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Special issue: Editorial

When embodiment breaks down: Language deficits as novel avenues into movement disorders

Adolfo M. García [a,b,c,*] *and Agustín Ibáñez* [a,b,d,e,f,*]

[a] *Laboratory of Experimental Psychology and Neuroscience (LPEN), Institute of Cognitive and Translational Neuroscience (INCYT), INECO Foundation, Favaloro University, Buenos Aires, Argentina*
[b] *National Scientific and Technical Research Council (CONICET), Buenos Aires, Argentina*
[c] *Faculty of Education, National University of Cuyo (UNCuyo), Mendoza, Argentina*
[d] *Universidad Autónoma del Caribe, Barranquilla, Colombia*
[e] *Center for Social and Cognitive Neuroscience (CSCN), School of Psychology, Universidad Adolfo Ibáñez, Santiago, Chile*
[f] *Centre of Excellence in Cognition and Its Disorders, Australian Research Council (ACR), Sydney, Australia*

ARTICLE INFO

Article history:
Received 5 December 2017
Reviewed 11 December 2017
Revised 14 December 2017
Accepted 18 December 2017

If cognition is broadly shaped by an interplay of embodied mechanisms (Barsalou, 1999; Gallese & Lakoff, 2005; Gentsch, Weber, Synofzik, Vosgerau, & Schutz-Bosbach, 2016; Pulvermüller, 2005; Zwaan, 2014), then cognitive deficits could be profitably reinterpreted as *disruptions of embodiment* (Birba et al., 2017). Despite its simplicity and obviousness, this straightforward implication has not been systematically assessed in the literature, let alone with a focus on specific target populations featuring systematic disturbances in circumscribed higher-order domains. The present Special Issue seeks to bridge such a gap by delving into the intimate links between movement disorders and impairments of syntax and action language (namely, verbal expressions alluding to bodily movements).

For years, these connections have been gaining momentum in the literature. Different authors (e.g., Pulvermüller, 2010; Ullman, 2001) have set forth embodied accounts of syntactic processing, emphasizing its dependence on cortical and subcortical motor mechanisms. Similarly, the role of the latter circuits in action-verb processing has long been recognized in neuropsychology (e.g., Miceli, Silveri, Nocentini, & Caramazza, 1988; Neininger & Pulvermuller, 2003; Shapiro & Caramazza, 2003), cognitive psychology (e.g., Gentilucci & Gangitano, 1998; Glenberg & Kaschak, 2002; Glenberg & Robertson, 2000; Glenberg & Gallese, 2012; for a review, see; García & Ibáñez, 2016a), and neuroscience (Grossman et al., 2002; Pulvermüller, Preissl, & Lutzenberger, 1999; Shapiro, Moo, & Caramazza, 2006). All these seminal and more recent developments support embodied accounts of neurocognitive functions, in general, and linguistic subdomains, in particular.

In line with this perspective, our lab has committed to examining translationally viable links among diverse cognitive functions from an embodied and situated stance. In addition to our epistemological and theoretical works (Cosmelli & Ibáñez, 2008; García & Ibáñez, 2016a, 2016b; Ibáñez, Kuljis, Matallana, & Manes, 2014, Ibáñez et al., 2016), we have integrated neuroscientific, neuropsychological, and behavioral tools to assess context-sensitive cross-domain processes in key target populations, such as racial prejudice

* *Corresponding authors*. Institute of Cognitive and Translational Neuroscience (INCYT) & CONICET, Pacheco de Melo 1860, Buenos Aires, 1126, Argentina.
E-mail addresses: adolfomartingarcia@gmail.com (A.M. García), aibanez@ineco.org.ar (A. Ibáñez).
https://doi.org/10.1016/j.cortex.2017.12.022

between minority and majority ethnic groups (Ibáñez & Manes, 2012; Ibáñez, Haye, González, Hurtado, & Henríquez, 2009), distinctive patterns of moral cognition in extreme terrorists (Baez et al., 2017a), and the anticipation of others' movements in expert tango dancers (Amoruso et al., 2014, 2016). Moreover, we have employed multidimensional approaches to assess the disruption of specific cognitive skills in diverse mental conditions (Baez, García, & Ibáñez, 2016; Baez et al., 2014, 2015, 2016, 2017b; García-Cordero et al., 2016; Hesse et al., 2016; Ibáñez et al., 2011, 2013, 2017; Ibáñez & Manes, 2012; Melloni et al., 2016; Santamaría-García et al., 2017), especially including *motor diseases*.

In particular, our research on the latter has been largely focused on syntactic and action-language deficits, with a view to constraining neurolinguistic models and identifying potentially sensitive cognitive biomarkers (Birba et al., 2017; Cardona et al., 2013; García & Ibáñez, 2014). In this sense, our studies on Parkinson's disease (PD) have shown that such impairments are primary (i.e., not epiphenomenal to domain-general dysfunctions) (Bocanegra et al., 2015, 2017), proportional to the level of basal ganglia atrophy (Abrevaya et al., 2017), traceable in spontaneous discourse (García et al., 2016a), and significant even in asymptomatic subjects carrying mutations in vulnerability genes (García, Sedeño et al., 2017). We have also demonstrated the selectivity of such alterations in Huntington's disease (HD) patients and their asymptomatic relatives (García, Bocanegra et al., 2017; Kargieman et al., 2014). Furthermore, we have reported unprecedented evidence of action-language deficits in cerebellar ataxia, specifying associated abnormalities at genetic, neuroanatomical, and functional levels (García et al., 2016b). Also, we have shown that at least some of these abnormalities are absent in patients with peripheral (i.e., predominantly musculoskeletal) motor disorders (Cardona et al., 2014). Of note, such findings align with multiple reports of selective or differential alterations of syntax and/or action-language processing in other movement disorders, including motor neuron disease (e.g., Bak & Chandran, 2012), amyotrophic lateral sclerosis (ALS) (e.g., Ash et al., 2015), progressive supranuclear palsy (e.g., Bak, O'Donovan, Xuereb, Boniface, & Hodges, 2001), corticobasal degeneration (e.g., Cotelli et al., 2006), and cerebral palsy (Geytenbeek, Heim, Knol, Vermeulen, & Oostrom, 2015), in addition to several other studies on PD and HD (for a review, see Birba et al., 2017).

Considering this empirical corpus, and extending our previous work on language embodiment (Aravena et al., 2010; García & Ibáñez, 2016b, 2016c), our team has recently advanced the so-called "disrupted motor grounding hypothesis" (DMGH) (Birba et al., 2017). The proposal is actually simple: the very lesions which compromise the mapping and sequencing of hierarchically organized movement patterns also disturb the lexico-semantic mapping of movement (action language) and the sequencing of hierarchically organized lexical patterns (syntax). We surmised that these (and potentially other) impairments were not merely anatomo-clinical coincidences. On the contrary, they seemed to constitute higher-level manifestations of abnormalities in functionally akin lower-level mechanisms –that is, predictable consequences of the embodied nature of cognition. As shown by the works reviewed below, this Special Issue constitutes a powerful platform to test the DMGH through a coordinated, multi-center effort and explore its theoretical and clinical implications as well as its ramifications.

1. The issue, at a glance

The issue comprises 15 papers, organized in two parts. Part I deals with disruptions of embodied language functions in movement disorders. It consists of six research reports, two reviews, and a viewpoint article, all of which directly target the core notions described above. Then, Part II explores ramifications of our proposal through five empirical studies and an additional literature review.

1.1. *Part I: Disruptions of embodied language functions in movement disorders*

The bulk of Part I focuses on particular lexical categories, namely, action verbs and nouns. In both cases, we first present reviews of relevant evidence and then introduce new empirical studies. Next comes an experiment targeting syntactic markers, followed by a viewpoint article on the translational possibilities of extant findings.

The majority of the contributions focus on PD, the most prevalent neurodegenerative motor disorder worldwide (Samii, Nutt, & Ransom, 2004). To begin, Gallese and Cuccio (2018) consider reports of action-verb difficulties in this population from the perspective of the "neural exploitation hypothesis" (Gallese, 2008). According to the authors, such impairments reflect the dependence of action semantics on sensorimotor systems, positing that the latter were ontogenetically recruited to extend their original functions and subserve particular linguistic domains. The article closes with a discussion of how embodied principles should be incorporated in a comprehensive account of the links between language and movement disorders.

New insights into such links are offered by several original reports. Introducing a novel behavioral approach, García et al. (2018) inquired whether the appraisal of action-related meanings in PD is also compromised in the face of ecological textual materials. Specifically, they assessed patients with and without mild cognitive impairment (PD-MCI and PD-nMCI, respectively) through questionnaires for two naturalistic narratives which differed in their action load. In PD-MCI, action appraisal deficits were the only ones that proved uninfluenced by domain-general dysfunction and that robustly classified patients from controls via multiple group discriminant function analyses. More strikingly, in PD-nMCI such deficits were selective and they allowed classifying patients and controls with higher accuracy than a sensitive executive battery. This suggests that action-semantic impairments may constitute early primary markers of PD, even despite the contextual support offered by integrated discourse.

In the following study, Quilico Cousins, Ash, and Grossman (2018) combined behavioral and magnetic resonance imaging (MRI) data to investigate differential patterns of embodied disturbances in two contrastive motor disorders. They recruited patients with PD (characterized by basal ganglia compromise) and ALS (characterized by motor cortex

degeneration) and assessed production of verbs in which the body is presented as the agent (e.g., *The boy grabbed the cookie*) or the theme/recipient (e.g., *The boy is falling*) of an action. PD patients showed reduced production of both categories, alongside a correlation between cognitive dysfunction and production of mental/stative verbs. However, these deficits were not associated with grey matter volume in critical cortical or subcortical motor regions. Conversely, results from the ALS sample showed selective agent-body verbs impairments in patients with severe motor compromise, and an association between cognitive impairments and production of theme-body verbs. Interestingly, too, the agent-theme dissociation in this group was related to the volume of the premotor cortex. Taken together, these findings hint to the differential contribution of subcortical and cortical motor regions to specific body-verb categories.

Also, action verbs seem to be differentially impaired in PD and primary cervical dystonia, characterized by hypokinetic and hyperkinetic manifestations, respectively. Relying on a neuropsychological approach, Bayram and Akbostanci (2018) found that patients from the two populations had the same overall performance as controls in phonemic, semantic, and action fluency tasks. Nevertheless, whereas controls produced more action than non-action verbs in the action fluency task, no such difference was observed in either patient sample. Also, only patients with dystonia were outperformed by controls in action-verb production. These findings suggest that specific patterns of action-verb impairments may depend on the type of motor anomalies manifested by the patients. Moreover, the authors maintain, they challenge radical views of embodiment.

Complementary evidence shows that embodied language deficits in movement disorders are not confined to action verbs. Cotelli et al. (2018) review several reports on lexical production across neurodegenerative extrapyramidal disorders, including PD, corticobasal syndrome, and progressive supranuclear palsy. The evidence shows that both action *and* object naming are compromised in these disorders, although deficits are typically more marked in the former domain. The authors discuss their findings in terms of the embodied cognition framework, and propose that clinical protocols for movement disorders should incorporate language assessments tapping both verb and noun processing skills.

Further evidence in this direction is offered by Buccino et al. (2018). In their behavioral study, participants viewed pictures and nouns depicting graspable and non-graspable objects and they had to press a button only when the object in question was real. Whereas healthy subjects responded more slowly to stimuli denoting graspable objects, such a delay was absent in PD patients, who also made more errors. Thus, in line with recent models (Birba et al., 2017; García & Ibáñez, 2016b), motor-network atrophy seems to compromise the integration of manual movements with processing of action-susceptible stimuli.

Interestingly, another behavioral experiment by Silveri et al. (2018) suggests that, in certain settings, nouns may actually prove harder than verbs for PD patients. Participants performed two word-derivation tasks (noun-from-verb, noun-from-adjective) and two word-root-generation tasks (verb-from-noun, adjective-from-noun). Results showed that, as compared to controls, patients were less accurate in the noun-from-verb derivation task, namely, the one in which stimuli possessed the largest number of alternative responses. Considering these findings, the authors propose that verb deficits in PD may reflect a word selection disturbance which is aggravated in proportion to the number of lexical candidates.

More clinically relevant insights come from HD. Hinzen et al. (2018) administered a story-telling task to patients with manifest HD, gene-carriers in the pre-manifest stage, and healthy controls. Importantly, voxel-based morphometry in HD subjects revealed atrophy of the striatum and other cortical areas implicated in syntactic processing. Building on previous reports of morphosyntactic deficits in these populations, text analysis focused on quantitative output, fluency, and three syntactic aspects: reference, connectivity, and concordance. Blind scores from independent raters revealed impairments across all five dimensions for the manifest patients, and selective deficits in reference and connectivity for the pre-manifest group. Also, overall output in manifest patients positively correlated with the volume of two relevant basal ganglia structures: the bilateral putamen and pallidum. These findings suggest that syntactic performance in naturalistic verbal tasks may signal gross and subtle motor-network alterations even before the onset of visible movement symptoms.

Part I closes with a viewpoint article (Gianelli, 2018). The author argues that current findings on language embodiment have not yet been profitably translated into the clinical arena. In particular, she maintains that more sensitive tasks could be developed to this end by designing action-language paradigms which factor in contextual demands and linguistic perspective —a challenge that cuts across, theoretical, methodological, and clinical dimensions.

1.2. *Part II: Beyond the links between embodied language and movement disorders*

The contributions in Part II extend the issue's overarching framework beyond the links between embodied language functions and movement disorders. The first three studies do so by addressing the relationship between such functions and motor mechanisms in healthy subjects. Then, the final three papers explore how the breakdown of embodied systems affects other linguistic and non-linguistic skills.

During a semantic categorization task involving action and abstract verbs, Dalla Volta et al. (2018) examined modulations of event-related potentials (ERPs) aligned to the word onset and to the subjects' motor response. Source reconstruction analysis showed that action-verb onset was associated with recruitment of fronto-parietal circuits, while the subjects' response was related to later activity in temporo-parietal regions. The authors conclude that sensorimotor networks are engaged by action verbs irrespective of task-specific response strategies. Moreover, they discuss potential clinical implications of their findings.

While the role of sensorimotor circuits in action-language comprehension is well established, little is known about their potential contributions to processing of other lexical categories. Dreyer and Pulvermüller (2018) address this topic focusing on words that evoke emotional and mental

associations. During functional MRI scanning, healthy subjects read nouns from both categories as well as action-related words. Surprisingly, as shown by region-of-interest analyses, face motor regions were implicated in processing of mental nouns, previously proposed to rely exclusively on amodal semantic systems. The authors argue that cortical motor areas are also involved in processing (at least some) non-action categories, which opens interesting and controversial questions for future research.

Another surprising finding comes courtesy of Casado et al. (2018), who employed electroencephalography to investigate the embodied foundations of syntactic processing via two forms of sentence self-administration. In the linear condition, successive sentence chunks were triggered by pressing three consecutive buttons with three consecutive fingers. In the non-linear condition, fingers were used to press the first and third buttons, but the middle position required a foot response. ERP analysis showed that, when sentences included incorrect verbs, non-linear administration involved increased modulations of the P600 and reduced modulations of the LAN component. Given that such brain potentials are implicated in early and late syntactic processes, respectively, these results may reflect the shared recruitment of syntactic and motor-sequencing functions.

A final set of papers examined the disruption of embodied mechanisms in other verbal and non-verbal domains. Moseley and Pulvermüller (2018) reviewed reports on structural and functional brain abnormalities in autism spectrum conditions from an embodied stance. The authors propose that alterations of long-distance fronto-temporal and fronto-parietal connections may compromise sensorimotor integration dynamics in these disorders, potentially giving rise to the patients' typical cognitive and socio-interactive difficulties. Theoretical and clinical implications are derived therefrom.

Next, the behavioral study by Takacs et al. (2018) targeted children with Tourette syndrome to examine the role of the basal ganglia in sequence learning. Relative to typically developing children, those with Tourette exhibited enhanced accuracy (with similar reaction times) on both sessions of a two-day procedural learning protocol. Alongside previous findings of enhanced grammatical skills in this condition, the evidence suggests that particular motor-network alterations may boost sequential processing capacities.

Finally, Guell et al. (2018) discuss the embodied functions of the cerebellum, another critical motor hub. In particular, they emphasize affinities between the embodied cognition framework and the notion of "universal cerebellar transform". Their proposal emphasizes the interplay among sensorimotor, affective, and otherwise cognitive mechanisms via cortico-cerebellar connections. The ensuing hypotheses are extended to the domains of action semantics and syntax.

2. Towards a translationally viable view of embodiment

Taken together, the works comprised by this Special Issue foster theoretical and clinical breakthroughs within the embodied cognition framework. Broadly speaking, they all support the overarching notion that language functions are rooted in experientially relevant sensorimotor regions (Barsalou, 1999; Cardona et al., 2013; Fischer & Zwaan, 2008; Gallese & Lakoff, 2005; García & Ibáñez, 2016b; Pulvermüller, 2005). Yet, beyond that general pattern, they support and extend the DMGH as postulated at the outset.

First, the works on clinical samples corroborate that fine-grained linguistic domains can prove markedly impaired following motor-network disruptions (Bayram & Akbostanci, 2018; Buccino et al., 2018; Cotelli et al., 2018; Quilico Cousins et al., 2018; Gallese & Cuccio, 2018; García et al., 2018; Gianelli, 2018; Guell et al., 2018; Hinzen et al., 2018; Silveri et al., 2018). Specifically, the evidence suggests that damage to critical hubs, such as the motor cortex and the basal ganglia, can distinctively compromise functionally germane linguistic subdomains, irrespective of etiologies or clinical profiles. However, as shown by some of the contributions, at least a subset of embodied language domains could become differentially affected depending on the patients' underlying condition (Bayram and Akbostanci, 2018; Quilico Cousins et al., 2018). Therefore, this growing empirical corpus could lead to the development of both transnosological and disease-specific markers.

Even more promisingly, at least some of the approaches reported herein (Hinzen et al., 2018) seem sensitive enough to reveal deficits in *preclinical* disease stages. Previous studies have also demonstrated that tasks tapping action-semantics and syntactic skills can detect subtle impairments before overt motor symptoms become manifest in different neurodegenerative conditions (de Diego-Balaguer et al., 2008; García, Sedeño et al., 2017; García, Bocanegra et al., 2017; Kargieman et al., 2014; Nemeth et al., 2012). By the same token, the tasks employed throughout this Special Issue could lead to the establishment of new protocols to detect motor network disruptions in asymptomatic subjects who, because of familial antecedents or confirmed mutations in vulnerability genes, face the risk of developing a movement disorder. This is important considering that, in neurodegenerative motor diseases, embodied language deficits can emerge years before kinetic alterations can be observed, arguably due to the particular functional specializations of the subnetworks affected early in each condition (Birba et al., 2017).

Interestingly, part of the evidence presented allows expanding the DMGH as originally postulated. For example, embodied approximations to language functions also seem useful to understand the impact autism spectrum conditions Moseley and Pulvermüller (2018). Moreover, even impairments of non-verbal functions can be directly interpreted in terms of underlying motor-grounding disruptions Takacs et al. (2018). As suggested by these studies, then, the relevance of the DMGH for characterizing the impact of brain disruptions seems to go beyond motor disorders and linguistic processes per se.

Finally, even the works targeting non-pathological populations could inform translationally viable developments. For example, specific embodied language tasks, such as those requiring word reading Dreyer and Pulvermüller (2018), word categorization Dalla Volta et al. (2018) or sentence processing Casado et al. (2018), have been shown to markedly engage motor circuits in healthy subjects. Such tasks could thus be used in future studies on samples with motor diseases, with a

view to establishing new relevant biomarkers, as done in previous studies (e.g., Cardona et al., 2014).

All in all, this Special Issue stands apart from mainstream approaches to neurocognitive impairments in that it sets forth firm bridges between specific pathophysiological mechanisms, clinically observable deficits, and highly selective cognitive disturbances which can rarely be tapped via standard, coarse-grained neuropsychological instruments. The bottom line is that embodied language tasks seem highly relevant to characterize higher-order cognitive deficits in motor diseases and to establish their potential usefulness as early or even pre-clinical markers of these and other conditions. Considering the sound empirical foundations and theoretical plurality of the embodied cognition framework (Barsalou, 1999; Gallese & Lakoff, 2005; Gentsch et al., 2016), the worldwide spread of movement disorders (Samii et al., 2004), and the urgent need to develop relevant cognitive biomarkers (García & Ibáñez, 2014, 2016b), we believe that the collaborative effort crystallized by this volume could promote a timely dialogue between theoretical and applied arenas within cognitive neuroscience.

Acknowledgments

This work was supported by CONICET, CONICYT/FONDECYT (Regular 1170010), FONCyT-PICT (2012-0412 and 2012-1309), FONDAP (15150012), and the INECO Foundation.

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