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Chapter 1

LANGUAGE ASSESSMENT OF ACTION/VERB PROCESSING IN PATIENTS WITH PARKINSON'S DISEASE: A CRITICAL ANALYSIS THROUGH THE MULTILEVEL MODEL

Maria Teresa Carthery-Goulart[1,2], Henrique Salmazo da Silva[3], Juliana Bruno Machado[4], Roberta Roque Baradel[4] and Maria Alice de Mattos Pimenta Parente[5]

[1]Professor at the Federal University of ABC, Brazil
[2]Researcher at the Behavioural and Cognitive Neurology Unit, School of Medicine, São Paulo University, Brazil
[3]PhD student at the Graduation Program of Neuroscience and Cognition at the Federal University of ABC, Brazil
[4]Master Graduation Program of Neuroscience and Cognition at the Federal University of ABC, Brazil
[5]Visiting Senior professor at the Graduation Program of Neuroscience and Cognition at the Federal University of ABC, Brazil

ABSTRACT

Verbs are the best lexical items to verify the effects of motor learning in language processing. However, compared to nouns, this category has received less attention in studies about lexical disturbances in neurological diseases. Difficulties in verb/action processing have been found in patients with Parkinson's disease, suggesting that frontoestriatal and subcortical areas contribute to the semantic processing of verbs. This finding highlights the possibility of verifying the assumptions of the Embodied Cognition (EC). According to this theory, language processing of action verbs would engage areas involved in planning and execution of the actions represented by those verbs in the motor cortex. The literature in this field has pointed to conflicting results and action/verb cerebral representation, and its impact in language difficulties in Parkinson's disease have been intensively debated. These controversies may be studied in terms of the multilevel

model (Kemmerer, 2014) that predicts that the design of the task will require differential access to the motor features of the verb meaning and that areas related to visual perception, particularly the lateral posterior temporal cortex play a role in semantic processing. The type of task and psycholinguistic variables need to be taken into account since they can measure different levels of semantic processing. In addition, in order to check EC assumptions, studies must contrast distinct types of verbs, for instance action vs. emotional/psychological; biological vs. non-biological; verbs requiring and not requiring tools. Another semantic feature of concern is specificity. Kim and Thompson (2004) distinguish light and heavy verbs and discuss their different speed of deterioration in neurodegenerative diseases. Considering this panorama, this chapter will present, a summary of the different approaches about action/verbs semantics, current debates about verb neural representation and an analysis of the evaluation directed to patients with Parkinson's disease. A Pubmed and Scopus search was conducted in December/2014 using the terms "action verb" OR "verb" OR "verbs" AND "Parkinson's disease" with no time restriction. We retrieved 35 studies and selected 22 for analysis, excluding reviews and studies not related to action/verb semantics in PD. The methodology and findings of those 22 studies were analyzed and contrasted with theories that explain the neural representation of action/verb semantics, in particular the multilevel model and Embodied Cognition accounts. The challenge for new studies is to identify those semantic properties, understand how they are related to cortical processing and develop suitable tools to analyze these features in different profiles of Parkinson's disease.

Keywords: Parkinson disease; multilevel model, embodied cognition, verbs, lexical/semantic processing

INTRODUCTION

Verbs are the best lexical items to verify the effects of motor learning in language, but the study of neural lexico-semantic representations has neglected this category and focused on nouns for a long time. Difficulties in using verbs were described by Pick in 1917 (in Critchley, 1970), and the Neuropsychological interest for this class of words initially concerned their morphosyntatic function. At the last decade of the last century, selective difficulties for verbs and nouns were shown in patients with cerebral focal lesions (Miceli, Silveri, Nocentini & Caramazza, 1988; Caramazza & Hillis, 1991), as well as after the degeneration that occurs in Alzheimer's Disease (Kim & Thompson, 2004). The interest on the difficulties to process verb meanings by patients with motor disorders is even more recent and has had implications for the Embodied Cognition theory. According to this theory, language processing derives from experience, and thus the semantic processing of action verbs recruit areas involved in planning and executing those actions in the motor cortex. However, the literature in this area has pointed to conflicting results regarding action/verb cerebral representation and its impact on language difficulties in motor disorders such as Parkinson's disease.

This chapter has the purpose of discussing the results of a systematic review about action/verb processing in patients with Parkinson's Disease (PD), presenting the current panorama in this area of research. Before addressing the pathology, however, we will present the set of studies that made scientists draw their attention to the production of verbs in PD. First, we will describe some important concepts about the semantics of verbs. We follow with

a brief history of the theoretical landmarks, which promoted interest in the study of neural representations of verbs and the current controversies. Finally, we present the results of our systematic review and analyze the methodologies and main findings of 23 recent studies for a critical discussion of the neural representation of action/verb semantics in terms of the strong and weak versions of the Embodied Cognition theory. In this context, we emphasize the contribution of multilevel models to interpret the controversial findings of the studies. We focused on the semantic processing elicited by different tasks and the points to be considered in future research.

THE SEMANTICS OF VERBS

Verbs and nouns present many syntactic and semantic differences. These systems require distinct mechanisms: while the lexical-semantic system is based on declarative memory, the syntactic system corresponds to procedural memory (Ardila, 2012). In addition, verbs have a unique syntactic role; they act as the center of a sentence, linking the other elements.

In the semantic level, when compared to nouns, verbs represent actions and "relational" concepts (Gentner, 1981), while nouns refer to objects or events. Also categorization differs between the two grammatical classes. Hierarchical models propose that nouns are categorized according to the group they belong (i.e. *elephant* is a wild *animal*, big, and has a trunk, etc.), answering to a question "WHAT IS IT?" (Rosh & Mervis, 1975). Verbs are categorized according to HOW the action is held (i.e. *running* is *walking fast*) (Miller & Fellbaum, 1991).

Kim and Thompson (2004) proposed a hierarchical categorization of verbs based on higher or lower levels of specificity. On the top, we find "light verbs", those who have little semantic information, but an important syntactic role (i.e. *can, to be, to do*, etc.). Then, generic and specific verbs, which possess richer semantic information associated with their meanings. Specific verbs are more complex and demand more cognitive resources in their processing, e.g. *to run* is semantically more complex than *to walk*, because *to run* is one of the possible ways *to walk*. Thus, semantically simpler verbs – the generic verbs – can be used in broader contexts, whereas semantically more complex ones – the specific verbs – are used to refer to more restrictive actions. For instance, the action represented by the verb *"to cut"* can be held in different ways: with a knife, with the hands, with a scissor, etc. while *"to saw"* is held in only one way and requires a tool.

Specificity is an important feature in language processing. This was evidenced both in lexical development and in language deterioration. Older children use more fluently specific verbs (Tonietto, Parente, Duvignau & Gaume, 2008), while in Alzheimer's Disease and Semantic Dementia, the occurrence of generic verbs is higher (Kim and Thompson, 2004; Méligne et al., 2011).

Another semantic classification was proposed by Levin (1993), which considered syntactic and semantic features. In an exhaustive study of the English language, the author found more than 200 verb classes, all of which can be grouped as similar in meaning. Many studies in Neuropsychology and Neuroscience of Language used this classification, usually employing some of the proposed categories to generate assumptions on their neural correlates, which depend on the semantic properties of the verbs. For instance, in action verbs research, Kemmerer (2008), used fMRI to record brain activity elicited by five broader

categories: Running (e.g. *to run, to walk)*, Speaking (e.g. *to whisper, to yell*), Hitting (e.g. *to hit, to poke*), Cutting (e.g. *to cut, to slice*) and Change of State (e.g. *to crack, to smash*). In this study, verbs were classified according to their semantic features: ACTION, MOTION, CONTACT, and TOOL USE, and the author held a neuroanatomical prediction to verify whether semantic knowledge is grounded in sensorimotor systems, the basis for the Embodied Cognition approach, detailed below. Kemmerer (2008) highlighted the variability of these classifications according to the semantic structure of a language and the need of cross-cultural studies.

Thus, we have a hierarchical model of verbs' categorization concerning the level of semantic specificity and verified both in language development and in its dissolution due to different forms of dementia processes. However, the order in which specificity facilitates neural processing, as well as how it affects verb processing in patients with motor degenerative disorders has not yet been studied. On the other hand, anatomical hypotheses were postulated from the syntactic-semantic features of verbs and the development of those models was only possible due to the evolution of Cognitive Neuropsychology, detailed below.

THEORETICAL MODELS THAT PROMOTED THE VERBS NEURAL REPRESENTATION STUDIES

The recent increase of studies focusing on neural correlates of verb processing and their difficulties depended on the theoretical evolution of Cognitive Neuropsychology. In this field, language is considered a complex activity, which involves different mental processing. In an initial period, the models used a computational metaphor or a hypothetical neural conexionism, and the modularity notion proposed by Fodor (1983). In this modularity proposal, language, as other cognitive functions, was seen as an "encapsulated" process, and thus, could only be studied separate from other functions. Computational models were replaced by the so called "Cognitive Revolution", led by Bruner (1986). This revolution replaced *meaning* by *representation,* and so, language became the center of human cognition. A decade later, language studies turned to integration to other systems, as working memory and attention (e.g. Gathercole & Baddeley, 1993).

Despite the interaction between different cognitive functions, language was still analyzed separately from other systems. The semantic knowledge was considered as an organization of abstract concepts and, thus, independent from sensory-motor processes. Furthermore, besides recognizing memory and attention interferences in language, this theory (nowadays known as *amodal* theory), does not consider the body as a participant of semantic knowledge.

A new proposal on acquisition and development of psychological capacities arises from Embodied Cognition theory (EC) (Shapiro, 2011). This approach proposes the integration of perceptual, linguistic, and motor functions when trying to understand internal, as well as external, individual phenomena. From this associative perspective, such information processing can recruit adjacent areas even if these areas are specialized in other functions (Wilson & Foglia, 2011). Linguistic processing approximates *meaning* to the real object or action, and language is no longer understood as an abstract representation of the world.

The EC returns to Wittgenstein's (1953) ideas that propose that lexical learning is directly related to the individual interaction with the world. Thus, to EC the subject associates the meaning of the actions that he performs and the objects with which he interacts to the description of those given by the external world, integrating movement, perception, and language. Thus, the body is seen as the cause or condition for cognitive constitution, establishing an interdependent relation between processing and bodily relation with the world. Therefore, verbs are the lexical items per excellence to verify the effect of motor learning through language (Shapiro, 2011; van Dam, Rueschemeyer & Bekkering, 2010; Barsalou, Simmons, Barbey & Wilson, 2003).

The mirror neuron theory supports EC theory (Kohler, Keysers, Umilta, Fogassi, Gallese & Rizolatti, 2002). The former, through studies with apes, postulates that when observing an action and/or planning it, motor and premotor cortices are activated, respectively. In the language field, linguistic learning results from experience with the external world, and therefore semantic processing of action verbs, would activate the same motor and premotor cortices. Therefore, to EC theory, holding, observing and describing an action would evoke the same neuronal apparatus, in other words, when we say the word "*walk*" the mental homunculus actually moves (Pulvermuller, Härley & Hummel, 2001; Barsalou et al., 2003).

However, EC findings are not supported by all experimental data and those controversies favor the maintenance of explanations in terms of the amodal model. This model, as said above, postulates that the words' meanings in the lexicon are independent from perceptual inputs and motor outputs. The debate between these two positions (i.e. EC and amodal model) promoted the advancement of the current knowledge about neural representation in healthy subjects and motor system pathologies, as well as the proposal of a conciliating approach: the multilevel model (Kemmerer, 2015). Thus, before analyzing the studies of verb processing in patients with Parkinson's Disease we will present, in the next section, a brief panorama of the discussions of neural correlates of action/verb processing.

CONTEMPORARY MODELS ABOUT NEURAL VERB REPRESENTATION

Firstly we will explore some of the work that, based on the EC theory, find verbs activating motor areas (primary motor cortex M1; precentral gyrus and several premotor cortex areas) or areas responsible for movement perception (posterolateral temporal cortices - PLTC and Middle temporal area MT+). This approach is called strong Embodied Cognition position. Then, we will illustrate some of the work of the authors that defend that concepts of verbs are independent from movement representation and modality-specific regions, and instead organized, according to semantic aspects of verbs, the amodal model. Lastly, we will present the multilevel model, a weak version of the EC theory.

Strong Embodied Cognition Position

The idea that verb processing is different from noun processing arises from double dissociations found in studies with aphasic patients (for a review see Vigliocco, Vinson, Druks, Barber & Cappa, 2011). Studies of focal neurological lesions have shown that the

lexicon is represented by different neuronal networks through grammatical word differences: anterior frontal areas would be responsible for verbs representation and temporal areas, for nouns. However, recent studies with patients with cerebral focal lesions have shown that verb processing demands a large neural network, and thus it is unlikely that clear separate areas for nouns and verbs exist. Kemmerer, Rudrauf, Manzel and Tranel (2012), proposed six different tasks requiring expression, comprehension and semantic similarity judgments of verbs, and evaluated 226 brain damaged patients using this set of tasks. Sixty-one patients had difficulty in one or more tasks; four had difficulties in all tasks and the rest had a complex dissociation and association between tasks. Despite the left hemisphere predominance of the difficulties, an extensive neural net was found to be related to these deficits: the inferior frontal gyrus; the ventral precentral gyrus, extending superiorly into what are likely to be hand-related primary motor and premotor areas; and the anterior insula, the ventral postcentral gyrus; the supramarginal gyrus; the posterior middle temporal gyrus. The authors concluded that their results confirmed EC's postulates.

Shapiro et al., (2005), tried to replicate the findings of double dissociation in aphasics in an experiment using PET scans with healthy participants. The findings of that study also showed prefrontal cortex activation in verb processing, while temporoparietal areas bilaterally were activated in processing nouns.

Trying to specify the relationship between language and motor functions, from EC theory, Pulvermüller et al., (2001) hypothesized that associative learning – also called semantic learning – recruited the neuronal network responsible for bodily movements for mouth, hand and leg actions. Mouth action verbs would be represented cortically in a more restricted area in the inferior frontotemporal region; hand-action verbs, in inferior and medial frontotemporal areas; whilst leg-action verbs would have a more extended processing, involving superior frontal sites.

The studies that used fMRI technique to address the semantics of verbs, having support of Pulvermüller's associative theory, found, as expected, representation of mouth-action verbs in the inferior prefrontal gyrus (Hauk, Johnsrude & Pulvermüller, 2004; Tettamanti & al, 2005; Azzis-Zadeh, Wilson, Rizzolatti & Jacobini, 2006; Rüschemeyer, Brass & Friederici, 2007), or in the posterolateral temporal cortex (Kemmerer, Castillo, Talavage, Patterson, & Wiley, 2008). When leg-related action verbs were studied, the majority of findings pointed to activation on the prefrontal or superior frontal motor area, which coincides with the homunculus motor representation (Hauk et al., 2004; Tettamanti et al., 2005; Kemmerer et al., 2008), except for the findings of Azzis-Zadeh et al., (2006), which showed a prefrontal medial activation to movements. However, neural representation of movements held by the hands still present contradictory findings. Azziz-Zadeh et al., (2006) found that hand’s and leg's representations overlap, which contradicts the assumptions of the somatotopic theoretical model.

Specifying the semantics of verbs held by hands, Kemmerer et al., (2008) showed that, in distinguishing movements of clapping hands from cutting with hands, the former activated superior motor areas and the last ones, medial premotor and temporal and frontoparietal network. To these authors, the presence of premotor areas is justified by a higher demand on planning skills, since the vast majority of cutting verbs need tools. Moreover, Yang, Shu, Bi, Liu & Wang (2011), taking advantage of the uniqueness of the Chinese writing, designed an experiment with 3 stimuli groups: (1) hand verbs containing hand root; (2) tool verbs containing tools root; and (3) tool verbs containing hand root. They found that all verbs

elicited left medial frontal cortex and left inferior parietal activations and, activation on the premotor region was found for all conditions when subtracting hand movements in the analysis. Tool verbs, as in a previous study, presented higher connectivity, with frontoparietal representations and activation of the posterior temporal cortex. The authors interpreted this dispersion as evidence of higher semantic processing demands to accomplish the complex task of verb comprehension involving tools. Despite the quite interesting experiment design, focusing on Chinese writing aspects, which implicates a hand or an instrument symbol, the results may be biased by the fact that the writing of these roots gives extra implicit information.

Besides motor areas, verb comprehension also recruits the temporoposterolateral cortices (PLTC and in the left middle temporal gyrus (LMTG). The pioneer study, showing that the LMTG activation related to verbs, was published by Martin, Haxby, Lalonde, Wiggs & Ungerleider (1995). Later, several works showed that this activation occurs in different tasks, such as generation of action verbs, semantic relatedness judgments, and semantic triads. Moreover this activation was found in different languages using as stimuli different types of verbs, as action verbs and mental state verbs (for a review see Bedny & Caramazza, 2011). PLTC is close to the middle temporal area (MT+), a brain region that processes movement of animate beings. Despite the debate regarding the function of the PLTC in verb processing, this area in the left hemisphere presents greater responses to motion-related than non-motion related verbal descriptions (Tettamanti et al., 2005). Thus, for the authors that support the strong position of EC, the activation of those areas subserve a high-level motion perception (Kemmerer, 2015). However, a great amount of the work designed to address the strong EC position has problems in controlling stimuli regarding psycholinguistic variables and in analyzing the processing demands of the task. Neuroimaging studies show a joint activation for verbs and nouns, indicating that semantic representation of words (nouns or verbs) rests on lexico-semantic traits (or psycholinguistics criteria), such as concreteness (Lee & Federmeier, 2008), frequency (Vigliocco, Vinson, Arciuli & Barber, 2008) and ambiguity (Lee et al., 2008; Li, Jin & Tan, 2004).

On the other hand, controversial findings on the neural representation of hands' movements may be explained in terms of the use of these verbs. Hand actions are developed only in superior mammals, and in the humankind they present vast semantic variability. It is probable that this diversity in hand actions have biased the tasks. For instance, in the experiment designed by Pulvermüller et al., (2001), there are verbs that denote very specific movements, as *to box* and others, very generic as *to beat.* The neural differentiation of objects and verbs, when taking into account the concreteness criterion, which distinguishes action verbs from mental/psychological verbs, is already known (Crepaldi, Berlingeri, Paulesu, & Luzzatti & et al., 2011), but so far, we haven't found studies about neural organization considering verbs' specificity, which classify action verbs in generic and specific verbs.

The importance of psycholinguistic factors on brain processing was shown by Hauk, Davis, Ford, Pulvermüller e Marslen-Wilson (2006). Through a regression analysis of electrophysiological data, they showed that the time course of processing of the lexicon psycholinguistics features varies. Their results suggest a bottom-up processing in lexical decision tasks, in other words, the visual aspects, as word extension, are detected early in time, followed by word frequency, and the semantic aspects are processed later in the brain. It is worth noting that this work used nouns whereas the time course of different lexical aspects of verb processing has not been studied yet.

Lastly, task complexity can influence experimental results. Tasks that demand higher cognitive resources favor noun/verb dissociation, stressing the role of executive functions and working memory (Cappa, 2012; Cristescu, Devlin & Nobre, 2006). Thus, differences found between psycholinguistic features and neural correlates indicate the need to control the morphosyntactic and semantic variables between the grammatical groups (nouns/verbs) and a carefully design the experiment, choosing an adequate task, which is fundamental to analyze the activation pattern (Cappa, 2012).

The Amodal Model

Strong criticisms of experiments that defend EC theory come from researchers that support the amodal model. This model postulates that semantic representations are accessed independently from the modality of the stimuli. This theory starts with many experiments focusing on nouns, and only later focused on verbs semantics. Even if there is a small number of works focusing the semantics of verbs, they had great repercussion in the debates about neural representation of verbs.

The main postulates of this theory are: (1) if the same brain area is activated by different modalities when concept is presented (oral, written words or figure presentation), it is possible to conclude that this brain area represents that conceptual knowledge is supramodal in nature; (2) the overlapping of brain areas when activated by different tasks does not mean that the same mechanism is involved, and lastly, (3) the amodal theory defends that it is not possible to know whether rapid processing of motor areas involved in verb comprehension is the cause of semantic comprehension of these verbs or a consequence of retrieving semantic knowledge (Mahon & Caramazza 2008; Caramazza, Anzellotti, Strnad & Lingnau).

To verify if the same brain areas are activated by different presentation modalities of a concept, Fairhall & Caramazza (2013) designed an experiment in which subjects performed a typicality rating of one item within its category. **N**ouns of five semantic categories were: tools, clothes, fruit, birds and mammals. Different blocks presented the written word or its picture. Using Representation Similarity analyses (RSA) they found that two brain regions, the posterior middle/inferior temporal gyrus (pMTG/ITG) and cingulate/precuneus (CP) responded in a similar way to all categories.

In another study, Wei et al., (2013) used living (animals) and artifact categories in three different tasks (object picture-naming task, object picture associative-matching task; object sound-naming task), and non-semantic tasks as control. Through a regression analysis, the authors observed that the LMTG was the core component that accounted for 74% of the semantic processing performance variation only on semantic tasks and not on number processing, which is a non-object-concept task. The authors conclude that the LMTG is the core of a network that undertakes the conceptual processing for nouns. Furthermore, Bracci Cavina-Pratesi, Ietswaart, Caramazza and Peelen (2011) have shown that the lateral occipital temporal cortex responses to tools overlapped with hand responses, but not with other object categories. They proposed a high-order semantic function in the visual cortex.

Bedny et al., (2008) designed an experiment to verify whether the activation of PLTC is due to sensory-motor features of verbs or, in an alternative interpretation, if these activations result from a modality independent processing. They elaborated an experiment of semantic judgment of varying pairs of verbs, regarding the amount of motion information. As expected,

higher activation in PLTC were obtained with verbs when compared to nouns. Moreover, the verb's advantage was independent of the amount of motion, that is, action and abstract verbs obtained higher responses than nouns. The authors claimed that the PLTC is responsible for the retrieval of events. Conceptual properties of the events are organized according to their semantic aspects and do not involve the sensory-motor experience.

This study compared neural activations between normal seeing individuals and congenitally blind ones. It caused a big impact and supported amodal position, verifying whether visual experience influences the semantic processing of verbs. Bedny and Caramazza (2011) tested the hypothesis that the LMTG modulates representation of motion of verbs, and thus whether verb concepts are grounded in a sensorial representation of the motion. They compared sighted and blind subjects in verb processing. Following the authors, if the EC hypothesis is true, the LMTG would be altered in those who had never seen. The study showed that the LMTG was equally engaged for nouns and verbs and that the same profile was found in congenitally blind individuals. For the authors, those results showed that LMTG storage concepts are independent from the subjects' experiences and, therefore, do not depend on its visual representation. However, it is possible that this region stores some kind of movement representation, which, in sighted individuals, has a visual aspect.

Even with radical oppositions to the EC, the authors consider that "although the neuroanatomical data suggest that word comprehension is supported by modality-independent representations, there is also wide evidence that language, perception, and action are not isolated modules, but rather interact dynamically" (Bedny & Caramazza, p. 92).

The Multilevel Model

Kemmerer (2015), in the context of EC or Grounded Cognition, proposed a model according to which the meanings of action verbs would recruit precentral motor areas, but not *always* neither in a *fast* or *automatic* fashion. Recruitment of motor areas would vary according to the demands of the task and would not be always necessary for comprehension. Instead, it would happen only when motor simulations were needed to process meanings. In addition, depending on the context or type of verb, the lateral posterior temporal cortex would also be activated to allow visual perceptual processes that would enrich the semantic representation or attempt to complete it in order to compensate deficits in patients with diseases affecting the motor system (Kemmerer, 2012).

Despite neurophysiological evidences in healthy subjects, which favor the strong version of the EC account, findings with patients presenting diseases affecting the motor system have not been entirely consistent with its assumptions (for a review see Silva et al., 2014). Therefore, the multilevel model proposed by Kemmerer (2015) is a conciliating alternative and manages to explain some of those controversial findings. This model has two important advantages: (1) it explains the absence of a dramatic language deficit in verb/action processing, predicting that motor simulation is optional rather than necessary; (2) it contributes to the description of the underlying mechanisms to compensate for action/verb semantic deficits, and explains the variability of behavioral results among patients with motor diseases.

The multilevel model brings some elements of the neurobiological model of semantic processing proposed by Binder e Desai (2011), i.e. the assumption that the demand on

sensorial and motor simulations is quite variable in several modalities for comprehension (e.g. spontaneous oral language, object recognition, reading). For example, given the speed of spontaneous oral language it would be unlikely that all the content was fully processed with simulation or re-experience of motor, sensorial and emotional aspects. In that situation, abstract schemes or concepts, whose nature is not modality specific, would be accessed quickly and manipulated for communication, demanding nothing or almost nothing of visual imagery or motor simulation. On the other hand, situations in which unfamiliar/infrequent sentences are employed or where specific lexical elements are inserted would require access to the complete semantic representation, including perceptual and motor areas as well as emotional ones (although empirical evidence on the latter is scarce as they have been neglected by most studies in this theme). In sum, in Kemmerer's account the higher the familiarity and the amount of contextual information, the less necessary it is to access detailed representations in modality specific systems.

Kemmerer's model proposes that knowledge has a flexible architecture in which low level systems (specific modality - for action, perception and emotion) and high level systems (multi- and cross-modal) denominated *hubs* have different roles in semantic processing. The author incorporates to his model the assumptions of the Hub and Spoke framework (Pobric, Jefferies & Lambon Ralph, 2010). That model has empirical evidence from patients with semantic dementia (or semantic variant of primary progressive aphasia) whose main symptom is a progressive difficulty to process word/object meanings affecting comprehension and expression (severe anomia) and that correlates with progressive atrophy of the temporal poles bilaterally. The Hub and Spoke model (Pobric, Jefferies & Lambon Ralph, 2010) considers that the anterior portions of the temporal lobes are critical centers for semantic processing and that they are modality-invariant or amodal, whose function is "binding together the cortically distributed sensory and motor features of concepts; organizing those representations so that the boundaries of concepts are delimited more or less precisely, thereby allowing individuals to efficiently judge category membership" (Kemmerer 2014, p.322). It is worth to highlight that the idea of a semantic hub, though quite defined in the literature, is not consensual. For instance, Binder and Desai (2011) reject the notion of a single semantic hub and support that depending on the nature of the information, other areas would also work as hubs. The temporal pole would be a hub for static semantic knowledge (integrating information to the "what" route) whereas the parietal inferior lobe would integrate semantic aspects related to events (to the "where" route). These aspects still require empirical evidence, however, both hub models (unique or multiple) argue in favor of the hypothesis that semantic knowledge access may not necessarily involve the activation of specific modality areas (spokes) and that a weaker version of EC would be more appropriate to explain the findings in patients with diseases that affect the motor system.

Another issue of debate is the number of spokes and the modality specific information processed by them. In Kemmerer's model, two spokes are highlighted, one with motor features of the verbs (in motor areas/precentral cortex), and another that process visual motion features/high level motion perception.

According to the author, part of the semantic processing of action verbs would require implicit and automatic retrieval of different types of visual movement patterns (similar to the activation of motor patterns proposed by the strong version of EC). In his work with brain damage, these visual patterns recruited the posterolateral portion of the left temporal lobe in all the categories of verbs he studied (Kemmerer, 2015). The author recognizes, however, that

the activation of these areas could also reflect post-comprehension visual imagery or also more abstract perceptual aspects, since his findings could not be conciliated with the aforementioned ones of Bedny et al., (2012) and that support the amodal theory. Bedny et al., analyses indicated that the left PLTC responded significantly more to verbs than nouns, regardless of the amount of motion conveyed by the words, and regardless of whether the subjects were sighted or blind.

Now, we turn to the question of when and how these features (motor and perceptual) would be accessed for the semantic processing. For that, in the following session we analyze the findings of the systematic review in verb/action semantics and PD.

VERB DIFFICULTIES AND EC ACCOUNTS IN PARKINSON DISEASE

PD is a neurodegenerative disease characterized by bradykinesia (slowness of movement), rigidity, tremor, gait, and posture problems. It is caused by a progressive loss of dopamine in the nigrostriatal tract, reducing the projections of the basal ganglia to the frontal motor regions. The deficits in the dopaminergic pathways cause hypo-activation of the supplementary motor area and primary motor cortex, and hyper-activation of the ventral premotor cortex, reflecting a compensatory mechanism (Kemmerer et al., 2013; Cardona et al., 2013). PD is an interesting framework for investigations on the role of the frontal network in the Semantics of verbs due to the possibility of exploring, in the same patient, the ON and OFF effects induced by medication (Levodopa) and by Subtalamic Nucleus (STN) stimulation. In a recent review, we summarized the findings in this area and discussed their contributions to support the Embodied Cognition theory (Silva et al., 2014). Here we update the literature review in order to discuss controversial findings in terms of cognitive demands and different approaches of cognitive models that explain semantic memory processes.

A Pubmed and Scopus search was conducted in December/2014 using the terms “action verb” OR “verb” OR “verbs” AND “Parkinson’s disease” with no time restriction. We retrieved 35 studies and selected 23 for analysis, excluding reviews and studies not related to action/verb semantics in PD.

As shown in Table 1 the tasks used to study verb processing in patients with Parkinson’s disease used several different tasks: spontaneous conversation, naming picture; word generation, verbal fluency; lexical decision tasks; imagery, go/non/go task; semantic judgment tasks and action compatibility effect (ACE).

Free Oral Conversation

One of the postulates of the multilevel model is that more automatic tasks would not always require motor regions for semantic processing, and thus we would expect that the use of verbs in spontaneous conversation would not be affected in PD. That was the finding of Nikumb (2014), which to our knowledge was the only study to explore the semantics of verbs in natural conversations. The author recorded conversations and compared PD patients and controls (spouses) regarding the mean number of verbs produced per minute.

Table 1.

Study	Task	Performance of PD group relative to CG	PD group ON or OFF State/ DBS ON or OFF State
Nikumb (2014)	Free oral conversation	Participants with PD produced significantly fewer high-motion verbs compared to low-motion content verbs. However, control participants also produced significantly fewer high-motion verbs compared to low-motion content verbs. T	Not applied.
Letter et al., (2012) (EEG)	Passive Reading	Not applied.	In ON the differences in density currents were found to be larger in left-hemispheric areas than in the right-hemisphere. Activation of motor, pre-motor and parietal areas was lateralized according to clinical motor signs.
Silveri et al., (2012)	Passive Reading	No interaction between grammatical class and group was observed. PD patients were slower but as controls whereas accuracy had ceiling scores for both groups.	No effect of DBS ON and OFF state.
Bertella et al., (2002)	Naming	A noun/verb dissociation with a relative verb deficit was found in patients affected by PD	Not applied.
Cotelli et al., (2007)	Naming	PD patients were more impaired in action naming than in object naming. Manipulability factor was not significant.	Not applied.
Rodríguez-Ferreiro et al., (2009)	Naming	PD patients presented a significant impairment in action naming compared to object naming, whereas healthy participants and Alzheimer disease patients did not have differences.	Not applied.
Herreira, Rodríguez-Ferreiro & Cuetos (2012)	Naming	Not applied.	RT differed for high and low motor content pictures in PD patients off medication, compared to the same patients.
Silveri et al., (2012)	Naming	PD group had poorer performance (accuracy and reaction time) on naming nouns and verbs than healthy control group. Significantly worse performance was observed in PD. In DBS OFF state patients had less accuracy as compared with controls in naming actions, but not for objects.	PD patients were significantly more accurate and faster in the DBS-ON stimulation condition in both object and action naming. Differences in DBS ON x OFF were observed for verbs. PD DBS-ON patients had fewer anomias and semantic errors in naming actions. No correlation of naming performance and memory and executive functions was observed in PD group

Study	Task	Performance of PD group relative to CG	PD group ON or OFF State/ DBS ON or OFF State
Nguyen et al., (2013)	Go/no Go task	An interaction was found between PD dominance and upper and lower limb verbs. Patients with greater upper limb deficit were slower in answering upper limb than lower limb verbs. However, patients with lower limb greater deficits did not show differences in responding to upper and lower limb verbs.	
Herrera, Cuetos & Rabinboca (2012)	Verbal fluency - phonological, semantic and action fluency.		T Differences in the total of words produced were observed in both the phonological and action categories between PD OFF/ON and PD OFF and healthy controls. There were no significant differences between PD patients ON medication and controls. Relative to frequency of words, PD OFF emitted words with higher frequency in action fluency than healthy control group.
Tomasino et al., (2014)	Lexical decision	Not applied.	Results pointed that accuracy not differed between groups. RT for action-related verbs was significantly faster for positive than negative commands in the DBS-ON, while they were identical in the DBS-OFF 50%
Fernandino et al., (2013a)	Lexical decision associated with priming effect and judgment task	Lexical decision task showed faster reaction time for both groups for hand-action verbs than for abstract verbs. Prime effect difference was not observed. In judgment task action verbs responses were slower than for abstract verbs	
Boulenger et al., (2008)	Lexical decision associated with priming effect		During OFF state of dopaminergic treatment no priming was found for action verbs, whereas recovery was found during ON state. Concrete nouns were not affected by the dompaminergic treatment.
Péran et al., (2003)	Generation task	Patients had the poorer performance for verb-verb and noun-verb generation but similar performance on noun productions. Patients had more grammatical errors in three tasks involving verbs. Significant negative correlation between performances on the condition that required a switch between category, i.e., noun/verb condition and Dementia Rating Scores	Not applied.

Table 1. (Continued)

Study	Task	Performance of PD group relative to CG	PD group ON or OFF State/ DBS ON or OFF State
Castner et al., (2008)	Generation task	PD participants, regardless of Subtalamic Nucleus (STN) stimulation condition, produced more errors in the verb–verb condition	Semantic attribute of probes (visual or motor features) did not relate on response errors for PD participants (in the ON and OFF) and controls. In the PD ON stimulation condition, selection constraint (ratio of selection of words) was significantly correlated with mean error in the noun–verb condition and verb–verb condition
Crescentini et al., (2008)	Generation task	In noun generation, strong associations between stimuli and responses led to better performance in the PD group in this task. Relative to verbs, PD patients were significantly impaired in all conditions of verb production in comparison to the control group. PD patients made significantly more grammatical errors and no-response errors. Executive functions in PD group were associated with errors in verb generation.	Not applied.
Péran et al., (2009) (fMRI)	Generation task	No differences were observed between types of substantives, but relative to generation of actions. No correlations were observed between performance and UPDRS and cognitive scores. In fMRI data, severity of disease was associated with action generation in bilateral post-central girus, left operculum frontal area, left supplementary motor area and right superior temporal cortex.	Not applied.
Péran et al., (2013) (fMRI)	Generation task	Not applied.	Generation of action had more errors than Object naming (ObjN). GenA elicited significantly more activation than either ObjN in left prefrontal cortex, left middle precuneus. MSoA showed significantly more activation than ObjN in the prefrontal cortex bilaterally and in the parietal–occipital junction bilaterally. ON>OFF for [GenA vs ObjN] contrast showed mainly premotor areas and for [MSoA vs ObjN] thalamus and premotor areas. However, differences between OFF> ON did not show significant differences.

Study	Task	Performance of PD group relative to CG	PD group ON or OFF State/ DBS ON or OFF State
Herreira & Cuetos (2012)	Generation task	PD OFF, ON and performance of control group were compared.	PD patients OFF medication said words less associated with the target compared with when they were on state. In the OFF state patients generated less semantic related responses for verbs than control groups, while PD ON have the same performance than controls. No differences were observed for nouns between PD OFF or PD ON and healthy controls.
Fernandino et al., (2013b)	Lexical/semantic processing of phrases	Patients, but not controls, were slower to respond to literal and idiomatic action than to abstract sentences. Groups did not differ in accuracy levels.	
Fernandino et al., (2013a)	Semantic similarity judgment	Accuracy was significantly lower for PD patients than for controls, while RT did not differ between groups. In PD group accuracy in the action condition was lower than in the abstract condition.	
Kemmerer et al., (2013)	Semantic similarity judgment	There was no effect of group, indicating that PD patients have the accuracy of control group. RT of action verbs and no-action verbs did not differ between groups.	Patients failed to respond to significantly more items in OFF condition than in ON. PD ON and OFF have the same accuracy. In RT, differences were in Cutting x Hitting in PD OFF< NC and PD ON < NC. RT for change of state were longer than psych verbs in PD ON < NC and PD OFF < NC. Non-parametric correlations were observed between PD OFF – duration of disease and accuracy in cutting and psych verbs.
Ibáñez et al., (2013)	Action Compatibility Effect	PD presented only differences in RTs in the neutral trials compared with compatible and incompatible trials. There was no ACE effect in PD group, in opposition of control group data. KDT accuracy was highly associated with the ACE. A negative correlation between hand-KDT error trials and the ACE.	Not applied.

Moreover, the occurrence of high- and low-motion verbs was quantified. No quantitative and qualitative differences were found between patients and controls. All subjects produced more low–motion verbs and no deficit was found in the PD group in this task when compared to the control group. Although the multilevel model prediction is that the degree of motion would affect the performance of patients with motor diseases, the degree of automaticity of the task could have facilitated the use of verbs by PD patients.

Reading Tasks

Reading can be classified as automatic processing, mainly for very frequent words and when the irregular grapheme-phonemic conversion requires a direct access to semantics. Letter et al., (2012) evaluated 7 PD Dutch patients through a silent reading task associated to EEG recordings and LORETA analysis and compared ON and OFF Levodopa states. The stimuli consisted of thirty hand-action verbs and 30 non-action verbs and the authors used a subtraction method to study the neural correlates of action verbs. Ten regions of interest were analyzed and consisted of five homolog pairs in each hemisphere: Precentral (premotor) cortex; Inferior frontal cortex, Dorsolateral prefrontal cortex (DLPFC), Superior temporal cortex and Inferior parietal cortex (part of the supramarginal gyrus). Higher current densities were found in the on-state as compared to the off-state in all evaluated brain areas and for some patients activation was lateralized according to clinical motor signs. Given the nature of the task and neuroimaging data, these results support the strong version of the EC theory. However, a limitation of this study is that the sample was quite small.

Silveri et al., (2012) investigated the impact of Deep Brain Stimulation (DBS) in a reading aloud task of nouns and verbs. The authors evaluated 12 PD patients that were instructed to read the words aloud as fast as possible. No differences were found between ON and OFF states. Moreover, a ceiling effect for reading accuracy was observed both for nouns and verbs, and PD were slower than controls in both grammatical categories. The results are discussed in terms of executive demands of the task. The authors propose that PD implies in an executive dysfunction, which impairs active lexical search as they find differences in naming (discussed below) but not reading. Another interpretation could be that the grapho-phonemic processing in reading a regular written system, such as Italian, could reduce the semantic processing of the verbs. Also it is possible that the Reading task was extremely simple for both groups and the greater RT obtained by the PD patients could be due to their motor limitations. Moreover, in this study, the major limitation is that it compares nouns to verbs instead of different verb categories.

The two studies that used reading tasks seem to present opposite results. It is difficult to compare them only regarding the task, since one required silent reading and the other reading aloud. Differences in their design could also have influenced the results. The former compared ON and OF Levodoppa states and the latter DBS stimulation effect, thus their main objective was to verify treatment approaches.

Naming Tasks

Although a formal task, naming can also be considered an automatic procedure, since it is frequent in daily conversation and does not require complex semantic processing. Except for Herrera and Cuetos (2012) who investigated naming of high and low motion action verbs, the four other studies analyzed noun/verb differences. Two of these noun/verb studies (Bertella et al., 2002 and Cotelli et al., 2007) found a disproportionate deficit for verbs compared to nouns. Bertella suggested that their findings show the role of fronto-striatal system in verb processing, which could be in accordance to the EC model. However, Cotelli et al., (2007), besides noun and verbs comparison, tested the influence of a semantic attribute - manipulability (the involvement of fine hand movements), and found that performance of PD patients was not influenced by this feature but instead by the grammatical class of the stimuli, which would be in favor of the amodal model claim. However, manipulability was assessed in nouns and verbs (i.e. objects which can or cannot be manipulated and actions that do or do not involve fine hand movements), which may limit the interpretation of this finding.

Silveri et al., (2012) did not use a control group, but instead investigated On and OFF DBS effects. Only action naming was impaired in the OFF state and the findings were explained in terms of grammatical class differences and cognitive demands of the task. Silveri et al., used naming and reading tasks and found that only the former was impaired in PD. Therefore, their finding could also be explained according to the weaker version of EC.

The other two studies (Rodrígues-Ferreiro et al., 2009 and Herrera and Cuetos, 2012) compared PD patients' performance to healthy adults and Alzheimer's Disease (AD) patients. Rodrigues-Ferreiro used the classical verb/noun comparison and interpreted the verb difficulties in terms of the EC account. PD patients presented a significant impairment in action naming compared to object naming, whereas healthy participants and Alzheimer's disease patients did not have category differences. The authors propose that verb representation is grounded in neural networks in which motor brain areas contribute to their processing.

Finally, in the study of Herrera & Cuetos, the authors used a measure of performance that took into account accuracy and reaction times for high and low motion verbs. PD patients were seen on and off Levodopa and presented longer reaction times in response to all pictures when OFF medication. Moreover, regression analysis using RT differences between PD ON/OFF found that higher motor content verbs were more impaired in the OFF state. It is interesting to remark that the use of more fine measures, like RT, allowed the detection of a clear motion effect, not found in the study of Nikumb (2014). Thus, as expected by the multilevel model, in a more restricted situation there will be greater participation of the sensori-motor neural network.

In sum, even with some studies that have obtained opposite results, a deficit in naming verbs was found in patients with PD. Evidences of the multilevel model are obtained by the comparison between reading and naming tasks as well as by the relationship between the semantic attribute of motion of the verb, when very fine analyses are undertaken.

Go/Non Go Task

Using TMS to test the strong view of EC Nguyen et al., (2013) compared PD patients with upper versus lower limb dominance in a go/no go task. Target verbs were 30 limb, 29 lower limb and 30 psych verbs. An interaction was found between PD dominance and upper and lower limb verbs. Patients with greater upper limb deficits were slower in answering to upper limb verbs compared to lower limb ones. However, patients with greater deficits in lower limbs did not show differences in responding to upper and lower limb verbs. These results support Pulvermüller's theory of associative learning, and have refined the studies about PD patients and verb processing concerning the classification of the patients regarding their impairments. Go/no go task does not require deep semantic processing, but it requires a greater amount of attentional resources, and thus the interaction found can be influenced by executive capacities of the patients.

Verbal Fluency

Herrera, Cuetos & Rabiboca (2012) assessed 20 PD patients and 20 control subjects with four verbal fluency tasks: phonological fluency (words beginning in F), semantic fluency (animals and supermarket items) and action fluency (infinitive form of verbs, ''things you can do''). Patients were asked to produce as many words as they could from each category in 60s, in ON and OFF Levodopa states. The total of words produced in the phonological and action categories differed between PD OFF/ON and PD OFF/Healthy controls. There were no significant differences between PD patients on medication and controls. An analysis of the frequency of the words produced in action fluency demonstrated that PD OFF emitted words with higher frequency compared to the control group. Results are explained in terms of dopamine dependency for lexical retrieval. The authors mention that patients have difficulties retrieving verbs with greater semantic action content that would be related with an under-activation of motor and premotor areas during the condition OFF medication. The qualitative results are in accordance to the multilevel model in the sense that less frequent or semantically more complex verbs will require motor simulations.

Lexical Decision and Semantic Judgement Tasks

Boulenger et al., (2008) developed a lexical decision task with priming in order to verify the effect of Levodopa. Stimuli were action verbs and concrete nouns. During the OFF state of dopaminergic treatment, no priming was found for action verbs, whereas recovery was found during the ON state. Concrete nouns were not affected by the dopaminergic treatment. These results support the role of motor system in action verbs.

The study of Fernandino et al., (2013a) applied lexical decision with priming (implicit task) and semantic judgment tasks (explicit task) in PD patients and healthy controls, testing the processing of action and abstract verbs in Parkinson's Disease. For the lexical decision task with priming, a set of 80 verbs and 80 phonologically legal pseudo words were used. Half of the verbs referred to voluntary hand/arm actions (e.g. *to grasp, to squeeze*), and the others referred to abstract concepts (e.g. *to depend, to improve*). The semantic similarity

judgment task used a set of 120 action verbs and a set of 120 abstract verbs (39 action verbs and 36 abstract verbs also appeared in the lexical decision task). The results in lexical decision tasks suggested that controls had faster reaction times for hand-action verbs than for abstract verbs, when in PD patients this effect was not observed. Similar to controls, patients' responses to action trials (2451 ms) were significantly slower than responses to abstract trials (2332 ms). In contrast, patients' accuracy in the action condition (.955) was lower than in the abstract condition (.975). No prime differences were observed. In the Semantic Judgment task, PD had similar results to controls as they had slower responses for verbs than for nouns. In contrast, in this task action verbs responses were slower for abstract verbs. The authors concluded that their results do not agree with general verb impairment among PD, but the differential impairment of the motor network on the two tasks was a "function of a core meanings associated with a word, which supports the amodal approach." Nevertheless, this study shows the impact of the tasks in implicit procedures and seems to favor the processing of action verbs while the explicit processing would give the opposite result, impairment on action verbs. The greater amount of cognitive semantic resources in the explicit task will also favor an interpretation according to the multilevel model.

Imagery Task

Tomasino et al., (2008) applied single pulse transcranial magnetic stimulation (TMS) in the hand motor area of the left hemisphere during three different tasks with action verbs: (1) silent reading; (2) motor imagery, that is, judgement whether the written verb involved hand rotation; and (3) judgment of frequency of occurrence in a newspaper. TMS did not alter the time of responses of silent reading and of frequency judgment whereas in rotation imagery task, responses were more rapid (compared to TMS vertex). The authors clearly postulate that their results do not support the strong EC view. Motor hand area is not mandatory for comprehension of verbs *per se*. Although the EC theory postulates that in order to understand a verb there is a simulation of an action, they only found motor area involvement in processing verbs when the task explicitly requires simulation of the action. Once more it is shown that the grounded representation of verbs depends on the type of task and the complexity of semantic resources required.

Generation Tasks

In these tasks participants are given a word and are required to generate a semantically related item in the same or in a different morphological category. Two intra-category tasks - noun-to-noun (NN) and verb-to-verb (VV) and two inter-category tasks - noun-to-verb (NV) and verb-to-noun (VN) are usually employed. This task is cognitively demanding because the subject must engage in lexical search and requires deep semantic processing to compare the probes with the responses to be given. Six studies used this task, and two of them associated the task to fMRI. In all five studies PD patients had a disproportionate deficit in verb generation compared to nouns. However, three studies (Peran et al., 2003; Castner et al.; 2008 and Crescentini et al., 2008) explained the deficits in terms of the amodal model of semantic processing and attributed differences to lexical selection problem. Castner et al., (2008) tested

patients in STN stimulation condition (ON vs OFF state) and demonstrated that semantic attributes (visual and motor features) did not impact performance. The two fMRI studies (Perán et al., 2009; 2013) showed more activation of the left prefrontal cortex in verb generation. This area was also activated in manual simulation of the same actions, supporting EC theory. In this task the multilevel model predicted this activation and therefore we can conclude that these types of assessments can be useful to test the assumptions of EC in PD. Finally, Herrera and Cuetos (2013) invited patients and the control group to generate semantic related words based on 10 verbs (to sleep, to ask for, to stop, to cry, to cut, to touch, to climb, to jump, to run, to swim) and 10 nouns (flight, traffic light, mill, anchor, bus, cup, key, flute, umbrella, pen). Authors measured the strength of semantic association between response and stimuli, comparing with normative database responses in the healthy adult population. PD patients off medication said verbs less associated with the target compared with when they were on state. IN OFF state patients generated less semantic related responses for verbs than control groups, while PD ON have the same performance than controls.

Semantic Similarity Judgment Task

Kemmerer et al., (2013) exposed healthy controls (NC – normal control group) and PD patients in ON and OFF state in semantic similarity judgment task (SSJT) using three verbs in a triangular array — one at the top and two at the bottom — and the task was to indicate, as quickly and accurately as possible, which of the two bottom verbs are more similar in meaning to the one on top. For example: "*trudge limp stroll*". Triangular array was presented in 5s followed by 1s of blank screen. PD patients failed to respond to significantly more items in OFF condition than in ON. There was no effect of group, indicating that PD patients did not perform significantly worse than healthy participants. Authors did not find accuracy differences between PD ON and OFF. Relative to RT, Kemmerer et al., (2013) observed that the RTs for change of state were longer than psych verbs in PD ON < NC and PD OFF < NC. RT of action verbs and no-action verbs did not differ between groups.

Lexical/Semantic Processing of Phrases

Fernandino et al., (2013b) investigated PD patients and healthy control subjects in a task of sentence plausibility judgements. Participants had to decide whether the sentence was plausible and to respond as fast and as accurately as possible by pressing one of the two response buttons with their preferred hand (all participants chose to use their right hand). Fifty nonsense sentences and 100 plausible sentences were presented. Nonsense sentences were grammatically well-formed but constructed so that the verb was semantically incompatible with one or both of its arguments (E.g. "*The business is pinching the sunset"*). The plausible sentences were divided into four conditions: literal action ("*The woman is pinching my cheeks*"), non-idiomatic metaphoric action ("*The cost is pinching the consumers*"), idiomatic action ("*The business is pinching pennies*"), and abstract ("*The business is saving cash*"). The 25 sentences in each of the three action-related conditions were built by combining a set of 21 action verbs – all referring to hand/arm actions – with different noun phrases. Patients, but not controls, were slower to respond to literal and idiomatic

actions than to abstract sentences. Groups did not differ in accuracy levels but in reaction times. The authors interpreted their findings in terms of the stronger version of EC. However, a gradation of activation of motor areas is proposed, according to semantic properties of the verb in the context of a sentence. This gradation and the differences in time, but not in accuracy, could also be explained in terms of the multilevel model.

Action Compatibility Effect

Ibáñez et al., (2013) evaluated PD patients and healthy control participants. Authors used the Action Compatibility Effect paradigm. Participants listened to sentences that implied an action with the hand in a particular shape as well as neutral sentences that did not imply an action with the hand. Participants indicated as quickly as possible when they understood each sentence by pressing a button using a pre-assigned hand-shape. No differences between compatible and incompatible trials were observed in PD; that is, differently from controls there was no ACE effect in the patients showing less participation of motor circuits. These results can also be explained by the EC account.

CONCLUSION

Controversies persist in this area with some researchers favoring the strong version of the EC theory, stating that integrity of the motor system is necessary to process action verbs even when used with figurative meaning whilst others support a weaker version of embodied cognition, that is, motor representations may enrich the semantics of verbs but are not necessary for the comprehension/production of verbs). However, the present review points out that controversial results may reflect the variety of objectives and experimental paradigms, which may influence the results and interpretations. Therefore, based on the multilevel theory, it is easier to understand the task effects. The clear cut between the amodal view and the strong EC account can be explained in terms of contextual cues and task cognitive demands. In summary, it seems possible to conclude that more automatic language use situations, such as spontaneous conversation, would not evidence the participation of the motor system in semantic processing. On the other hand, the embodied components are more consistent when the task requires deep semantic processing and more attentional and executive resources.

The studies that aimed at verifying the impact of pharmacological treatment and DBS have shown positive effects in PD. It is not clear though, whether the effects in semantic processing are due to better attentional and executive functioning or to specific effects on the motor system. Some studies point to the relationship between the type of motor impairment and lexical semantic processing; however we still don´t have evidence of the several subtypes of PD. For future studies, we emphasize the need for identifying relevant semantic attributes and analyzing their impact in tasks requiring different levels of semantic processing. Few studies considered semantic attributes, and even fewer compared the same group of patients in different tasks. Therefore, the diversity of experimental approaches and tasks require the

continuity of researches in this area to understand the effects of PD in language and treatment alternatives.

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