Cognition 131 (2014) 311–322

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

How embodied is action language? Neurological evidence from motor diseases

Juan F. Cardona [a,b,c,1], Lucila Kargieman [a,b], Vladimiro Sinay [a], Oscar Gershanik [a,b], Carlos Gelormini [a,b], Lucia Amoruso [a,b], María Roca [a], David Pineda [d], Natalia Trujillo [d], Maëva Michon [e], Adolfo M. García [a,b], Daniela Szenkman [a,b], Tristán Bekinschtein [f], Facundo Manes [a,b,g], Agustín Ibáñez [a,b,e,h,*]

[a] Laboratory of Experimental Psychology and Neuroscience (LPEN), Institute of Cognitive Neurology (INECO), Favaloro University, Buenos Aires, Argentina
[b] National Scientific and Technical Research Council (CONICET), Buenos Aires, Argentina
[c] School of Psychology, Catholic University of Pereira (UCP), Risaralda, Colombia
[d] Neuroscience Research Programme, University of Antioquia, Medellin, Colombia
[e] UDP-INECO Foundation Core on Neuroscience (UIFCoN), Diego Portales University, Santiago, Chile
[f] Cognition and Brain Sciences Unit, Medical Research Council, Cambridge CB2 7EF, United Kingdom
[g] Australian Research Council (ARC) Centre of Excellence in Cognition and its Disorders, NSW, Australia
[h] Universidad Autónoma del Caribe, Barranquilla, Colombia

ARTICLE INFO

Article history:
Received 2 May 2013
Revised 15 January 2014
Accepted 4 February 2014

Keywords:
EPD
NMO
ATM
Action language
Representations
Embodied cognition

ABSTRACT

Although motor-language coupling is now being extensively studied, its underlying mechanisms are not fully understood. In this sense, a crucial opposition has emerged between the non-representational and the representational views of embodiment. The former posits that action language is grounded on the non-brain motor system directly engaged by musculoskeletal activity – i.e., peripheral involvement of ongoing actions. Conversely, the latter proposes that such grounding is afforded by the brain's motor system – i.e., activation of neural areas representing motor action. We addressed this controversy through the action-sentence compatibility effect (ACE) paradigm, which induces a contextual coupling of motor actions and verbal processing. ACEs were measured in three patient groups – early Parkinson's disease (EPD), neuromyelitis optica (NMO), and acute transverse myelitis (ATM) patients – as well as their respective healthy controls. NMO and ATM constitute models of injury to non-brain motor areas and the peripheral motor system, whereas EPD provides a model of brain motor system impairment. In our study, EPD patients exhibited impaired ACE and verbal processing relative to healthy participants, NMO, and ATM patients. These results indicate that the processing of action-related words is mainly subserved by a cortico-subcortical motor network system, thus supporting a brain-based embodied view on action language. More generally, our findings are consistent with contemporary perspectives for which action/verb processing depends on distributed brain networks supporting context-sensitive motor-language coupling.

1. Introduction

A major area of debate for neurocognitive theories of language concerns the mechanisms underlying motor-language coupling. Most accounts of action language fit well

* Corresponding author at: Laboratory of Experimental Psychology and Neuroscience (LPEN), Institute of Cognitive Neurology (INECO) and CONICET, Pacheco de Melo 1860, Buenos Aires, Argentina. Tel./fax: +54 (11) 4807 4748.
E-mail address: aibanez@ineco.org.ar (A. Ibáñez).

[1] This work is part of J.F. Cardona's ongoing Ph.D. dissertation at Favaloro University, Argentina.

http://dx.doi.org/10.1016/j.cognition.2014.02.001
0010-0277/

within the embodied cognition framework, which proposes that cognitive processes are essentially grounded in bodily experience (Gallese & Lakoff, 2005; Gallese & Sinigaglia, 2011). Nevertheless, not all embodied cognition theories are conceptually identical, as they feature different views on the cognitive status of representations (for a conceptual review, see Wilson, 2002).

On the one hand, a radical, *non-representational embodied view* rejects traditional accounts based on internal representations (Alsmith & de Vignemont, 2012; Clark, 1997; Gallagher, 2005b; Van Gelder, 1995). This position suggests that peripheral sensory organs (i.e., musculoskeletal structures) automatically and unconsciously provide the necessary feedback for the execution of both gross motor programs and fine tuning, in the absence of semantic representations. In other words, cognitive processes are claimed to depend on the physical body much more than commonly assumed.

According to this view, the availability of perceptual and motor information dispels the need to invoke internal (mental) representations as the constructs that could explain complex behavior. Cognition-action couplings are understood as complex behaviors emerging from interactions among body, environment, and brain, in the absence of computational representations.

Admittedly, this non-representational account proves disfavored in contemporary cognitive neuroscience. However, it has been fruitful to explain phenomena observed in the fields of robotics (Beer, 2003; Brooks, 1999; Pfeifer, Bongard, & Grand, 2007; Pfeifer & Scheier, 1999); coordinated social activity in animals (Ballerini et al., 2008; Barrett, 2011; Reynolds, 1987); visuomotor search, such as the outfielder problem (Bingham, 1988; Fink, Foo, & Warren, 2009; McBeath, Shaffer, & Kaiser, 1995); and developmental changes in object recognition (Thelen, Schoner, Scheier, & Smith, 2001). Moreover, the non-representational account has provided new insights into language-motor coupling (Wilson & Golonka, 2013).

For the non-representational perspective, linguistic information precipitates actions by means of a coupled environment-body system (Wilson & Golonka, 2013). Linguistic, as well as perceptual, information would emerge from situated constraints (Wilson & Golonka, 2013). Therefore, in the absence of word-meaning representations, action-sentence couplings would result from situation-bound processes engaging both relevant linguistic information and musculoskeletal structures (Barwise & Perry, 1983). However, the dearth of empirical research suited to test this hypothesis renders it speculative and, hence, unpopular.

On the other hand, the more lenient *representational embodied view* focuses on the neural mechanisms involved in motor representation (Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012). This hypothesis claims that motor activity and verbal representations of actions are mutually dependent processes at the brain level. Confirmatory evidence comes from several behavioral and neuroimaging studies showing significant overlaps between cortical motor areas engaged in action-related language and action execution (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Hauk, Johnsrude, & Pulvermüller, 2004; Pulvermüller, 2005; Tettamanti et al., 2005). Embodied cognition hypotheses are the object of intense discussions (Willems & Francken, 2012). The precise role of brain motor areas and musculoskeletal structures in cognitive domains is still a matter of debate (Calvo & Gomila, 2008). Current models suggest a potential role of supramodal convergence zones in semantic grounding, in addition to sensory-motor circuits (Kiefer & Pulvermuller, 2012). However, the embodied mechanisms underlying action-verb processing remain unknown (Kiefer & Pulvermuller, 2012) and must be empirically established.

In this sense, the opposing views outlined above could be tested by assessing the role of two systems in the grounding of action-verb processing, namely: (a) the peripheral or musculoskeletal system (PMS) and (b) the brain motor system (BMS). Specifically, a comparison of motor-language interactions in patients with injuries compromising either system may shed light on the role(s) that PMS and BMS areas play in action-verb processing (see Section 1.3).

To our knowledge, no previous report has investigated the relative involvement of PMS and BMS in verbal processing or their relevance in language deficits in motor diseases. One direct way to test these hypotheses is to explore motor-language coupling in neuromotor conditions that impair either PMS or BMS structures. A better understanding of this phenomenon may clarify the specific level of body involvement in action language processing.

1.1. The action-sentence compatibility effect

Recent studies have examined the interaction between action semantics and motor performance through the action-sentence compatibility effect (ACE) paradigm (Aravena et al., 2010; Borreggine & Kaschak, 2006; De Vega, Moreno, & Castillo, 2013; De Vega & Urrutia, 2011; Glenberg & Kaschak, 2002). The ACE was originally found by Glenberg and Kaschak (2002). In their study, participants read sentences describing actions which denoted movements towards or away from the body and pressed one of two buttons located either close to, or away from, the body. The ACE is defined as longer reaction times (RTs) for incompatible relative to compatible action sentences. Similarly, Aravena et al. (2010) asked participants to judge sentences describing motor actions typically performed with an open hand (e.g., clapping) or a closed hand (e.g., hammering). Once again, RTs were faster when the hand response was congruent with the action in question. Importantly, Aravena et al. (2010) found brain markers of bidirectional effects between language comprehension and motor processes. More recently, the ACE paradigm was successfully used to tap action-language deficits in a motor disease –namely, early Parkinson's disease (EPD, Ibáñez et al., 2013).

1.2. Motor conditions evaluated in the present study

1.2.1. PMS affectation and BMS preservation: Neuromyelitis optica

Neuromyelitis optica (NMO), also known as Devic's disease, is a demyelinating disease that affects white matter