# Processes and verbs of doing, in the brain

## Theoretical implications for Systemic Functional Linguistics

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Systemic Functional Linguistics (SFL) has long been characterized by its openness towards contributions from other fields. However, it has remained virtually uninformed by neuroscience. Such a disconnection has become all the more unfortunate since SFL ventured into the cognitive domain (Halliday & Matthiessen 1999). Opening a new avenue of disciplinary interaction for SFL, this paper reviews experimental studies on the neurocognitive basis of processes and verbs of doing, highlighting their manifold implications for the theory. Available data corroborates the SFL assumptions that these processes and verbs are (i) conceptually different from participants and nouns, (ii) functionally distinguishable from other process and verb types, and (iii) non-arbitrarily related to each other. Moreover, the evidence shows that (at least some of) the conceptual distinctions within semantics are naturally grounded in more basic (motor and perceptual) neurocognitive distinctions. This, we propose, calls for an elaboration of the stratified SFL model via the inclusion of a sensorimotor stratum. More generally, the article seeks to foster an empirically sound and theoretically relevant dialogue between SFL and promising approaches within cognitive neuroscience.

*Functions of Language* 23:3 (2016), **305–335**. DOI 10.1075/fol.23.3.02gar
ISSN 0929–998X / E-ISSN 1569–9765 

## 1. Introduction

Systemic Functional Linguistics (SFL) is a prime example of how the study of language can thrive through interdisciplinary efforts. For over half a century, the theory has fruitfully incorporated insights from sociology (e.g. Hasan 1973, 2004), education theory (e.g. Halliday *et al.* 1964), and informatics (e.g. O'Donnell & Bateman 2005), among other fields. Likewise, it has been applied in varied disciplines, such as descriptive linguistics (e.g. Halliday 1967a, 1967b, 1968; Halliday & Matthiessen 2014), educational studies (e.g. Christie & Unsworth 2005), translation studies (House 1997), stylistics (Goatly 2010), clinical linguistics (e.g. Korner *et al.* 2010), and computational linguistics (e.g. Fawcett *et al.* 1996; O'Donnell & Bateman 2005). The variety of areas just listed corroborates the claims that "a salient feature in the evolution of systemic theory [has been] its permeability from outside" and that "systemic theory has never been walled in by disciplinary boundaries" (Halliday 1985: 6).

In the thirty-odd years which have elapsed since the statements above were printed, few research arenas have grown as notably as cognitive neuroscience. Among other achievements, this multifaceted field has shown that brain structure and dynamics constrain the functional organization of high-order cognitive domains (e.g. Gazzaniga *et al.* 2013), including language, on several levels and in different modalities (e.g. Price 2010). Such breakthroughs notwithstanding, SFL has remained virtually uninformed by neurocognitive research. This probably reflects Halliday's (1978) foundational dismissal of psychological levels of interpretation as relevant but unnecessary for the exploration of language — a position epitomized by the mantra "I stop at the skin" (Halliday, qtd. in Fawcett 1993: 628). However, as argued by Butler (2013), SFL could benefit from a dialogue with cognitive and neural science. In fact, Halliday himself has recently ventured into the cognitive domain, on the assumption that "the processes of language take place in physiological (including neural) and physical space and time" (Halliday & Matthiessen 1999: 602). Moreover, despite his preference for a phenomenological outlook on cognition, he has acknowledged that neuroscientific research may illuminate aspects of language organization and use (Halliday, p.c.). Thus, in pursuing a "subcutaneal" perspective, this paper may prove unusual but not incompatible with the contemporary scope of Hallidayan SFL.

While these new interdisciplinary bridges were laid out at the turn of the century, so far only two papers have been published in an attempt to explore the neurological correlates of SFL constructs, i.e. Melrose (2005, 2006). These works

consider the possible role of mirror neurons[1] in ideational semantics, and interpret neuroimaging evidence on attitude, evaluation, and theory of mind in the light of interpersonal semantics. The publications highlight the contribution of prefrontal areas to both metafunctions. More ambitiously, they put forward gross anatomical correlates for several SFL constructs, such as lexicogrammatical choice (inferior frontal gyrus, ventrolateral prefrontal cortex, and the caudate nucleus) and syntactic structuring (Broca's area and the basal ganglia). In addition, Melrose (2005, 2006) considers the possible neural underpinnings of lexical categories and participant roles, as well as the systems of mood, theme, and information focus. He also discusses the neurological basis of language ontogenesis, language phylogenesis, and context of situation. As a corollary, Melrose (2006: 106–107) even discriminates between "'ideational areas' of the brain (inferior parietal lobe)" and "'interpersonal areas' (the anterior insula)".

While the spirit of this work is commendable, it features two main shortcomings. First, it sacrifices empirical robustness to topical comprehensiveness. Melrose addresses so many issues in these relatively short papers that most of his claims are not sufficiently supported by empirical data. As he himself acknowledges, "[t]his, of course, is all highly speculative, and indicates the extent to which further research is needed if we are to fully understand how language is processed in the brain" (Melrose 2005: 419). Second, Melrose fails to show how SFL models may be constrained or expanded by the evidence in question. He proposes that some conceptual distinctions in SFL are mirrored by hypothetical neural dissociations, but this is not further developed theoretically.

The present paper seeks to establish new links between SFL and cognitive neuroscience, while overcoming the two shortcomings above. We will focus on the neurocognitive basis of processes and verbs of doing (PVDs), and use the evidence to elaborate on two key notions in systemic-functional theory: stratification and naturalness. Specifically, we aim to show that some of the realizational distinctions within semantics are naturally grounded in more basic (non-linguistic) neurocognitive distinctions. This, we propose, warrants the postulation of an additional stratum in the SFL model. More generally, by restricting our analysis to one fine-grained construct and foregrounding the conceptual implications of the evidence, we seek to promote an empirically sound and theoretically relevant dialogue between neuroscience and SFL.

1. A mirror neuron (or the mirror system in humans) fires equally when individuals perform an action and when they observe the same action performed by another person (Rizzolatti & Craighero 2004). Mirror activity has been proposed to support cognitive functions such as language, imitation, emotion, and theory of mind. However, many of the claims surrounding the functional attributes of the mirror system have recently come under fire (Hickok 2014).

The remainder of this paper is organized as follows. First, we review the main SFL postulates about the cognitive organization of the linguistic system, with an emphasis on the ideation base in general and PVDs in particular. Second, we survey the main methods used to explore the neurocognitive basis of PVDs. Third, we present evidence to test three hypotheses implicit in Halliday & Matthiessen's (1999) cognitive model, all involving such processes and verbs. Fourth, we use the evidence to shed light on the notion of naturalness and expand upon the stratificational architecture of SFL. Finally, we discuss the prospects of a 'neuro-SFL' and outline avenues for further research in that direction.

## 2. Cognitive assumptions of SFL about the organization of the ideation base

SFL conceives of language as a social semiotic, that is, a resource to construct meanings in everyday interactions (Halliday 1978; Halliday & Matthiessen 2014). In cognitive terms, this logogenetic process (Halliday & Matthiessen 1999) unfolds as language users make a myriad of (mostly unconscious) choices within hierarchically organized systems of options, or strata: context, semantics, lexicogrammar, phonology (or graphology), and phonetics (or graphemics). The overall stratificational architecture of SFL is depicted in Figure 1 (adapted from Halliday & Matthiessen 2004: 25).

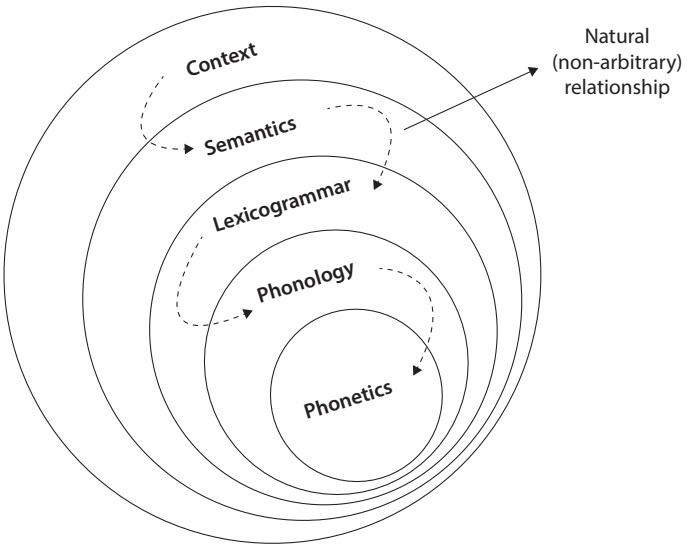



**Figure 1.** The stratified SFL model (adapted from Halliday & Matthiessen 2004: 25)

In its most basic form, the stratificational account of language production in SFL would be as follows. In a given communicative scenario, features of the situational context prompt speakers to make ever more delicate choices within their semantic potential (i.e. the whole range of meanings they can communicate). A constellation of meanings thus chosen is realized by configurations of lexicogrammatical options, which are selected from a wider array of choices (including grammatical patterns, phrases, and words). The ensuing wording is then realized as a phonological sequence, which, in turn, is realized by phonetic items. For language perception and comprehension, the strata would be traversed in the opposite direction.

A crucial point in this model is that the relationship between semantics and lexicogrammar is natural. Unlike the arbitrary links that exist between lexicogrammar and phonology (and between semantics and phonology in the child's protolanguage), SFL proposes that options in the adult grammar are semantically motivated, in that they emerged and are deployed under semantic constraints. In the words of Halliday (1994: xviii),

> [t]he existing interface, that between meaning and expression, was already arbitrary, or was becoming so in the later protolinguistic stage: there is no natural connection between the meaning 'I want that, give it to me' and the sound *mamama* or *nanana* often pronounced by a ten-month old as its realization … But it was not necessary that the new interface, that between meaning and wording, should become arbitrary; indeed there was every reason why it should not, since such a system, by the time it got rich enough to be useful, would also have become impossible to learn.

The corollary is that distinctions at the lexicogrammatical level are guided by more basic (and ontogenetically previous) semantic categories. The semantic options through which we model our experience constitute the ideation base, a system of meaning dimensions in our minds that is organized in the form of clines (Halliday & Matthiessen 1999).[2] Such semantic alternatives allow us to represent situations and express them verbally.

Typically, situations are construed around processes, representations of the varied goings-on around and inside humans.[3] The vast majority of processes

**2.** The present paper is not concerned with semantic or lexicogrammatical aspects of either the interpersonal or the textual metafunctions.

**3.** Strictly speaking, in Halliday & Matthiessen's (1999) account, semantic units in the ideation base are classified as 'figures'. However, this term proves of limited use elsewhere in the SFL literature and, for practical purposes, the more familiar term 'process' will be used here.

involve participants, i.e. entities which are engaged in them.[4] For example, in the clause *The boy pressed a button*, the process PRESS involves two participant roles: an actor (*the boy*) and a goal (*a button*). Although processes and participants are inextricably connected, they are ontologically different. Whereas processes prototypically represent temporally dynamic events, participants refer to individuated atemporal entities. Such semantic differences are mirrored at the lexical level. While processes are prototypically realized by verbs, participants are realized by nouns (or, alternatively, by adjectives).

According to Halliday & Matthiessen (1999), four main process types can be recognized in the ideation base: processes of doing (e.g. EAT), sensing (e.g. SEE), saying (e.g. CLAIM), and being (e.g. BECOME). At the lexical end of the lexicogrammatical continuum, these are typically realized by verbs such as *eat*, *see*, *claim*, and *become*, respectively. In the remainder of the paper, we will focus on PVDs.

PVDs are concerned with physical action. They refer to the bodily activity of animate entities, including the whole range of movements we are able to perform with our legs, arms, hands, fingers, mouth, and so on — even if they involve sources of energy from outside the participant, as in the case of FALLING. While these processes and verbs (just as those belonging to any other type) cannot be easily classified into discrete categories, they can be identified as such by probing their grammatical reactancies and affordances. Halliday (qtd. in Martin 1996: 338) has provided eloquent linguistic evidence to support their distinctiveness by comparing them to other processes and verb types. For instance, in terms of directionality, processes of doing are one-way, whereas processes of sensing are two-way: unlike the latter, the former do not typically allow users to construe the same situation by using antonymic verbs and reassigning participant roles while preserving the same voice (e.g. *Gaby enjoyed it* can be reconstrued as *It pleased Gaby*, but no such rewording is possible for *Agustina punched it*). Furthermore, contrary to processes of sensing, processes of doing do not lend themselves to metaphenomenological uses, as they do not allow for one proposition to be embedded in another (e.g. *Gerónimo believes he is right*, but **Gerónimo kicked he is right*).[5]

Although Halliday & Matthiessen's (1999) model ascribes cognitive plausibility to the notions and distinctions just surveyed, the evidence which warrants their postulation comes from the analysis of text samples, that is, the **products** of the cognitive system. Undoubtedly, analytical abstractions based on patterns of verbal output are very useful to guide explorations of the cognitive system(s)

4. In addition to processes and participants, situations may also implicate circumstances, that is, specifications of the conditions under which the event takes place (e.g. time, location, manner).

5. Note that these criteria were originally postulated to probe the broader categories of material and mental processes.

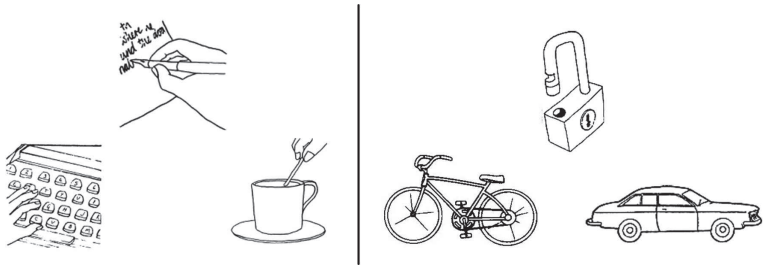
which led to their production in the first place. However, they cannot be *a priori* assumed to be cognitively plausible. It may well be the case that the human mind and brain feature systemic distinctions which mirror those abstracted from their verbal outputs, but this must be empirically determined. A fruitful approach to do so is to frame the distinctions in question as neurocognitive hypotheses and to test them by considering experimental data from both brain-damaged and neurotypical participants.

Adopting such an approach, we will test three distinct SFL assumptions about the cognitive organization of PVDs, namely, that these processes and verbs are (i) conceptually different from participants and nouns; (ii) functionally distinguishable from other process and verb types; and (iii) naturally related to each other — meaning that their relationship is non-arbitrary. These hypotheses, we shall argue, can be tested against neurocognitive evidence. Moreover, the evidence can be used to expand the stratificational model through an answer to the following question: what are semantic distinctions based upon?

## 3. Neurocognitive methods

A wide array of behavioral tasks and neuroscientific techniques allows us to address the hypotheses above. The present account is by no means exhaustive. It is merely intended to familiarize readers from fields other than cognitive neuroscience with the main materials, procedures, and technologies mentioned throughout the review.

At the behavioral level, two useful instruments to assess the cognitive distinctiveness of processes of doing and participant entities are the Kissing and Dancing Test (KDT, Bak & Hodges 2003) and the Pyramids and Palm Trees (PPT) test (Howard *et al*. 1992). Each of these tests consists of 52 triads of black-and-white images. Such triplets are composed of a cue picture at the top and two conceptually related pictures at the bottom. Participants must point to the picture that is most closely related to the cue. Crucially, all images in the KDT depict motor actions, such as TYPING or STIRRING. Instead, the images in the PPT test depict concrete objects, such as a BICYCLE or a CAR (Figure 2). Since no verbal response is needed in either test, they are good proxies of semantic representations of actions and participant entities, respectively. Usually, both tests are complemented by a verbal version, in which pictures are replaced by their names.



Sample trial from the KDT Sample trial from the PPT test

**Figure 2.** Examples of trials in the Kissing and Dancing Test (Bak & Hodges 2003) and the Pyramids and Palm Trees test (Howard *et al.* 1992)

Other behavioral tasks tap together both semantic and lexical representations. For example, in picture naming studies, subjects are shown images of actions (depicting processes of doing) or objects (depicting participant entities) which they must name out loud using a verb or a noun, respectively. In associated word production tasks, subjects must respond to cue words by producing a lexical associate, via synonymy, metonymy, hyponymy or hyperonymy, depending on the case. Importantly, stimuli can be manipulated to explore potential differences between specific semantic and lexical categories.

Finally, there are paradigms which engage the semantic system to a lesser extent — although it can hardly be presumed to be fully inactive during verbal processing. The most widely used ones involve lexical decision tasks, during which subjects are shown sequences of letters and must indicate whether each string constitutes a real word by pressing one button for 'yes' and another one for 'no'.

The dependent variables in all these tasks are accuracy and reaction time. Performance level is determined by quantifying correct and incorrect responses and by measuring the speed with which subjects respond. Note that all tasks involving lexical processing can be used to assess specific word-class contrasts, such as verbs vs. nouns, or verbs of doing vs. verbs of sensing.

When complemented by direct brain measurements from neurological patients, these tasks can indicate whether damage to a specific cerebral region selectively impairs processing of certain options within the ideation base and the lexicogrammar. For instance, if damage to area A leads to impaired processing of PVDs but not processes and verbs of sensing, whereas damage to area B results in the opposite pattern, then we would have evidence for the functional autonomy of both types of representation as well as their distinct neuroanatomical locations.

Moreover, ongoing brain activity patterns can be measured as patients or neurotypical subjects perform these tasks. This yields real-time evidence for the neural mechanisms supporting the cognitive operations at hand (e.g. processing of

PVDs vs. processing of participant entities). Some techniques, such as event-related potentials (ERPs), offer temporally accurate but spatially imprecise information about the electrophysiological modulations elicited by specific stimuli (e.g. verbs vs. nouns). Instead, other techniques, such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), are characterized by great spatial resolution but poor temporal resolution; they are very informative about which neural regions are differentially or selectively engaged as certain representations are evoked, but they do not shed very precise light on when those activation patterns occur. Finally, repetitive transcraneal magnetic stimulation (rTMS) produces ephemeral virtual lesions in a preselected brain area to test whether it supports specific representations or skills. The rationale is that those transient lesions interfere with the normal operations of the stimulated area, so that compromised cognitive skills can be (partially) attributed to the latter.[6]

## 4. Testing three hypotheses about PVDs in the ideation base

Using the methods above, multiple neuroscientific experiments have offered critical evidence to test the three cognitive hypotheses derived from SFL premises. This section reviews such data. We focus on studies which have specifically addressed contrasts involving PVDs. Additional evidence may be found in other studies with broader concerns.

Two related points must be made at this point. SFL is not the only theory featuring the distinctions implied in hypotheses (i) and (ii), and neither does it underlie the experiments discussed below. This, however, does not hinder the interdisciplinary review proposed. Since the empirical results described involve natural kinds in linguistics, they can be aptly reinterpreted in terms of alternative theoretical frameworks. At the same time, this means that the conclusions in Sections 4.1 and 4.2 could, *mutatis mutandis*, be extrapolated to other models of language. However, this is not the case for hypothesis (iii) as it is treated in Sections 4.3 and 5, since there the notion of naturalness is framed in SFL-specific terms.

### 4.1 Hypothesis 1: Processes and verbs of doing are conceptually different from participants and nouns

The first hypothesis is that PVDs are conceptually different from participants and nouns. This leads to the prediction that both sets of representations should be

**6.** For a more thorough treatment of these neuroimaging techniques and their application in language studies, see Rodden & Stemmer (2008).

neurocognitively dissociable: they should elicit distinguishable brain activity patterns in neurotypicals and they should be differentially impaired subsequent to damage in specific brain areas.

A considerable amount of research on cognition has relied on task-related functional imaging data from healthy adults. The ensuing patterns of activation are taken to reflect the brain regions or networks implicated in the ongoing cognitive processes. However, such an approach does not reveal whether each brain region makes a specific or unique contribution to these processes. This limitation is partly circumvented through a lesion model approach (Rorden & Karnath 2004), whereby associations between impaired performance and lesioned or atrophied brain regions indicate which areas play a central role in processing specific types of information (e.g. PVDs). By contrasting performance in tasks involving PVDs across individuals with damage to different portions of the brain, the role of each component of the neurocognitive model may be convincingly established.

Bak & Hodges (2003) used the KDT and the PPT test in two patient groups with different pathologies: semantic dementia (SD) and frontal variant frontotemporal dementia (fvFTD). Both conditions are characterized by progressive atrophy of specific brain regions. On the one hand, early atrophy in SD involves bilateral (but asymmetric) compromise of the anterior temporal lobes (including the amygdala and the hippocampus, and later the posterior temporal region), as well as the ventral anterior insula (McGinnis 2012). Among many other functions, these regions have been implicated in the perception and integration of perceptual attributes. Clinically, individuals with SD experience a cross-modal loss of semantic knowledge. On the other hand, early patterns of atrophy in fvFTD mainly affect frontal regions (medial frontal, orbitofrontal, and anterior cingulate cortices, bilaterally), followed by deterioration of temporal areas (Ibáñez & Manes 2012). Such atrophy patterns affect networks involved in action processing, among other functions.[7] The results revealed consistently greater impairments in the PPT test for the SD group, and in the KDT for the fvFTD group. Such differences were found for both the picture and the word versions of the tests. They reached statistical significance for words in SD and for pictures in fvFTD, suggesting that both the processes and the verbs referring to bodily actions are neurofunctionally distinct from the concepts and nouns associated with participant entities.

Converging data has been obtained through picture naming studies, tapping into semantic and lexical mechanisms at the same time. In line with the above results, such studies have shown clear associations between action naming and

7. The most prominent clinical feature in fvFTD is an insidious change in behavior with a decline in social and personal conduct, emotional dysregulation, compulsive behavior, disinhibition, and executive deficits.

left frontal areas, and between object naming and left temporal regions. This has been separately demonstrated in clinical studies with samples featuring focal lesions (e.g. Tranel *et al*. 1997) and atrophy-induced diffuse damage (e.g. Cappa *et al*. 1998). For example, in a study by Silveri *et al*. (2003), fvFTD patients showed greater impairments in naming actions than objects as compared to patients with Alzheimer's disease, a pathology characterized by atrophy in bilateral posterior cortices and medial temporal lobe regions, such as the hippocampus and the parahippocampal cortices.

More relevant data comes from patients with other neurodegenerative diseases. Relative to object naming, action naming is more significantly compromised in Parkinson's disease (PD), a disorder compromising frontobasal circuits, characterized by motor symptoms such as resting tremor and bradykinesia (Bertella *et al*. 2002; Rodríguez-Ferreiro *et al*. 2009). Conversely, the opposite is true in Alzheimer's disease (Cappa *et al*. 1998). Significantly lower reliance on PVDs by PD patients has also been documented through computerized analysis of spontaneous discourse (García *et al*. 2016).

Additional evidence for differential circuits subserving PVDs and participants/nouns has been offered by brain stimulation studies. Silveri *et al*. (2012) observed that PD patients improved action naming more than object naming upon stimulation of the subthalamic nucleus, a substructure of the basal ganglia involved in the control of action selection. Action naming, as opposed to object naming, was also specifically facilitated in healthy subjects undergoing rTMS of the left dorsolateral prefrontal cortex (Cappa *et al*. 2002), an important region for action planning and control which has profuse connections with motor structures. Additional rTMS evidence for a differential involvement of left frontal structures in the representation of PVDs can be found in Gerfo *et al*. (2008).

Semantic and lexical mechanisms are also jointly engaged in related-word production tasks. Evidence from this paradigm aligns with the findings above. For example, the healthy subjects assessed by Martin *et al*. (1995) were shown drawings of common objects and asked to perform three tasks: name them, generate an associated action word, and generate an associated color word. Note that the latter two conditions involved accessing PVDs and participant entities/nouns, respectively. The tasks were then repeated with verbal stimuli. PET recordings revealed that the generation of action words activated Broca's area (involved in action observation and motor production) and the cerebellum (involved in motor execution and coordination), as well as the middle temporal gyrus (just anterior to the area involved in the perception of motion). Conversely, the generation of color words selectively activated a region in the ventral temporal lobe just anterior to the area involved in the perception of color.

Also, in an fMRI study by Shapiro *et al*. (2006), subjects were asked to produce verbs, nouns, pseudoverbs, and pseudonouns presented within stimulus phrases to appropriately complete subsequent cue phrases. Whereas verbs yielded selective activations in left prefrontal and superior parietal sites, distinctive noun activations were recorded in the left inferior temporal lobe. Greater left inferior frontal activations for verbs, as opposed to nouns, were also reported in the semantic decision study by Tyler *et al*. (2004) and the semantic judgment study by Longe *et al*. (2007).

Tasks with lesser semantic involvement also reveal topographically similar dissociations between verbs and nouns. Relative to noun processing, verb processing is more difficult for Broca's aphasics — featuring frontal lesions — (e.g. Saffran 1982) and less difficult for anomic patients — characterized by temporal damage (e.g. Miceli *et al*. 1988). A clinical related-word production study corroborated the dissociation, as PD patients exhibited greater deficits in generating verbs than in generating nouns (Péran *et al*. 2003). The same pattern was observed in a fvFTD patient performing a word reading task (d'Honincthun & Pillon 2008). Moreover, the greater impairments for verbs subsequent to frontal damage and for nouns following posterior atrophy can equally occur in oral and written modalities (Hillis *et al*. 2004).

Imaging studies with neurotypicals performing lexical decision tasks have also shown greater left inferior frontal activations for verbs (e.g. Perani *et al*. 1999). The existence of different neural generators for verbs of doing and nouns was also corroborated in ERP studies (Pulvermüller *et al*. 1999a, b). Furthermore, transient inhibition of the left prefrontal cortex through rTMS resulted in higher latencies for verbs and pseudoverbs than for nouns and pseudonouns during inflected word generation tasks (Cappelletti *et al*. 2008; Shapiro *et al*. 2001).

In sum, neurocognitive evidence strongly supports the functional dissociation between PVDs, on the one hand, and participants and nouns, on the other. Tasks requiring activation of PVDs (semantic association of actions, action naming, related-verb production, lexical decision on verbs) consistently yield differential associations with frontobasal structures implicated in motor planning and execution as well as action observation. Conversely, tasks involving representations of participant entities and nouns (semantic association of objects, object naming, production of related nouns, lexical decision on nouns) correlate with activity in temporal regions implicated in the processing and integration of perceptual features as well as higher order conceptual processing. This corroborates the SFL assumption that, within the ideation base, processes of doing are functionally distinguishable from participant entities, just as verbs of doing are partially distinguishable from nouns.

### 4.2 Hypothesis 2: Processes and verbs of doing are functionally distinguishable from other process and verb types

The studies reviewed above relied either mostly or exclusively on PVDs in contrast to nouns. Hence, the neurofunctional distinctiveness of the former may not be idiosyncratic, but rather symptomatic of a more general feature of all process and verb types. To rule out this possibility and support the hypothesis that PVDs are functionally distinguishable within the ideation base, they must prove dissociable from other process and verb types.

Fernandino *et al.* (2013) had PD patients perform a lexical decision and a semantic similarity judgment task on two types of verbs: verbs of doing (e.g. *grasp*, *squeeze*) and abstract verbs denoting no physical action (e.g. *depend*, *improve*). The results were compelling. In both tasks, the patients' performance was selectively impaired for verbs of doing, which warrants the conclusion that they are neurofunctionally distinguishable from other verb types. In the authors' own words, the design of the study "rules out the possibility that the deficit … reflects a general impairment in verb processing, rather indicating that the differential effect of motor system impairment on the two conditions was a function of the *core meanings* associated with the words" (Fernandino *et al.* 2013: 72; italics original).

Likewise, in a semantic decision experiment by Dalla Volta *et al.* (2014), native Italian speakers had to indicate whether visually presented words involved a concrete (physical) action or an abstract process. The stimuli consisted of verbs of sensing and verbs of doing denoting hand, foot, and mouth actions. ERP data revealed that verbs of doing and verbs of sensing involved different brain generators in both early (around 270 ms) and late (roughly 350 ms) time intervals. Concrete verbs showed involvement of bilateral parieto-frontal networks which underlie motor-action processing, including body-part-specific activations in the primary motor cortex. By contrast, abstract verbs recruited regions outside the sensorimotor system, with a predominance of right-sided frontal, prefrontal, and temporo-parietal regions. This further suggests that PVDs and processes/verbs of sensing rely on different neural generators and are functionally and spatiotemporally dissociable.

Compatible results were obtained in an fMRI experiment by De Grauwe *et al.* (2014). A lexical decision task including verbs of doing and sensing showed increased activations for the former in areas supporting motor action and perception (pre- and post-central gyri, central sulcus, and parietal operculum). This effect was observed for simple verbs, but not for complex ones. Interestingly, the same pattern was obtained when bilingual participants performed the task in their non-native language, irrespective of the verbs' cognate status.

Seemingly contradictory observations have been reported by Kemmerer *et al.* (2013), whose behavioral study found no differences in accuracy or reaction-time between verbs of doing and a set comprising verbs of sensing and being. However, the study results may have been biased by two important methodological limitations, namely, reduced sample size (10 PD patients and 10 controls) and poor stimulus control (the stimulus blocks were matched only for frequency and length, but other critical variables known to modulate behavioral responses and underlying neural activity, such as imageability and familiarity, were not controlled for; moreover, the block containing verbs of sensing was not matched for length).

Further studies on motor disorders confirm that PVDs are functionally distinct within the ideation base. Specific impairments in these processes and verbs have been documented in experiments assessing PD samples through picture naming (Bertella *et al.* 2002; Rodríguez-Ferreiro *et al.* 2009), related-word production (Péran *et al.* 2003), lexical decision (Boulenger *et al.* 2008), and verbal fluency (Herrera & Cuetos 2012) tasks. The same finding has been reported in populations with other neurodegenerative motor disorders, such as motor neuron disease/amyotrophic lateral sclerosis, involving cortical damage to primary motor neurons (Bak 2013; Bak & Hodges 2004; Bak *et al.* 2001, 2006; Hodges & Bak 1997; Neary *et al.* 2000); progressive supranuclear palsy, characterized by gradual deterioration of cortical and subcortical motor regions (Bak *et al.* 2001, 2006); corticobasal degeneration, which involves damage in neocortical and basal ganglia structures (Cotelli *et al.* 2006; Silveri & Ciccarelli 2007); and Huntington's disease, featuring atrophy of the basal ganglia and frontostriatal regions (Kargieman *et al.* 2014). Thus, it appears that the elastic space which PVDs occupy within the ideation base is closely connected to motor systems, which are directly engaged by the physical events they denote.

Additional evidence comes from the action-sentence compatibility effect (ACE) paradigm, which taps the ability to integrate comprehension of PVDs with manual actions — for an in-depth treatment of this functional synergy, see García & Ibáñez (2016a). In this task, participants listen to sentences involving actions typically performed with an open hand (OH, e.g. *clapped*) or a closed hand (CH, e.g. *hammered*), as well as neutral sentences denoting non-manual actions (e.g. *visited*). Upon comprehension of each sentence, participants press a button with a pre-assigned hand-shape (open or closed). The combination of response type and sentence type generates compatible (OH sentence and OH response, or CH sentence and CH response), incompatible (OH sentence and CH response, or vice versa), and neutral (neutral sentence with either response) trials. In neurotypicals, compatible conditions reliably yield shorter reaction times than incompatible conditions (Aravena *et al.* 2010; Borreggine & Kaschak 2006; Glenberg 2006). However, the ACE is not observed in PD patients (Cardona *et al.* 2014). This

suggests that the intimate connection between PVDs and physical action is rooted in the neural circuits supporting the ideation base.

By the same token, using a keyboard-based verb-copying task, García & Ibáñez (2016b) found that preparatory processes for typing were significantly delayed for action verbs relative to abstract verbs, and even more so for manual vs. non-manual verbs. Consistent with this finding is the observation that the perception of verbs of doing related to specific body parts activates motor-content-specific regions. For example, hearing the word *kick* activates cortical areas engaged by leg movement (Aziz-Zadeh *et al*. 2006; Hauk *et al*. 2004; Tettamanti *et al*. 2005). However, such results do not warrant the postulation of an entirely somatotopic mode of organization for PVDs (see Section 5).

Even more direct evidence for a connection between PVDs and motor circuits has been reported by Ibáñez *et al*. (2013). In their second experiment, epileptic patients performed the ACE task with direct intracranial recordings of primary motor/premotor cortices and left cortical regions involved in semantic processing (inferior frontal and middle/superior temporal gyri). The results showed simultaneous bidirectional effects. On the one hand, motor preparation affected processing of PVDs, as indexed by an N400[8] at the abovementioned gyri. On the other hand, PVD processing modulated activity in movement-related areas, as shown by a motor potential at primary motor and premotor cortices. Such findings indicate that the neurocognitive influence between motor information and PVDs is reciprocal. Moreover, a recent study with PD patients showed that their deficits in PVDs (significantly poor performance on the KDT and production of verbs of doing) constitutes a *sui generis*, language-specific affectation, as they were independent of executive impairment and general cognitive status (Bocanegra *et al*. 2015).

Taken together, this evidence is consistent with the hypothesis that PVDs occupy a distinct functional locus within the ideation base. Moreover, it suggests that they are grounded in lower-level, non-linguistic neurocognitive systems responsible for motor action.[9] The functional specificity of PVDs is reinforced by fMRI and ERP studies showing that somatotopically mapped motor areas are not significantly activated during processing of verbs of being (Kemmerer *et al*. 2008) or verbs of sensing (Dalla Volta *et al*. 2014; Tettamanti *et al*. 2005). Such a finding has important theoretical implications for SFL, as will be discussed in Section 5.

**8.** The N400 is an electrophysiological component of brain activity which reliably indicates semantic lexico-semantic, as opposed to phonological or syntactic, processing (Kutas & Federmeier 2011).

**9.** Note, however, that differential activity peaks in the left primary motor cortex for verbs of doing, relative to verbs of sensing, may occur at a post-conceptual stage, even if no such modulation occurs in time windows related to automatic lexico-semantic processes (Papeo *et al*. 2009).

### 4.3 Hypothesis 3: Processes and verbs of doing are naturally related to each other

SFL assumes that the interface between meaning and wording is non-arbitrary, which implies that processes of doing and verbs of doing are naturally related to each other. This tenet has been proposed by way of descriptive linguistic analyses, in the absence of experimental proof of their cognitive plausibility. Arguably, the very nature of the hypothesis renders it very difficult to test in controlled neuroscientific designs, and, while no study seems to have explored it directly, a number of empirical observations are consistent with it.

The naturalness hypothesis would be falsified by the demonstration that grammatical class differences exist within the cognitive system, even if they were not motivated by semantic distinctions. Some studies have set out to test that possibility by comparing performance on words and pseudowords. In clinical studies, the underlying assumption is that impaired performance in verbs and pseudoverbs with spared performance on nouns and pseudonouns (or vice versa) would indicate that the deficit does not have a semantic origin, as pseudowords do not mean anything.

Laiacona & Caramazza (2004) have indeed argued that the lexicon is organized in terms of strictly grammatical (word class) distinctions, upon the observation that one patient was selectively impaired in action naming as well as verb and pseudoverb inflection tasks (Shapiro & Caramazza 2003), whereas another one showed selective deficits in object naming as well as noun and pseudonoun inflection (Shapiro *et al*. 2000). However, it is not necessarily true that pseudowords do not evoke semantic representations. Speakers may indeed attribute meaning to them, perhaps guided by sound symbolism, phonological similarity to real words or other idiosyncratic conceptual associations. Moreover, such semantic associations may have been guided by the syntagmatic context accompanying the stimuli. The task used by Shapiro & Caramazza (2003), for instance, called for the production of plural forms of singular pseudonouns (*a wug — many wugs*) and past-tense forms of present-tense pseudoverbs (*he wugs — they wug*). It is likely that the presence of determiners or quantifiers in the nominal groups led patients to interpret the pseudonouns as referring to objects, while the presence of pronouns in the clauses featuring pseudoverbs may have prompted their interpretation as processes.

Vigliocco *et al*. (2011) assessed this possibility by asking native English speakers to guess the meaning of forty pseudowords in a syntagmatic context (e.g. *many wugs*, *he wugs*). The definitions thus obtained were presented to another group of native English speakers, who had to guess whether each definition referred to an object, an action, an abstract concept or something else. When presented as part

of a nominal group, pseudowords were judged to denote objects 84% of the time. Instead, when preceded by a pronoun, they were considered to refer to actions 83% of the time. These results show that pseudoverbs and pseudonouns may consistently and differentially activate semantic representations of actions (processes of doing) and participant entities, respectively. Thus, the behavioral patterns elicited by pseudowords cannot be unequivocally interpreted to reflect meaning-free or semantically unmotivated lexicogrammatical distinctions.

For the naturalness hypothesis to be effectively confirmed, the evidence should point to neurocognitive commonalities between processes of doing and verbs of doing, on the one hand, and participants and nouns, on the other. The problem remains: how can one disentangle semantic and lexicogrammatical effects? Barber *et al*. (2010) devised a clever approach to address this issue. They recorded ERPs in native Italian speakers as they read words from different grammatical classes referring to the same events, e.g. *corsa* ('run', as a noun) and *correre* ('run', as a verb of doing). At the semantic level, the stimuli included both processes of doing and of sensing. A critical finding was that grammatical class effects mirrored semantic effects. ERP waveforms at centro-parietal sites in the 300–450 ms time window equally discriminated nouns from verbs and words of sensing from words of doing. This was interpreted as a modulation of the N400 component, a reliable index of semantic processing. Notably, the grammatical class and semantic effects were not dissociable in terms of latency, duration or scalp distribution. In light of these findings, the authors maintain that they "did not observe any early effect of grammatical class, or any qualitative differences between the signatures of grammatical class and semantics, suggesting that the difference between nouns and verbs and between motor and sensory words has a common semantic origin" (Barber *et al*. 2010:71). This finding aligns well with the claim that word class distinctions in the lexicogrammatical continuum are semantically motivated, as proposed by the stratified SFL model.

One further observation proves compatible with the naturalness hypothesis. As shown in Sections 4.1 and 4.2, the varied neurodegenerative motor diseases which compromise processes of doing at the semantic level (as assessed by the picture version of the KDT, for example) systematically involve deficits in verbs of doing, as shown in varied verbal tasks with different levels of semantic involvement (from very high in picture naming to negligible in lexical decision). Similarly, impaired performance on the PPT test (tapping semantic processing of participant entities) is usually accompanied by deficits in noun processing. Such patterns of congruency between specific subsets of semantic representations and the lexical units which typically realize them also support the view that meanings and wordings are connected in a non-arbitrary fashion.

## 5. Theoretical implications for SFL: Expanding the stratificational model

To recap, the present literature review supports three conclusions about the neurocognitive organization of the ideation base in general and PVDs in particular. First, whereas PVDs are subserved by more anterior brain regions engaged in action planning, execution, and visualization (frontobasal areas), participants/nouns are grounded in more posterior perceptual/conceptual regions (left inferior temporal areas). Second, PVDs depend on distinguishable neurocognitive mechanisms which are (at least partly) independent from those subserving other process and verb types. Third, specific lexical contrasts (viz. verbs of doing vs. nouns) seem to depend on neural regions which also support congruent distinctions at the semantic level (viz. processes of doing vs. participant entities).

Note, however, that these findings do not imply absolute dissociations between completely separable neural circuits. Indeed, PVDs have been shown to be compromised subsequent to lesions beyond motor areas (Arévalo *et al*. 2012), whereas deficits in processing of participant entities and nouns are not exclusively associated with posterior damage (Bak 2013). Likewise, PVDs are not predictably impaired following lesions of the motor cortex (Saygin *et al*. 2004). Such non-discreteness at the neurocognitive level aligns well with the SFL view that different sets of options in the ideation base are organized as continua or clines (Halliday & Matthiessen 1999).

Neither does the evidence warrant the postulation of a strictly somatotopic organization of PVDs, let alone the lexicon as a whole. First, results invoked in favor of a somatotopic organization of words have not been consistently replicated (Arévalo *et al*. 2012; Postle *et al*. 2008; Tremblay & Small 2011). Second, the spatial coordinates reported in studies examining the somatotopy of PVDs vary greatly across subjects and studies (Aziz-Zadeh *et al*. 2006) and fail to match those of probabilistically defined maps of the primary motor and premotor cortices (Kemmerer & González-Castillo 2010). Finally, activity patterns elicited by PVDs do not entirely overlap with those yielded by action execution and observation (de Zubicaray *et al*. 2010).

Thus, the available findings must not be taken to reveal the brain's sensorimotor networks as the sole putative source of semantic and lexical distinctions in the ideation base. Instead, what the evidence does show is that PVDs, relative to participants/nouns and other types of processes/verbs, are differentially subserved by specific brain areas which, while not devoted uniquely to them, do play a critical role in their processing.

With these considerations in mind, the present review provides empirical support for three hypotheses implied in the cognitive SFL model proposed by Halliday & Matthiessen (1999), namely, that processes of doing and verbs of doing

are conceptually different from participants and nouns, functionally distinguishable from other process and verb types, and naturally related to each other. More interestingly, the theoretical implications of the present data go beyond the narcissistic exercise of finding neurocognitive correspondences for categorical distinctions within SFL. Specifically, the evidence opens the possibility of expanding the stratified SFL model.

Processes of doing activate networks which support our bodily action. They constitute a space within the ideation base which **models the repertoire of our physical behavior** so that it can be verbally construed. Instead, participant entities have been defined as "individuated, relatively atemporal regions in conceptual-semantic space that are more likely to be **identified by the set of their sensory properties**" (Black & Chiat 2003: 240, our emphasis). If these premises are correct, semantic options within the ideation base may be rooted in more basic, non-linguistic cognitive systems which subserve primary functions for the human organism. The evidence presented largely supports this claim. On the one hand, the frontobasal areas differentially associated with PVDs constitute crucial hubs in a distributed network responsible for motor preparation and execution as well as action observation. That is to say, their neural substrates show considerable overlap with circuits engaged by the preparation, execution, and perception of body movements, as in running, clapping or chewing. On the other hand, the temporal areas (mostly left inferior sites) engaged by processing of participants/nouns show considerable overlap with networks implicated in the perception and conceptual integration of sensory attributes (e.g. Martin *et al.* 1995). Such patterns are compatible with non-radical approaches within the embodied cognition framework, which posits that the neurocognitive representation of abstract categories is grounded in networks supporting relevant basic-level sensorimotor information (Barsalou 1999; Gallese & Lakoff 2005; Gallese & Sinigaglia 2011). In line with this overall stance, Cardona *et al.* (2013) have advanced a model of the neurocognitive organization of PVDs. Figure 3 depicts a coronal and lateral view of the left hemisphere. The shadowed regions of interest show the main frontotemporal, basal-ganglia, and thalamocortical aspects of the network sustaining PVDs. The arrows show how information mainly flows through two main overlap subcircuits in PVD processing. The frontal lobe, the basal ganglia, and the thalamus comprise loops which integrate motor observation/imagination and action programming. These regions play a complementary role in PVD processing. Another set of loops traversing the temporal lobe, the basal ganglia, and the thalamus would play a central role in the grounding of conceptual knowledge related to PVDs.

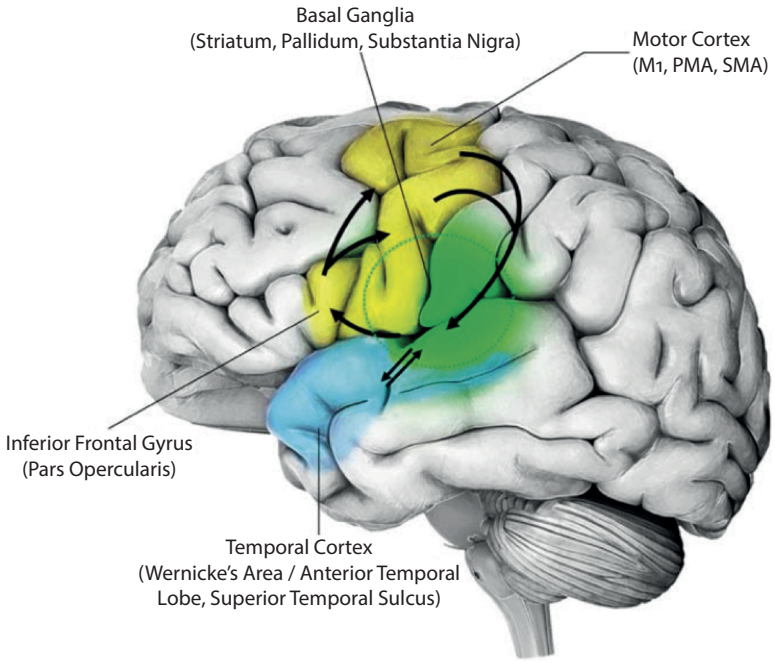



**Figure 3.** Neuroanatomical regions subserving processes and verbs of doing (modified with permission from Cardona *et al.* 2013: 1366)

The implication is that PVDs are **naturally** grounded in the neural networks supporting (non-verbal) motor information, which would mediate contextual constraints and the selection of meanings in the linguistic system. This claim aligns with results showing that comprehension of concrete nouns rapidly activates modality-specific networks supporting perceptual information from objects, such as shape (Wheatley *et al.* 2005), smell (González *et al.* 2006), and color (Simmons *et al.* 2007). Our contention is that such networks constitute an additional stratum which is naturally related to the semantics of the ideation base, and which may be termed sensorimotor level (Figure 4).[10]

What Figure 4 implies is that well-established semantic differentiations in the ideation base follow naturally from lower-level sensorimotor distinctions. The conical shape of the sensorimotor stratum indicates that whereas most of the cognitive space it represents greatly overlaps with the semantic system, it may also feature less extensive areas of overlap with hierarchically lower strata. This contemplates the possibility of direct interactions between the sensorimotor stratum and the lexicogrammar, phonology, and phonetics. Moreover, since the evidence

10. The term emerged as a modification of a previous label kindly suggested by Professor Ruqaiya Hasan.

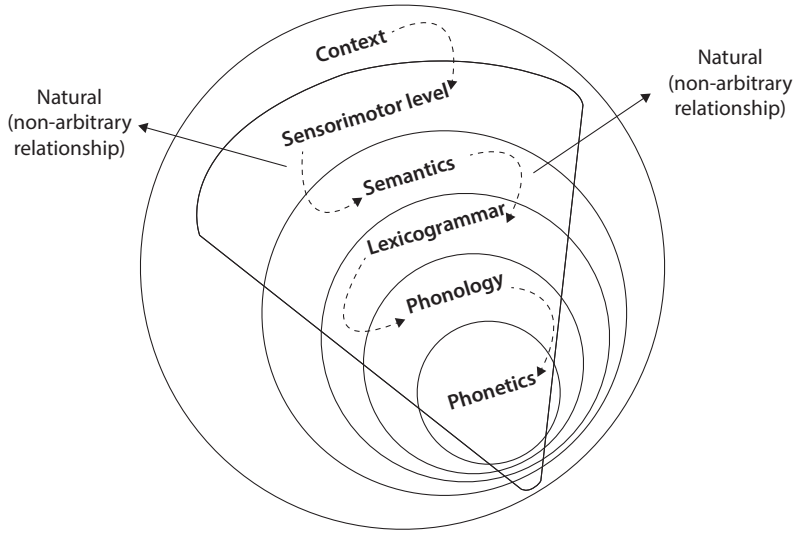



**Figure 4.** Expanding the stratified SFL model via an additional stratum (the sensorimotor level)

reviewed includes both productive and receptive tasks, this new stratum would operate in a bidirectional fashion, as is the case with the others.

Also, note that the sensorimotor stratum does not subsume any of the other strata in their entirety, which indicates that certain aspects of linguistic processing at each level may not be grounded in sensorimotor experience. Yet, this remains to be empirically determined. As far as the present study is concerned, the corollary for SFL is that just as options within the lexicogrammar are semantically motivated, so are options within semantics rooted in sensorimotor differentiations at the neural level.

More generally, this modeling exercise shows that empirical neuroscientific evidence can be produced both to test SFL hypotheses about the **cognitive** organization of the linguistic system and to foster theoretical developments in the field. When pursuing such interdisciplinary endeavors, SFL linguists should not limit their work to the quest of correlates that mirror theoretical distinctions or "prove the psychological reality" of their constructs. Models of language do not significantly progress that way. Instead, the communion with cognitive neuroscience should aim at (i) testing well-defined hypotheses explicitly or otherwise present in the grammatical theory (and correcting them if necessary); (ii) expanding the methodological toolbox of the field (for example, by showing how experimental designs involving neuropsychological tests, neuroimaging, and electromagnetic techniques can be used to examine the ensuing hypotheses); and, crucially, (iii) identifying theoretical advancements which may illuminate the links between

language and the social scenarios in which it is used — here, this was achieved by proposing a body-based interface between the context of situation and semantics. By following these premises, the crosstalk with cognitive neuroscience may inaugurate a rewarding interdisciplinary horizon for SFL in the twenty-first century.

## 6. Further research topics for a neurocognitive approach to SFL

Following the principles of "starting small" and "less is more", this paper has addressed only a very restricted set of SFL notions for which abundant neurocognitive evidence is available. Several questions that have been left unanswered could be explored in future 'neuro-SFL' studies.

Here we have dealt exclusively with PVDs. Therefore, the present conclusions cannot be generalized to all processes and verbs, let alone to all semantic and lexicogrammatical categories within the linguistic system. Further research is necessary to examine the neurocognitive underpinnings of processes and verbs of other types, such as sensing and saying. New empirical paradigms will need to be developed to this end. For example, the highly specific evidence afforded by the ACE task is informative of PVDs because it engages them with concurrent (congruent and incongruent) bodily actions. To explore the spaces of the sensorimotor level which support processes of sensing or of saying, for instance, it would be crucial to conceive of paradigms which somehow involve non-verbal aspects of such behaviors.

For instance, within-category distinctions in the domain of processes of sensing could be investigated by inducing different perceptual or affective states as subjects perform language tasks. Relevant evidence to build a research program in this direction can be found in Ferraro *et al*. (2003) and Barrett *et al*. (2007), who showed that emotional states induced through non-verbal stimuli prime processing of congruent lexical options. Available studies also suggest ways to test neurocognitive properties of more delicate lexical choices. For example, González *et al*. (2006) observed that odor-related words, as opposed to odor-neutral terms, activate smell-related structures in the primary olfactory cortex. Moreover, multiple case studies have reported category-specific deficits (e.g. selective difficulties using words which denote instruments, vegetables, or tools) in brain-damaged patients (for a review, see Capitani *et al*. 2003). Such evidence suggests that more delicate semantic and lexical choices may also be rooted in differentiations within the sensorimotor stratum. This possibility could be explored designing novel empirical paradigms or applying the same review strategy followed in the present paper.

The notion of grammatical metaphor (Halliday & Matthiessen 2014) could also be of great interest for neuroscientific studies. As opposed to congruent forms,

grammatical metaphors involve incongruent realizations of semantic options (e.g. the process DANCE is congruently realized by a verb in *They danced all night long* and incongruently realized by a participant in *Their dance lasted all night*). A recent experiment suggests that when words are transcategorized (e.g. when *lip* is used as a verb or *annoy* is used as a noun) ERP modulations are observed in electrophysiological components indexing syntactic evaluation but not semantic integration processes (Thierry *et al*. 2008). While such functional shifts fail to cover all the complexities inherent to the SFL notion of grammatical metaphor, they do represent a manageable point of departure for neurocognitive research on the issue.

Most of the evidence presented in this paper comes from isolated-word paradigms. More research is needed to assess how clausal constraints impact on the effects documented. Indeed, available research suggests that the differential effects between processes and participants, at the semantic level, and between verbs and nouns, at the lexical level, are modulated when they are embedded in sentence structure (Vigliocco *et al*. 2011). Promisingly, recent models have already been formulated of how grammar and syntax may be embodied in the brain (e.g. Kreiner & Eviatar 2014; Pulvermüller 2010).

Moreover, it would be interesting to explore how linguistic choices are affected by contextual constraints prompting different activation patterns in the sensorimotor stratum. In other words, further research is needed to examine the role of the body (and its neurocognitive underpinnings) as an interface between the contextual and the semantic strata. This line of research could shed crucial light on the notion of language as a social semiotic.

Of course, interdisciplinary dialogue should not be unidirectional. Indeed, SFL may have important contributions to make to cognitive neuroscience. Some steps have already been taken in this direction. García & Ibáñez (2014a) have relied on the SFL notions of field, tenor, and mode to advance methodological recommendations for language-based brain-coupling research. In addition, well-defined linguistic categories, such as PVDs, may be used to foster timely detection of and intervention in neurological disorders, such as PD (García & Ibáñez 2014b). These possibilities may expand the array of appliable areas through which SFL can make concrete social contributions.

## 7. Conclusion

This paper has argued for a neurocognitive approach to SFL research. In particular, converging neuropsychological, neuroimaging, and neurophysiological evidence has been gathered to test three distinct SFL assumptions about the cognitive organization of PVDs. The available data corroborates the hypotheses that these

processes and verbs are conceptually different from participants and nouns, functionally distinguishable from other process and verb types, and naturally related to each other. Moreover, the evidence warrants the postulation of an additional stratum mediating context and semantics, namely, a non-linguistic sensorimotor level which grounds semantic distinctions within the linguistic system. Further research combining SFL notions and neuroscientific methods could pave the way for a new avenue of interdisciplinary development in this comprehensive theory of language. In the long run, once the crosstalk with cognitive neuroscience has become fluent, we may even determine whether SFL proves better or worse than other theories at accommodating neurocognitive evidence and contemplate whether additional theoretical expansions or modifications can be reasonably postulated.

## Acknowledgements

This work was partially supported by grants from CONICET, CONICYT/FONDECYT Regular (1130920), FONCyT-PICT 2012–0412, FONCyT-PICT 2012–1309, FONDAP 15150012, and the INECO Foundation. The authors wish to express their gratitude to Professors Michael Halliday, Ruqaiya Hasan, David Butt, and Annabelle Lukin for their input and feedback on the original formulation of the ideas presented in this paper.

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