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Action in cognition: The case of language

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Abstract

Empirical research has shown that the processing of words and sentences is accompanied by activation of the brain's motor system in language users. The degree of precision observed in this activation seems to be contingent upon (1) the meaning of a linguistic construction and (2) the depth with which readers process that construction. In addition, neurological evidence shows a correspondence between a disruption in the neural correlates of overt action and the disruption of semantic processing of language about action. These converging lines of evidence can be taken to support the hypotheses that motor processes (1) are recruited to understand language that focuses on actions and (2) contribute a unique element to conceptual representation. This article explores the role of this motor recruitment in language comprehension. It concludes that extant findings are consistent with the theorized existence of multimodal, embodied representations of the referents of words and the meaning carried by language. Further, an integrative conceptualization of "fault tolerant comprehension" is proposed.

Keywords
language comprehension, embodied cognition, multimodality, conceptual representation, action

1. Introduction

A common function of language is to describe actions. But how are linguistically-mediated actions understood? A considerable amount of

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experimental evidence has supported the notion that the motor modality, in particular, is involved in the comprehension of language about action. That is, when a person hears or reads text involving action, there is activation of the motor system in his or her brain, which corresponds to the referential semantic content of the description (e.g., Glenberg and Kaschak 2002; Zwaan and Taylor 2006). This finding has been referred to as "indexing" (Glenberg and Robertson 1999) or "referential motor resonance" (Fischer and Zwaan 2008). An alternative view maintains that this approach and its effects "can be explained by a disembodied view of cognition if appropriate assumptions are made about the dynamics of activation flow between cognitive systems" and that "sensory and motor information plays, at best, a supportive but not necessary role in representing concepts" (Mahon and Caramazza 2008). According to this view, there most likely exists a level of abstraction above (or consisting of) multimodal representations (see Ghazanfor and Schroeder 2006 for partial support). At first glance, these two approaches appear to be completely at odds with one another. However, one goal of this paper is to demonstrate how closely coupled the two approaches are. To begin laying out our argument, we consider the neural overlap between action, imagination, and language comprehension.

2. Overlapping neural substrates underlie overt action, imagination, and language comprehension

If the action system plays a role during the comprehension of action descriptions, then action, the imagination of action, and the comprehension of language about action should involve overlapping neural substrates. Several functional-magnetic resonance imaging (fMRI) studies have indeed demonstrated that actively imagining an action is associated with activation in motor and premotor regions of the cortex (e.g., Filimon et al. 2007). Experiments using techniques with relatively high temporal resolution, such as transcranial magnetic stimulation (TMS; Buccino et al. 2005; Pulvermüller et al. 2005), magnetoencephalograms (MEG; Pulvermüller 2004; see Hauk et al. 2008 for a review), fine-grained movement-kinematic measures (Boulenger et al. 2006; Glover and Dixon 2002; Gentilucci and Gangitano 1998), and behavioral studies (Zwaan and Taylor 2006; Glenberg and Kaschak 2002) converge to demonstrate rapid, brief, automatic, and somatotopic (Pulvermüller 2005) motor activation during or immediately following the presentation of language describing action. Often, this is the case even when the word is not deeply processed (e.g., Pulvermüller 2004; Boulenger et al. 2006 who only exposed participants to a word) and during online reading (e.g., Taylor and Zwaan 2008). Given the spatial overlap (Raposo et al. 2009) between the regions that are involved in the execution of overt actions (Penfield and Rasmussen 1950), active imagery (Postle et al. in press), viewing actions (Calvo-Merino et al. 2005), and hearing, reading, and/or processing action descriptions (Glenberg and Kaschak 2002; Zwaan and Taylor 2006; Kemmerer et al. 2008), a reasonable conclusion is that these processes all rely on similar or partially overlapping, but probably not completely co-extensive brain regions.

Neurological data provide evidence for an important point. Lesioned or dysfunctional motor neurons are associated with disrupted semantic processing of action-related language. Although patients with such afflictions are typically capable of some form of comprehension, this is probably suboptimal at best. For example, Parkinson's patients, who typically display motor deficits while performing overt actions, have abnormal lexico-semantic processing for action verbs, but not for concrete nouns. When they are treated with Levodopa, which restores normal motor functioning, they come to have relatively normal processing for both concrete nouns and action verbs (Boulenger et al. in press). Likewise, patients with clinically and electrophysiologically-confirmed motor neuron disease have consistent and selective impairment for both the comprehension and production of verbs relative to nouns (Bak et al. 2001). Awaiting further neuropsychological data, the claim that motor neurons are not necessary to action-related language comprehension seems justified, as action word processing is impaired, but still possible, when motor neurons themselves are impaired. However, these data also support the claim that motor neurons provide a unique and substantive portion of conceptual representations of linguistic constructions about actions.

The degree of motor involvement appears to depend on the depth of semantic processing. An fMRI study revealed somatotopically organized activation in motor and premotor areas for action execution, but not for a "lexical task," such as passive word viewing (Postle et al. in press). This reflects a general pattern seen in fMRI studies; action execution and observation is often associated with detectible somatotopic organization using fMRI, but comparable effects are difficult to pin down for action words (see Postle et al. in press for a review; however, see Rüschemeyer et al. 2007, reviewed in the next section), specifically when relatively shallow processing tasks, such as lexical decision or passive word viewing, are used. Conversely, a deeper semantic task (Semantic Similarity Judgment) that requires participants to make very fine-grained semantic judgments (i.e. is *trudge* more similar to *limp* or *stroll*?) reveals remarkably fine-grained organization in the cortex for action parameters such as whether an action involves motion, contact, change of state, or tool use (Kemmerer et al. 2008). Given the poor temporal resolution of fMRI, finding processes associated with accessing word meaning is a serious challenge to researchers using that methodology (Postle et al. in press). With a sufficiently deep semantic task, however, verb meaning and neural states show a remarkable overlap that can be revealed with the superior *spatial* resolution of fMRI (Kemmerer et al. 2008). Obviously, the issue of how processing depth interacts with motor effects during language comprehension warrants further exploration and research.

Brain imaging studies show that exposure to action words activates motor and premotor areas (see Hauk et al. 2008 for a review). Unfortunately, they do not offer sufficient detail to provide decisive evidence vis à vis the claim that there is a high correspondence between the semantic content of action-related language and activation in the motor system. Behavioral studies are uniquely suited towards this end. Either premeditated action-planning or semantic processing that is deeper than simple word detection is sufficient to cause priming between linguistic input and goal-directed action; word-exposure (or lexical decision) alone has not been found to prime a goal-directed action (Lindemann et al. 2006). Dominant-handed responses to hand action verbs, relative to foot action verbs, are disrupted during a semantic decision task, but not during a lexical decision task and not (1000 ms) after a semantic decision has already been made (Sato et al. 2008). During a reach-to-grasp movement visual exposure to action verbs, relative to nouns denoting non-graspable objects, rapidly (within 200 ms) affects the reaching action (Boulenger et al. 2006); nouns denoting graspable objects (Glover et al. 2004) and adjectives describing size (Gentilucci and Gangitano 1998; Glover and Dixon 2002) have similar effects on a reach-to-grasp movement. When judging the sensibility of sentences describing actions towards and away from the body, responses towards the body are faster when following a sentence about an action towards the body (e.g., opening a drawer; Glenberg and Kaschak 2002). When reading sentences about direction-specific manual rotation (e.g., opening a jar) while engaging in manual rotation themselves, language users read action verbs faster when the sentence describes rotation that is congruent with the action that they are performing during reading (Zwaan and Taylor 2006).

Two important conclusions can be drawn exclusively from the behavioral data. First, the neural activation associated with linguistic input, reviewed above, most likely codes for actions that bear a close resemblance to those described by text. Second, this *action-specific* activation seems to only become manifest during tasks that require a depth of comprehension beyond simple word-detection or lexical decision (note the broad, often less-than-effector-specific activation for shallow linguistic tasks; however, see Rüschemeyer et al. 2007).

The literature reviewed above offers support for a few key points. First, overt actions, viewing actions, actively imagining actions, and reading about actions most likely rely on overlapping neural substrates and processes in motor and premotor cortical regions. Second, the neural activation observed during action word processing most likely codes for action-specific activation that matches the semantic content of text with some degree of precision beyond mere effector-specificity. Third, while we cannot say that healthy motor neurons are necessary for the comprehension of language about action, we can fairly say that motor neuron deficits induce a quasi-normal and suboptimal sort of comprehension that is often selective for verbs and action related language (e.g., Bak et al. 2001). Taken together, the literature suggests that neural regions that code for action performance are recruited to play a substantial role in the conceptual representation and semantic processing of language about action. Two issues clearly warrant further research: (1) how the depth of semantic processing affects the degree to which the motor system is activated during linguistic processing and (2) how comprehension works in people with neuronal dysfunctions that clearly lead to sub-optimal processing.

Although the findings we have reviewed up to this point are intriguing and lend credence to the claim that the motor system assists in or is required for the comprehension of language about action, a growing need to uncover the linguistic constraints for language-based motor resonance remains. Where and when in a stretch of language can we expect motor resonance to occur? It is to this question that we turn next.

3. The Linguistic Focus Hypothesis

The goal of comprehending a stretch of language is normally the construction of a mental representation of the referential situation, a situation model (van Dijk and Kintsch 1983; Zwaan and Radvansky 1998). Language constitutes a set of cues for forming such mental representations. It does so by systematically and sequentially guiding attention to aspects of the referential world (Langacker 2001; MacWhinney 2005; Zwaan 2004). Under this view, the recruitment of motor representations during comprehension occurs under the governance of linguistic constructions, which direct focus on the referential world. There is initial evidence for this Linguistic Focus Hypothesis (LFH) with regard to motor recruitment (Taylor and Zwaan 2008; Zwaan et al. in press).

In one experiment (Zwaan and Taylor 2006, Experiment 4), participants read sentences about direction-specific manual rotation while manually rotating a knob in order to proceed through sentences in groups of one to three words. When participants' actual manual rotation matched the direction of rotation described by the sentence, they were faster to read the critical verb that disambiguated the direction of rotation than when there was a mismatch between implied and actual rotation direction. In a subsequent study (Taylor and Zwaan 2008) the same paradigm was used, but the critical items were re-written such that the critical verb was followed by an adverb. The adverbs were intended to maintain focus on the action (e.g. *quickly*, *slowly*) in Experiment 1 and to direct focus towards the sentence subject (e.g. *happily*, *obediently*) in Experiment 2; this was done in accordance with the distinction made by linguists between action- and subject-modifying English adverbs (Nakamura 1997; Jackendoff 1972). According to the LFH, sustained focus on the action should be accompanied by sustained motor resonance while switching focus to the subject should not; the results supported this prediction (Taylor and Zwaan 2008).

A further experiment (Taylor et al. 2008) explored an untested assumption from Zwaan and Taylor (2006). The critical items in Zwaan and Taylor's (2006) Experiment 4 were designed such that the critical verb consistently disambiguated the direction of manual rotation. The underlying assumption was that this would be critical or essential to facilitating motor resonance compatible with the action. In the Taylor, Lev Ari, and Zwaan (2008) experiment, the critical items (e.g. *He examined the/pie through/the microwave/window and/**turned** the/timer./The cooking/time needed/to be/**shorter** [**longer**].*) were designed such that the instance of manual rotation was mentioned in the first part of the sentence, but without disambiguating information about the direction of rotation. The direction of manual rotation was clarified in a second sentence within each item, but this relied on an inference being drawn by participants (e.g. the cook turned the timer in order to reduce the remaining amount of cooking time. Therefore, he turned the timer counter clockwise.). Also, it is of interest to note that the critical disambiguating word in these items is an adjective, not a verb or adverb, as in all previously reported experiments using this methodology. The results supported the prediction that motor resonance for rotation direction was associated with text that disambiguated the direction of rotation (Taylor et al. 2008; see also, Gentilucci and Gangitano 1998; Glover and Dixon 2002 for results supporting the claim that adjectives referring to size rapidly affect the motor system).

Zwaan, Taylor, and de Boer (in press) provided further support for the LFH. They incorporated manual rotation sentences in stories (in Dutch) about a bank robbery. The critical sentences were descriptions of (1) actions being performed, (2) actions having been performed in the past and (3) actions intended to be performed. Motor resonance occurred only on the first two types of sentences. Zwaan and colleagues hypothesized that the focus in the latter type of sentence was not on the action itself, but on the preparation for it, which could not be detected by the rotation paradigm. For example, preparing to start the car does not involve manual rotation, but might involve taking the key out of one's pocket and inserting it into its slot. Moreover, in the first two sentences, motor resonance occurred as soon as sufficient information about the action had accrued. Because of the nature of Dutch syntax, this was often before the main verb in the sentence had been encountered. An example is *Hij greep de dop/en begon de fles/open te draaien (He grasped the cap/and started the bottle/to screw open)*. In sentences such as this, the preceding context and the object noun provide sufficient specification of the action, while the auxiliary verb provides focus on the action. Thus, the LFH can explain the—at first sight counterintuitive—finding that motor resonance sometimes does not occur on the action verb itself.

If language indeed systematically guides attention to different aspects of a referential situation, then we would not expect effects as those reviewed above to be limited to a single word class or to only occur in conjunction with a single word class, such as verbs. Instead, when discourse leads a language user to focus on an overt action that is being performed in the referential world, then we should expect the motor system to be activated. However, if the discourse focus is on a different aspect of the situation (e.g., the location or shape of an object or the mental state of a protagonist), then we would expect no such activation. Consistent with this claim is the finding that action words such as *kick* produced activation in corresponding motor areas of the brain when presented in isolation and to a lesser extent when presented in literal sentences, but not when presented in idiomatic phrases (e.g., *kick the bucket*; Raposo et al. 2009). Action verbs also do not produce motor resonance when they are the base of an abstract word (Rüschemeyer et al. 2007). For example, *greifen* (which literally means to grasp) produces motor activation, but *begreifen* (which means to understand) does not. The literature reviewed in this section offers support to the LFH in that entire sentences, verbs, adverbs, and adjectives induce motor resonance as a function of whether the content of the sentence focuses on or disambiguates some element of an overt action that is being performed in the referential world described by discourse.

We are now in a position to advance a theoretical proposal with regard to the role of the motor system in language comprehension, which we outline in the following section.

4. The Multimodality Hypothesis

Given the available data and after taking theoretical considerations into account (e.g., Barsalou 2008), we should be prepared to say that motor system activation is neither necessary nor sufficient for understanding action descriptions (see also Fischer and Zwaan 2008); however, this does not warrant the conclusion that the motor system plays an insubstantial role in understanding action descriptions. The multimodality hypothesis proposes that the representation of word meanings consists of "multimodal representations captured during experiences with its instances [being] reactivated to simulate how the brain represented perception, action, and introspection associated with" a word or concept's referent in the world (Barsalou 2008). This hypothesis is consistent with the occurrence of suboptimal comprehension when one or more modalities are dysfunctional or are otherwise incapable of contributing to a word's representation.

A series of examples may help to illustrate this point. In a recent conversation, one author of this paper spoke to the other author of a "double lutz" being performed. The listening author had no idea what a double lutz could be and could not remember ever hearing of it, but could figure out that it was some action that could be performed by experienced athletes. The listener could tell that the speaker's sentence was grammatical, but could not comprehend it in the same capacity that the speaker could.

Finally, during the conversation, the speaker explained that it was a jump that an ice-skater could perform. After receiving a scant, purely verbal description of what the action entailed (based on the speaker's limited experience of having seen double-lutzes performed on TV) the listener could at least make sense of the preceding conversation and had some level of comprehension of what was being described. The listener had ice-skated before and had jumped before (though never on ice-skates). This was enough for him to have some idea of what "double lutz" meant. However, this very scant "comprehension" likely cannot hold a candle to the comprehension that a professional figure skater, with years of experience double lutzing would have. Thus the non-expert listener can comprehend "double lutz" in context, but his comprehension is peculiar and quasi-normal, or "impoverished and isolated" (Mahon and Caramazza 2008).

This example illustrates that a direct mapping between motor experience and semantic content is not necessary for what a normal person would call comprehension. In fact, one would find it quite difficult to learn from reading a book if one required detailed experiential traces for its entire referential content! After all, reading books is one avenue by which we learn new things about the world. An empirical finding supports this view. Motor areas for simple motor programs were activated in non-expert language users reading about expert actions, whereas motor areas for complex actions were activated in the experts (Beilock et al. 2008). Ostensibly, the understanding that some action was being performed, presumably based on the knowledge of the other words in the sentence and on the syntactic knowledge that the unknown word was a verb, produced some form of motor resonance in the non-expert.

This fits well with the treatment of the multimodality hypothesis discussed above, which allows for comprehension to go forward even if one modality is completely "ignorant" or inexperienced within a given domain. This can occur if a concept consists of "multimodal representations captured during experiences with its instances [being] reactivated to simulate how the brain represented perception, action, and introspection associated with" a concept's referent in the world (Barsalou 2008). For example, visual experience can help us understand discourse about a high-jumper breaking a world record, even if the motor system of a listener has never been involved in performing a Fosbury flop before.

The focus of this article is the comprehension of language about action. At the risk of moving away from this focus, we will mention here that a more comprehensive multimodal account that includes experiential traces from several modalities (sensory, motor, emotional, and introspective) may help to account for the representation of abstract concepts such as "300,012, incredulous, astute, theory, embodied, false, and on and on" (Mahon and Caramazza 2008). This "pure multimodality" approach (Barsalou 2008) is, however, only one of what we see as five competing approaches to accounting for the same phenomenon: the representation of abstract concepts. A second, and closely related approach, is one proposing that multimodal representation inherently requires a level of abstraction that either consists of, or is a level above, multimodal representation (Mahon and Caramazza 2008). A third approach, second-order multimodality, holds that in order to account for some of these concepts, it may be necessary to propose a model that allows for some concepts to only be defined in terms of other concepts, which are themselves more directly grounded in experiential traces; a well-known example is that "zebra" could be grounded in terms of "horse plus stripes" (Harnad 1990). A fourth approach, metaphorical extension (Lakoff 1987), holds that abstract concepts are grounded in experiential traces (or "image schemata" to be more precise), but those traces are largely limited to the sensorimotor domain; time, for example, is represented as a function of space (Boroditsky 2000). Finally, a fifth approach, the modularity hypothesis, maintains that there exists an abstract "language of thought," (Fodor 1983) that processes symbols in a way similar to a Chinese Room (Searle 1980) and that meaning is extracted as a result of an encapsulated process consisting of symbol manipulation.

Surely a harmony between the data, theoretical considerations, and our own intuitions exists. However, "the goal of developing a theory of concepts will not be served by collecting more of the same data" (Mahon and Caramazza 2008). The key to moving forward, then, partially consists of taking all of the available data into account and moving forward with the most parsimonious account possible. We feel that the involvement of the motor system in comprehending text about intentional actions provides for a substantial portion of the "essence" of comprehension. Two key questions for moving forward are (1) whether this is the result of a straightforward learning mechanism (e.g. Hebb 1949) that pairs words with referents and (2) whether and exactly how this representation scheme scales up to "abstract" language.

We would like to propose an account for conceptual representation that attempts to harmonize the data and some of the theoretical approaches outlined above, which we call the *fault tolerant theory of conceptual representation*. On hypothesis one, multimodality, the behavioral, neuroimaging, and neuropsychological data suggest that comprehension of action-related language without motor experience, or with dysfunctional motor neurons, is quasi-normal and suboptimal, or impoverished and isolated. On hypothesis two (Mahon and Caramazza 2008), the neuropsychological data (e.g. Boulenger et al. in press) tell us that comprehension and deep semantic processing of action-related language is still at least somewhat possible without relevant motor experience or fully functional motor neurons. On hypothesis three, second-order multimodality, philosophical considerations (e.g. Harnad 1990) and examples (e.g. "double lutz") tell us that comprehension can go forward with as little as a scant definition of a novel verb, which we believe results in a second-order multimodal representation. On hypothesis four, metaphorical extension, the data tell us that users are less proficient at performing even a simple motor task when forced to activate an image schema that contradicts the internal one that they have for a given concept (Casasanto and Dijkstra submitted).

We propose, then, that language comprehension is fault tolerant because it benefits from a multi-variegated representation system that includes literal experiential associations, such as clockwise manual rotation and screwing in light bulbs (Zwaan and Taylor 2006), second-order multimodal representations, such as understanding "double lutz" as "an ice-skating jump," and metaphorical representations, such as "pride" activating an image schema for upward motion (Casasanto and Dijkstra submitted). If it is indeed the case that comprehending a text is tantamount to the construction of a situation model, or a mental representation, of the state of affairs denoted by the text (van Dijk and Kintsch 1983), then language users are going to engage any information within their memory that they have at their disposal to integrate the information that appears within the text. If it is indeed the case that conceptual representation is multi-variegated in this way, then we would expect comprehension to be possible even when one or two of the representation systems are "ignorant" of a given concept. Even without ever witnessing or performing a "double lutz," one can still understand text about double-lutzing, given that one knows that it is the sort of jump a person does while on ice skates. In other words, the comprehension system exhibits "graceful degradation." Having experience witnessing or performing an action leads to a rich mental representation, which eases the construction of a situation model of the described state of affairs, but comprehension is not rendered impossible by the absence of such detailed and fitting experiential traces.

A further example may help to illustrate the unique contribution that "embodied" (visual or motor) information can make to language comprehension. If a person had never witnessed an athlete performing a high-jump and had never high-jumped himself, but did understand that high-jumpers compete to jump over the highest bar, then they could understand the sentence, *The athlete attempted to win the gold medal by high-jumping over the bar*. However, if the remainder of the discourse required experiential knowledge to comprehend, then a person without visual or motor experience would fail to construct an adequate situation model. If a second sentence read, *His form was slightly off on his last attempt and he injured his neck on the landing*, a person who had never witnessed nor performed a high-jump would have difficulty understanding how this is a reasonable outcome, as the Fosbury flop is not an incredibly intuitive way to jump over horizontal bars.

That comprehension is not an all-or-none phenomenon is becoming increasingly apparent. If one is to comprehend a text, one must construct a situation model of the described state of affairs. The situation model may require background knowledge from any of the many mediums within the multi-variegated conceptual representation system of the language user. *The athlete attempted to win the gold medal by high-jumping over the bar* only requires a scant definition of what high-jumping consists; ... *he injured his neck on the landing* requires a more-detailed background knowledge about the form that Olympic high-jumpers use when high-jumping. Obviously, a person's ability to comprehend text can be absent, in the case of a person who does not know the language in which the text appears, or it can be highly sophisticated, detailed, or masterful, in the case of the Nobel Laureate author, economist, or scientist. However, between these two extremes, normal seven-year-olds have what we would call a rudimentary ability to comprehend text. Normal high school graduates or university students have an ability to make more fine-grained semantic distinctions and can therefore produce and comprehend more sophisticated text. Normal university graduates and professionals have a still more high-resolution semantic knowledge. The differences between these groups, we believe, is primarily influenced by background knowledge, which comes from experience reading text and experience in the world.

Bringing the available data and theories together, comprehension, according to the approach advocated by this paper, relies on a multi-variegated system for conceptual representation that relies on experiential memory (including motor, sensory, and intuitive experiential traces, e.g. Barsalou 2008), second-order grounding within the semantic network (e.g. Harnad 1990), and metaphorical extension (Lakoff and Johnson 1980). For a given discourse that requires the construction of a situation model to comprehend, one can not claim that any one of these parts of the conceptual system is necessary or sufficient for successful comprehension. This combination of representational options makes the comprehension system fault tolerant. Comprehension, then, can be likened to a table with six or more legs. Each of the legs of the table represents a part of the multi-variegated conceptual system and the degree to which the table is horizontal and stable represents the success of comprehension. If one or two legs of the table are removed, it may become less stable, but it will most likely remain reasonably horizontal. However, as one removes the legs, one-by-one, the table will eventually cease to be a table and comprehension will eventually become peculiar and quasi-normal. Thus, one unexpected outcome of the research on motor involvement in language comprehension is that it causes us to further scrutinize what it means to "comprehend language."

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