, in this model, the basal ganglia influence both frontal and temporal processing of action verbs. The basal ganglia's role in action selection primes simulation in the frontal lobes during language processing of action concepts. Also, the basal ganglia and motor cortex provide motor knowledge that enriches the more abstract level of conceptual processing in the temporal areas.

Results of impaired verb processing in PD would suggest that it is specifically the connections between the basal ganglia and motor regions of the frontal lobe, which are known to be responsible for movement, that are involved in processing action concepts. The interaction between PD motor dominance and upper- versus lower-limb verbs in the present study can be viewed as adding important insight into our understanding of the dialogue between the basal ganglia and frontal motor regions. It suggests that, in linguistic processing of action concepts, the connections between the basal ganglia and frontal regions is sufficiently fine-grained so that disturbances to the basal ganglia that lead to motor impairments of the arms and hands, also lead to selective impairments in processing upper-limb, but not lower-limb related actions. This would suggest that connections between the basal ganglia and motor cortex that are involved in carrying out specific physical actions overlap with those that are involved in processing physical action verbs of specific types. Thus, this motor-language coupling is fine-tuned to specific motor functions.

Interestingly, psych verbs, which are abstract and do not have bodily referents, are not predicted to be subserved by the connections between the basal ganglia and motor cortex. Consistent with the motor-language coupling model, psych verbs would be expected to be represented in temporal regions that are responsible for processing abstract concepts. Neuroimaging data have shown that comprehension of abstract, compared to concrete, language content has higher selective activation of the anterior temporal regions (Sakreida et al., 2013). There is no evidence in the present study that processing of psych verbs was impaired in PD patients relative to controls. This finding is consistent with the two previous studies that investigated psych verbs (Fernandino et al., 2012; Kemmerer et al., 2013). This might suggest that the connections between the basal ganglia and temporal areas are relatively intact, allowing for processing of this type of abstract concept.

Temporal regions also have been implicated in the processing of object concepts. For the most part, studies of PD patients have demonstrated that object noun processing is relatively intact. However, Cotelli et al. (2007) did find that PD patients were slightly impaired on noun processing compared to controls. This would suggest that there may be slight or no disturbances in the connections between the basal ganglia and temporal areas. Nonetheless, in Parkinson's disease, the main damage exists between the basal ganglia and motor regions, which appear to be responsible for both physical motor function and related action verb processing. Results from the present thesis indicate that this motor-language interaction may have a somatotopic relationship.

Conclusion

The present study took a new approach to investigating Parkinson's disease by taking into consideration the varying phenotypic expressions within the disorder, specifically differences in the degree of upper and lower limb motor impairments. Parkinson's patients with greater upper and greater lower limb impairments demonstrated differential processing of action verbs. These novel results suggest that the motor system may play a functional and selective role in the conceptual representation of action concepts. Furthermore, they provide insight into the communication between the basal ganglia and motor regions, and how the two interact with language areas of the brain. Finally, my experiments also provide support for grounded cognition views of conceptual representation and processing, and are inconsistent with amodal theories in which sensorimotor information plays no role, or solely an ancillary role, in cognitive functions such as language comprehension.

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Appendix A

Instructions for Action Decision Go/No-go Task

In this experiment, you will be asked to make decisions on each of a series of words. For each trial, the following is the sequence of events:

First, a + will appear on the screen for a brief period.

Following the +, a word will appear. Your task is to read this word in your mind, and then say “Go” if the word refers to either a physical or mental action (for example, "swim" or "enjoy"), or make no response at all if the word does not refer to either a physical or mental action (for example, "kitten" or "short").

On trials when you do respond, please say “Go” relatively loudly and clearly into the microphone that is in front of you. Please respond as quickly as you can while remaining highly accurate in your decisions.

This is not meant to be a difficult task in that we are not trying to trick you in any way.
It should be quite obvious if the word refers to an action or not.

However, people often think about “action” as physical actions only, like "swim". But please remember that you also say “Go” if the word refers to an “action” that happens in your mind, such as "enjoy" or "think" or "consider".

You will begin with 20 practice trials in order to get used to the task. Note that you will be given feedback during the practice trials, but not the actual testing trials.

If you have any questions, please ask the experimenter now.

Are you ready to begin?

Appendix B

Sets of Upper-Limb, Lower-Limb, and Psych Verbs Equated on Action Decision Latencies

Upper-limb	**Lower-limb**	**Psych**
build	*dropkick*	*admire*
carry	*flee*	*adore*
chop	*hike*	*agonize*
clap	*hop*	*agree*
clench	*jog*	*amaze*
dial	*jump*	*annoy*
dig	*kick*	*appraise*
dissect	*kneel*	*approve*
draw	*leap*	*believe*
flick	*lunge*	*deny*
grab	*march*	*despise*
grip	*patrol*	*dream*
hold	*prance*	*envy*
jab	*roam*	*forgive*
juggle	*run*	*frighten*
knit	*sidestep*	*grieve*
knock	*skate*	*hate*
lift	*skip*	*ignore*
point	*sprint*	*insist*
pour	*stand*	*justify*
pull	*step*	*learn*
punch	*stomp*	*ponder*
reach	*stride*	*praise*
scribble	*stroll*	*pretend*
scrub	*strut*	*regret*
slap	*tiptoe*	*scare*
smack	*tread*	*tolerate*
snatch	*walk*	*wish*
sweep	*wander*	*wonder*
wash		*worry*

Appendix C
Thesis Ethics Approval Notices

Western

Department of Psychology The University of Western Ontario
Room 7418 Social Sciences Centre,
London, ON, Canada N6A 5C1
[redacted]

Use of Human Subjects - Ethics Approval Notice

Review Number	12 04 03	**Approval Date**	12 04 03
Principal Investigator	Ken McRae	**End Date**	12 12 31
Protocol Title	Action –verb ratings on relatedness to upper and lower extremities		
Sponsor	n/a		

This is to notify you that The University of Western Ontario Department of Psychology Research Ethics Board (PREB) has granted expedited ethics approval to the above named research study on the date noted above.

The PREB is a sub-REB of The University of Western Ontario's Research Ethics Board for Non-Medical Research Involving Human Subjects (NMREB) which is organized and operates according to the Tri-Council Policy Statement and the applicable laws and regulations of Ontario. (See Office of Research Ethics web site: http://www.uwo.ca/research/ethics/)

This approval shall remain valid until end date noted above assuming timely and acceptable responses to the University's periodic requests for surveillance and monitoring information.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the PREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of research assistant, telephone number etc). Subjects must receive a copy of the information/consent documentation.

Investigators must promptly also report to the PREB:
a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to the PREB for approval.

Members of the PREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the PREB.

[redacted]
Clive Seligman Ph.D.

Chair, Psychology Expedited Research Ethics Board (PREB)

The other members of the 2011-2012 PREB are: Mike Atkinson (Introductory Psychology Coordinator), Rick Goffin, Riley Hinson Albert Katz (Department Chair), Steve Lupker, and Karen Dickson (Graduate Student Representative)

CC: UWO Office of Research Ethics

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Department of Psychology The University of Western Ontario
Room 7418 Social Sciences Centre,
London, ON, Canada N6A 5C1
[redacted]

Western

Use of Human Subjects - Ethics Approval Notice

Review Number	12 04 04	**Approval Date**	12 04 03
Principal Investigator	Ken McRae/Peter Nguyen	**End Date**	13 04 01
Protocol Title	Action-verb judgments		
Sponsor	n/a		

This is to notify you that The University of Western Ontario Department of Psychology Research Ethics Board (PREB) has granted expedited ethics approval to the above named research study on the date noted above.

The PREB is a sub-REB of The University of Western Ontario's Research Ethics Board for Non-Medical Research Involving Human Subjects (NMREB) which is organized and operates according to the Tri-Council Policy Statement and the applicable laws and regulations of Ontario. (See Office of Research Ethics web site: http://www.uwo.ca/research/ethics/)

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Curriculum Vitae

Name:	Peter Nguyen
Post-secondary Education and Degrees:	University of Western Ontario London, Ontario, Canada 2006-2011 B.Sc.
	The University of Western Ontario London, Ontario, Canada 2011-present M.Sc. candidate
Honours and Awards:	Western Graduate Research Award (2011 & 2012)
	Laurene Pattern Estate Scholarship (2009 & 2011)
	Western University's Continuing Admission Scholarship (2006 – 2010)
	Dean's Honor List at Western University (2006 – 2011)
Related Work Experience	Teaching Assistant The University of Western Ontario 2011-2013
	Research Assistant Neufeld Laboratory 2010-2012