



A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content

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ABSTRACT

Many studies have demonstrated that the sensory and motor systems are activated during conceptual processing. Such results have been interpreted as indicating that concepts, and important aspects of cognition more broadly, are embodied. That conclusion does not follow from the empirical evidence. The reason why is that the empirical evidence can equally be accommodated by a 'disembodied' view of conceptual representation that makes explicit assumptions about spreading activation between the conceptual and sensory and motor systems. At the same time, the strong form of the embodied cognition hypothesis is at variance with currently available neuropsychological evidence. We suggest a middle ground between the embodied and disembodied cognition hypotheses – grounding by interaction. This hypothesis combines the view that concepts are, at some level, 'abstract' and 'symbolic', with the idea that sensory and motor information may 'instantiate' online conceptual processing.

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1. Introduction

The role of sensory and motor processes in conceptual processing is a central topic of study in cognitive science. A broad hypothesis space is currently available regarding the potential role(s) of the sensory and motor systems in conceptual processing. At one end of the hypothesis space is the view that conceptual content is reductively constituted by information that is represented within the sensory and motor systems – the embodied cognition hypothesis. According to the embodied cognition hypothesis, 'understanding' is sensory and motor simulation. At the other end of the hypothesis space is the view that concepts are not constituted by information that is represented within the sensory and motor systems – the (so-called) disembodied cognition hypothesis. According to the disembodied cognition hypothesis, conceptual representations are 'symbolic' and 'abstract', and as such, qualitatively distinct and entirely separated from sensory and motor information.

Methodologies that permit the imaging of the normally functioning human brain have generated a large amount of data showing that sensory and motor activation accompanies conceptual processing. Such observations have been interpreted as providing support for the embodied cognition hypothesis compared to the disembodied cognition hypothesis. Other evidence cited in support of the embodied cognition hypothesis comes from behavioral studies of language-induced motor resonance. On the other hand, cog-

nitive neuropsychological studies of patients with sensory and/or motor impairments demonstrate that such impairments do not necessarily give rise to conceptual deficits.

Here we show that the currently available evidence that has been used to argue for or against the embodied cognition hypothesis is inadequate to resolve the issue of how concepts are represented in the brain. This is because the way in which the hypothesis space has been set up severely limits the utility of such evidence to speak to the positive role(s) that the sensory and motor systems may have in representing concepts.

The structure of the argument in this article is in two parts. In the first part, we show that a disembodied theory of cognition can account for the evidence that has been cited in favor of the embodied cognition hypothesis. The purpose of the argument in this first part of the article is to show that the embodied cognition hypothesis is without empirical support relative to other theories, because the available evidence is consistent with a strict representational distinction between 'abstract' and 'symbolic' conceptual content and sensory and motor representations. In the second part of the article, we sketch an account of concepts that occupies a middle ground between the embodied and disembodied cognition hypotheses.

1.1. Two roles for sensory and motor processes

The embodied and disembodied cognition hypotheses propose different roles for sensory and motor information in conceptual representation. According to the disembodied view of concept

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representation, the output of conceptual processing must, at some level of processing be packaged into a format that can be 'read' by the neural systems that enervate the body. For instance, consider the situation in which a person is presented with a hammer and asked to demonstrate its use. From the visual input of seeing the hammer, the concept HAMMER would be retrieved. That concept, on the disembodied cognition hypothesis, would be an 'abstract' and 'symbolic' representation that would not be constituted by information in the sensory and motor systems. This representation, once retrieved, would have to contact or 'index' the relevant information in the motor system about how to manipulate the object. In this sense, there would be interfaces between 'abstract' and 'symbolic' conceptual computations and the sensory and motor systems.

According to the embodied cognition hypothesis, conceptual processing *already* is sensory and motor processing. For instance, in the example of the person demonstrating the use of the hammer, the process of retrieving the concept HAMMER would itself be constituted by the retrieval of (sensory and motor) information about how to use hammers (i.e., swinging the arm, grasping the object, coordinating the visuo-motor relationships between the nail and the head of the hammer, etc.). On the extreme form of the embodied cognition hypothesis, there would be no 'interface' between a 'concept' and the sensory/motor system. The process of 'concept retrieval' would already be the process of retrieving the sensory and motor information that would directly mediate hammer usage. This does not mean that an embodied cognition hypothesis would not face its own challenges about specifying the nature of the interface between perceptual and motor systems (Hommel et al., 2001).

Concepts of concrete objects (e.g., HAMMER) could plausibly include, in a constitutive way, sensory and motor information. But consider concepts such as JUSTICE, ENTROPY, BEAUTY or PATIENCE. For abstract concepts there is no sensory or motor information that could correspond in any reliable or direct way to their 'meaning'. The possible scope of the embodied cognition framework is thus sharply limited up front; at best, it is a partial theory of concepts since it would be silent about the great majority of the concepts that we have. Given that an embodied theory of cognition would have to admit 'disembodied' cognitive processes in order to account for the representation of abstract concepts, why have a special theory just for concepts of concrete objects and actions?

2. The embodied cognition hypothesis: Is there a ghost in the motor system?

The data that have been cited in support of the embodied cognition hypothesis can be organized into four types: (I) 'direct' demonstrations (i.e., brain based measures) that the motor system is activated during perceptual and conceptual processing; (II) behavioral demonstrations that activation in the motor system spreads to conceptual and perceptual levels of processing; (III) demonstrations of motor and/or sensory activation induced by sentence comprehension; and (IV) impaired lexical decision performance for verbs compared to nouns in the context of a compromised motor system.

In this section, we show, that each class of findings can be accommodated by a view of conceptual representation that maintains a strict separation between 'abstract' and 'symbolic' conceptual content and sensory and motor information. The purpose of outlining an interpretation of the available evidence from the perspective of the disembodied cognition hypothesis is not to (ultimately) 'defend' that view. Rather, the purpose is to demonstrate that such evidence is at best only consistent with the embodied

cognition hypothesis since it is also consistent with the disembodied cognition hypothesis.

2.1. 'Direct' demonstrations of motor system activation during conceptual and perceptual processing

A major type of evidence cited in support of the embodied cognition hypothesis is that motor processes are automatically engaged when participants perform conceptual and perceptual tasks. Such motor activation has been observed in functional neuroimaging, neurophysiological recordings in non-human primates and humans, EEG, behavior, TMS, and kinematic analyses (for empirical reviews and theoretical discussions, see e.g., Barsalou et al., 2003; Boulenger et al., 2006; Gallese and Lakoff, 2005; Martin, 2007; Pulvermüller, 2005; Rizzolatti and Craighero, 2004). The empirical evidence is not in dispute. We assume three empirical generalizations to be true: the motor system is automatically activated when participants (a) observe manipulable objects; (b) process linguistic stimuli (e.g., action verbs) the meanings of which imply bodily action; and (c) observe the actions of another individual.

Such facts have been taken to indicate that the 'disembodied view' of concept representation is false. This conclusion does not follow, and a disembodied theory of concept representation is not embarrassed by those facts. In the context of a disembodied theory of concept representation, those facts would indicate that activation cascades from disembodied concepts to the sensory and motor systems that interface with the conceptual system. That there is spreading activation between, as well as within, cognitive and sensory/motor systems is not an 'ad hoc' add-on to the disembodied cognition hypothesis. There are many findings from diverse areas of the cognitive brain sciences that independently motivate the assumption that activation cascades between 'qualitatively' distinct levels of processing (see below for an example from the field of speech production in lexical access).

The (broadly construed) fact that the motor system is activated during conceptual and perceptual processing does, however, undermine that particular version of the disembodied cognition hypothesis that holds the following two assumptions: (a) concepts are represented independently of motor information; and (b) activation of conceptual representations does *not* result in activation spreading to the motor system. However, it is not clear that anyone has proposed such an extreme theory that excludes activation spreading from the conceptual system to the sensory and motor systems.

The theoretical distinction between cognitive structure and the dynamics of activation flow has figured prominently in other areas of research. One such area is the field of speech production in lexical access. We outline an example from that field that is analogous to current discussions about whether or not cognition is embodied.

2.1.1. An analogy from the field of lexical access in speech production

The processes involved in speech production include conceptual processing, lexical retrieval, and phonological encoding. In the course of naming a picture of a 'hammer', there is first (broadly speaking) perceptual analysis, then conceptual selection, then lexical retrieval, then phonological encoding. One psycholinguistic theory proposed (Levelt, 1989) that activation within the speech production system could not spread 'ahead' of any given selection event (discrete activation). In other words, if a speaker has yet to retrieve the lexical item corresponding to 'hammer', then the phonology of hammer will not be activated.

While early research (Levelt et al., 1991) seemed to support a discrete theory of activation dynamics in speech production, subsequent studies severely undermined that theory. For instance, if participants are asked to name a picture of a 'hammock' while

ignoring a distractor picture that is either phonologically related to the target (e.g., 'hammer'), or unrelated to the target (e.g., 'button'), it is found that naming latencies are faster in the phonologically related condition (hammock – hammer) than in the phonologically unrelated condition (hammock – button) (e.g., Morsella and Miozzo, 2002; Navarrete and Costa, 2005). Those data indicate that the phonology of unproduced picture names (e.g., hammer, button, etc.) is activated, even though the lexical items corresponding to those distractor pictures were not selected for production. From those data, it follows that a discrete theory of activation dynamics must be rejected (see also Spivey et al., 2005). In contrast, such data can be explained if it is assumed that activation within the speech production system can spread beyond levels of processing at which information has been selected for output – the cascaded processing assumption (e.g., McClelland and Rumelhart, 1981).

Phonological activation of unproduced words is analogous to the motor activation that has been observed to accompany conceptual processing (for instance, the automatic activation of the motor system when participants name 'tools'). However, while such motor activation has been used to draw the inference that motor information is constitutive of conceptual content (i.e., embodied cognition), the phonological activation of unproduced words has not been used to draw the parallel inference (and one is not tempted to) that the phonology of words is constitutive of their meaning.

To develop the analogy further, imagine that the above-described picture naming experiment was adapted to an fMRI experiment: participants name target objects (e.g., hammock) in the context of distractor pictures that are either phonologically related (e.g., hammer) or unrelated (e.g., button) to the target pictures. Suppose that one obtained a main effect of the factor phonological relatedness in those parts of the brain that are activated for phonological manipulations (see e.g., Bles and Jansma, 2008; Gitelman et al., 2005). As was argued for the behavioral study, it would still not follow that the concept HAMMER is represented in terms of, or constituted by, phonological information.

Imagine now that a further modification is introduced to this thought experiment: in addition to the distractor pictures 'hammer' and 'button', both depicting manipulable objects, distractor pictures depicting non-manipulable objects are also used. Considering the BOLD data, it is likely that there would be a main effect of the factor 'manipulability of the distractor object' in regions of the brain (e.g., left premotor cortex) that differentially respond to manipulable objects (see Martin, 2007 for review). The issue is whether the (hypothetically) observed activation in the left premotor cortex indicates that motor relevant information is constitutive of the concept HAMMER.

The importance of the analogy to the phonological activation of non-produced words in speech production is that it illustrates a clear alternative account of the activation of motor relevant information when observing, for example, manipulable objects. In order to interpret that motor activation as the activation of 'conceptually relevant' or 'constitutive information', one must first reject the alternative interpretation that the activation of the motor system is 'merely' a by-product of the way in which activation spreads throughout the system.

There is, however, an important way in which the analogy breaks down. The relation between the language effectors (e.g., mouth for spoken language) and concepts is arbitrary. The motor programs that generate the spoken English word 'hammer' are in no way systematically related to the meaning of 'HAMMER' – having first person experience pronouncing the word 'hammer' does not, in and of itself, add to one's understanding of the concept HAMMER. The situation is different for the relation between the motor system that controls the hand and arm movements that ef-

fect hammer usage, and the concept HAMMER. There is a sense in which the sensory and motor information involved in using hammers is instrumental in determining what it means for something to be a hammer. But this fact about the world does not, in and of itself, license the inference that motor activation induced by merely looking at a hammer means that that motor information is critical – online – in retrieving the concept HAMMER.

2.1.2. A closer look at motor system activation during conceptual processing

The focus of the discussion to this point has been on the inferences that can legitimately be drawn from the 'mere' fact that the motor system is activated during conceptual and/or perceptual processing. A number of studies have, however, demonstrated further characteristics of such motor activation. It has been argued that those characteristics compel an interpretation of the observed motor activation as uniquely supporting the embodied cognition framework. For instance, Pulvermüller and colleagues (for review see Pulvermüller, 2005) argued for the embodied cognition hypothesis on the basis of three characteristics of the way in which the motor system is activated during conceptual processing: the activation of the motor system is (a) *fast*, (b) *automatic*, and (c) *somatotopic*. Here we consider whether these three characteristics present qualitatively different challenges to a 'disembodied theory' of conceptual representation.

2.1.3. The activation of the motor system is fast

It has been demonstrated (for review, see Pulvermüller, 2005; see also Boulenger et al., 2006) that the motor system is activated within about 200 ms of the presentation of an action word referring to a bodily action. In order for the speed of motor system activation to be relevant for distinguishing between an embodied and disembodied interpretation, it would have to be known, independently, what types of cognitive processes are interposed between the perception of the action word and the activation of the motor system. In other words, it would have to be known that the activation of the motor system was not mediated by the retrieval of 'abstract' conceptual content. Of course, this is precisely the 'unknown' that is at issue.

There are (broadly construed) four possibilities. Consider the situation in which participants are presented with the word 'kick' and within ~200 ms, the 'leg' region of the motor system is activated. The four possibilities are: (1) the word 'kick' directly activates the motor system, with no intervening access to abstract conceptual content; (2) the word 'kick' directly activates the motor system and in parallel activates abstract conceptual content; (3) the word 'kick' directly activates the motor system and then subsequently activates an abstract conceptual representation; and finally, (4) the word 'kick' activates an abstract conceptual representation and then activates the motor system.

In order for the speed of motor system activation to be useful in adjudicating between an embodied and disembodied perspective, it would be necessary to first have evidence that distinguished among the four possibilities outlined above (or at least, distinguished the fourth from the first three). The question is whether the motor system is activated due to 'leakage' of (or cascading) activation from an 'abstract' conceptual level, or occurs in parallel to (or independently of) activation of the 'abstract' conceptual level.

2.1.4. The activation of the motor system is automatic

By automatic here is meant that such activation is observed even when participants' attention is diverted, at least to some extent, from the action word stimulus. This does not present a qualitatively different type of challenge to the argument that we have already sketched above. For instance, note that the example used above of the phonological activation of unproduced words

occurred for distractor pictures that participants were instructed to ignore.

2.1.5. *The activation of the motor system is somatotopic*

For example, when participants view action words referring to hand actions, the 'hand' area of motor cortex is activated, while when subjects view action words referring to leg actions, the 'leg' area of motor cortex is activated (e.g., Hauk et al., 2004; see also Tettamanti et al., 2005).

As noted above, there are a number of possible models of the cognitive processes that are interposed between the perceptual analysis of an action word and the activation of the motor system. If one were to assume, for the sake of argument, a disembodied cognition perspective, then it could be argued that the motor system is activated only after access to 'abstract' conceptual content (option 4 above). Given that (by assumption) the motor system is activated only subsequent to conceptual access, it may then be asked: How else (but somatotopically) could the motor system be activated? Or to put the issue a different way: when participants observe a 'hammer', the hand and not the foot area of the motor system is activated. This does not mean that such activation is not mediated by 'abstract' or 'symbolic' representations of the concept HAMMER.

The same logic may be applied to the observation that the phonology of unproduced words is activated. For instance, if a subject is naming a picture of a 'hammock', and is instructed to ignore the distractor picture 'hammer', it is known that the phonology of 'hammer' becomes activated. Given that (by assumption) the phonology of the word 'hammer' is activated only subsequent to conceptual access, it may then be asked: Is it surprising that the phonology of 'hammer' was activated and not the phonology of some other, random, word in the subject's lexicon? It is not surprising, because the concept HAMMER is connected (via the lexical node *hammer*) to the phonology of hammer. Cascading activation is constrained by the structure of the lexicon.

The analogy to the phonological activation of unproduced words is useful because one would not be disposed to saying that the phonology of a word is part of its concept, or even that phonological access aides or guides semantic analysis (although it could have such a role – see below for discussion). In the same line, as Pulvermüller (2005, p. 579) notes when discussing findings from his laboratory: "Even if action word processing activates the motor system in a specific somatotopic fashion, this does not necessarily imply that the motor and premotor cortex influence the processing of action words." Thus, the somatotopic activation of the motor system according to the meanings of action words, while interesting in its own right, does not resolve the issue of whether meaning is embodied.

2.1.6. *A closer look at privileged (or non-conceptually mediated) relationships between perception and action*

The immediately preceding discussion focused on experimental situations in which the activation of the motor system would either constitute a semantic analysis of the stimulus (embodied cognition), or follow from a semantic analysis of the stimulus (disembodied cognition). Such situations are best represented by experiments in which the motor system is demonstrated to be activated when participants are presented with printed action words associated with different parts of the body. This is because there is no direct mapping between an orthographic stimulus, and its semantic interpretation (whether that interpretation occurs over motor or more abstract content).

There are, however, other classes of stimuli that may afford a direct 'motor' interpretation. For instance, in the domain of language, it is known that there are mechanisms that directly translate orthographic input to phonological output, as indicated by the

Stroop effect (Stroop, 1935; for review, see MacLeod, 1991). With respect to manipulable objects such as 'hammers' it has been argued that there are procedures that directly map visual descriptions of the structure of the objects onto aspects of motor knowledge associated with object use (e.g., Caramazza et al., 1990; Riddoch and Humphreys, 1987). Similarly, with respect to observing the actions of other individuals, there are routes from vision to action that 'bypass' (or at least do not critically depend upon access to) the conceptual system (e.g., Rothi et al., 1991).

The implication is that, for certain types of visual stimuli, access to the motor system need not be mediated by conceptual processing. The question of whether motor processes are constitutive of conceptual content can be reformulated as the question of whether motor processes are constitutive of perceptual processing. The Motor Theory of Speech Production (Lieberman et al., 1967) is one hypothesis that makes specific claims to the effect that motor processing is necessary for successful recognition. Recently, there has been a reawakening of interest in motor theories of perception, sparked largely by discussion of mirror neurons. Mirror neurons are defined as neurons that discharge during motor movements and also during action observation (di Pellegrino et al., 1992).

However, and as should be clear, in the context of the 'mirror' properties of mirror neurons, the same questions about the dynamics of spreading activation arise as were discussed above in the context of the embodied theory of concepts (see also Jacob and Jeannerod, 2005, for further discussion). Do mirror neurons become activated only after perceptual analysis and recognition of the sensory stimulus, or is the activation of mirror neurons directly and causally implicated in that perceptual analysis?

2.2. *Behavioral demonstrations that activation in the motor system spreads to conceptual and/or perceptual levels of processing*

Another observation that has been argued to support an embodied theory of cognition is that activation of the motor system can result in automatic activation of perceptual and/or conceptual processes. The most direct demonstration of this phenomenon is provided by the TMS study of Pulvermüller et al. (2005) (see also Helbig et al., 2006).

Pulvermüller and colleagues (2005) had participants perform a lexical decision task over action verbs associated with either leg or arm actions. A single pulse of sub-threshold TMS was applied to either the 'arm' or the 'leg' area of motor cortex shortly after presentation of the word stimulus. The authors found that when TMS was applied to the 'arm' area of motor cortex, subjects were faster to make lexical decisions to arm words compared to leg words; in contrast, when the TMS stimulus was delivered to the 'leg' area of motor cortex, participants were faster to respond to 'leg' words than 'arm' words. Pulvermüller and colleagues (2005, p. 795) argued that their findings "...prove[] that sensorimotor areas can play a specific functional role in recognizing action words."

As discussed above, the observation that the motor system can be activated in a somatotopic way by action words does not distinguish between an embodied and a disembodied view of cognition. The reason is that the critical 'unknown' remains unknown: it is unknown whether the motor system becomes activated prior to, or rather only subsequent to, access to an 'abstract' conceptual representation. The present issue is whether the demonstration that activation cascades from the motor system 'back' to processes involved in lexical decision presents a qualitatively different type of challenge to the disembodied cognition hypothesis. The answer is no. From the perspective of the disembodied cognition hypothesis, stimulation of the motor system results in a cascade of activation back to the 'abstract' concept, and subsequently to the perceptual systems (and/or decision mechanisms) that generate

the observed variation in reaction times in the lexical decision task. Thus, the fact that activation reverberates both from sensory systems through to the motor system, as well as from the motor system 'back' to sensory systems, is silent on the critical issue of what types of representational content do or do not mediate such 'reverberations.'

2.3. Demonstrations of motor and sensory activation induced by sentence comprehension

The discussion to this point has focused on 'reverberations' within the sensory and motor systems induced by semantic analysis of isolated stimuli (e.g., pictures of manipulable objects, printed action words; see also Oliveri et al., 2004). Analogous effects have been observed when the relevant unit of meaning is not restricted to a single word or concept but to information conveyed in a sentence. As Buccino et al. (2005, p. 361) write: [According to the embodied cognition hypothesis]. . . the understanding of action-related sentences implies an internal simulation of the actions expressed in the sentences, mediated by the activation of the same motor representations that are involved in their execution." A number of research programs have sought to demonstrate that there is in fact motor (or sensory) activation during sentence comprehension. Such demonstrations have been made using motor evoked potentials (MEPs – induced by TMS) as well as behavioral effects.

For instance, Buccino and colleagues (2005) presented participants with sentences describing hand or leg actions, and simultaneously stimulated the 'hand' or 'leg' area of motor cortex with TMS. The dependent measure was the MEP elicited by the TMS pulse. The authors observed modulations in MEPs according to the semantic content of the sentences. Thus, MEPs recorded from the hand were modulated when participants were presented with sentences describing hand actions and the 'hand' area of motor cortex had been stimulated (the parallel effect was observed when MEPs were recorded from the foot in the context of sentences describing foot actions and a TMS stimulus to the 'foot' area of motor cortex was delivered). Buccino and colleagues (2005) also observed parallel effects behaviorally (without TMS) when participants had to respond either with a hand or a foot movement to the sentences describing hand and foot actions. The issue is whether such observations present a qualitatively different type of challenge to the disembodied cognition hypothesis than has already been covered in our discussion. The answer is no. The same arguments outlined above apply to Buccino and colleagues' study without amendment. To reiterate: that is because Buccino and colleagues' findings do not address whether or not activation of the motor system is mediated by the retrieval of 'abstract' and 'symbolic' representations of meaning.

Another important finding that has been argued to support the claim that language is embodied is the 'action-sentence compatibility effect' of Glenberg and Kaschak (2002). In that study (see Experiment 1), participants had to make judgments about the well-formedness of sentences by making a motor movement either away from the body or toward the body. On a given trial, participants could have been presented with the sentence, "Close the drawer", or with the sentence "Open the drawer." Participants were required to make a 'pushing' or 'pulling' movement (see Glenberg and Kaschak for details) in order to indicate their decision about the sensibility (meaningful/nonsense) of the sentence. The authors found that the meaning of the sentence interacted with the type of movements that participants made for their responses: when presented with the sentence "Close the drawer", subjects were slower to make a response involving a movement toward the body than they were to make a movement away from the body.

Findings such as the 'action-sentence compatibility effect', as well as the behavioral effect observed by Buccino and colleagues (2005) can be interpreted from the embodied cognition hypothesis as indicating that the semantic analysis of the sentence involves motor simulation of the corresponding actions. Thus, when participants must make a motor response, the motor system is already 'engaged' in semantic analysis, and there is a cost engendered for making the overt response. Implicit in that interpretation is the view that the decision mechanism that determines the observed variation in response times is sensitive to information that is encoded by the current state of the motor system. Thus, the explanation of the observed effects reduces to an account of the decision mechanism, rather than to the motor activation per se. What distinguishes the embodied interpretation of those data from a disembodied cognition interpretation is a claim about how the motor system comes to be activated. According to the embodied cognition hypothesis, the motor system is activated because that activation is causally involved in the semantic analysis of the sentence. According to the disembodied cognition hypothesis, the observed motor activation is due to information spreading throughout the system.

That the relevant variable in explaining the above findings must involve reference to a decision mechanism is demonstrated by the fact that equivalent findings are observed when the semantic analysis of the sentence does not involve motor-relevant information, but rather a particular perceptual experience. For instance, Zwaan et al. (2002) presented participants with sentences of the form: (1) "The ranger saw an eagle in the sky" and (2) "The ranger saw an eagle in the tree." Those authors found that participants were faster to respond to a picture of an eagle with its wings outstretched after sentence (1) than after sentence (2). Similar effects in terms of object orientation (as opposed to object shape) have been observed by the same group (Stanfield and Zwaan, 2001; for review and discussion, see Zwaan, 2004). In the case of behavioral effects that depend on the activation of sensory (as opposed to motor) information, it is perhaps more straightforward that the explanation of such effects must make reference to a decision mechanism that is operating over any information that it has available.

Our intention is in no way to detract from the elegance and ingenuity of the above reviewed experiments. Our point is merely that those data, while interesting in their own right, do not provide the unequivocal support for the embodied cognition hypothesis that they have been argued to provide. Those findings do demonstrate that the motor and sensory systems are activated but they do not demonstrate that activation of motor or sensory information constitutes the semantic analysis of the sentence – and that is the critical issue at stake.

The argument that we have outlined here is not new. Similar debates can be traced to a number of areas in cognitive psychology. One clear example comes from the research of Seidenberg and Tanenhaus (1979) and Donnenwerth-Nolan et al. (1981). Those authors demonstrated an influence of orthographic similarity on rhyme judgments for auditorily presented words (see also Tanenhaus et al., 1980 for an analogous effect between visually presented primes and targets that are phonologically but not orthographically related; for recent review, see Muneaux and Ziegler, 2004). The basic finding reported by Seidenberg and Tanenhaus (1979) was that subjects are faster to decide that two words rhyme when they are orthographically similar (e.g., *pie-tie*) than when they are orthographically dissimilar (e.g., *rye-tie*). What is surprising about those data is that orthography has an influence at all on the decision process of whether the two auditorily presented words rhyme. In this case, however, the implication is not that there is a representation in common between phonology and orthography. Instead, it is concluded that the auditory presentation of a word automatically leads to activation of its

orthography, and that the decision process promiscuously uses any information that is available for the execution of that task.

The conclusion of this section is straightforward: in the current literature, conclusions are drawn about the nature of representations underlying sentence comprehension on the basis of findings that do not compel such inferences. Such findings can be accommodated by theories that: (1) draw a sharp representational distinction between ‘abstract’ conceptual content and sensory and motor information, and (2) do not assume that sensory and motor content is causally involved in sentence comprehension. Such an alternative view would stress instead the types of information that become promiscuously available to the decision mechanism even in those tasks that seemingly depend on only one type of information for their proper performance.

2.4. Impaired lexical decision performance for verbs compared to nouns in the context of a compromised motor system

Above we discussed behavioral demonstrations that activation in the motor system spreads to conceptual and/or perceptual levels of processing. We argued that such findings are compatible with the disembodied cognition hypothesis if appropriate assumptions are made about the dynamics of activation flow between and/or within cognitive systems. A stronger test of the embodied cognition hypothesis would consist in studying perceptual and conceptual processing subsequent to suppression or impairment of the motor system. We are not aware of rTMS experiments along those lines, but there have been in recent years several neuropsychological studies that have focused on that issue.

Neininger and Pulvermüller (2003) studied the ability of patients with (predominantly) right frontal lesions (and left hemiparesis) ($n = 12$) and patients with right temporo-occipital lesions ($n = 6$) to perform a lexical decision task. The words used in the lexical decision task consisted of nouns with strong visual associations and verbs with strong action associations. (An additional group of control patients with spinal or peripheral nerve injuries, as well another group of nouns with both visual and action association were also included in the study; see Neininger and Pulvermüller for details.) The authors found an interaction between patient group and word type in accuracy but not in response times. Patients with right frontal lesions were less accurate in making lexical decisions over action verbs, compared to nouns with strong visual associations. In contrast, patients with right temporo-occipital lesions were less accurate in making lexical decisions for nouns with strong visual associations than for action verbs (see Fig. 1A).

Boulenger et al. (2008) combined a masked priming paradigm with a lexical decision task to study semantic priming effects in a non-demented group ($n = 10$) of Parkinson’s patients who were either off or on dopaminergic treatment. It is known that Parkinson’s patients show relative inactivation of motor cortices when they are off, compared to when they are on, dopaminergic treatment (see Boulenger et al., for discussion and references). Participants in Boulenger and colleagues’ study were presented, on every trial, with a masked stimulus, followed immediately by a target word. Participants’ task was to perform a lexical decision over the target word. There were two critical manipulations in the experiment. First, the target words could either be action verbs or concrete nouns, and second, the masked stimulus could either be the same as the target word (identity condition), or a consonant string (baseline condition). The empirical question studied by the authors was whether the magnitude of the masked priming effect (identity < consonant string) was modulated as a function of whether the Parkinson’s patients were off or on dopaminergic treatment. The authors found that this was the case, but importantly, only for action word targets and not for concrete nouns (see Fig. 1B for a representation of the findings).

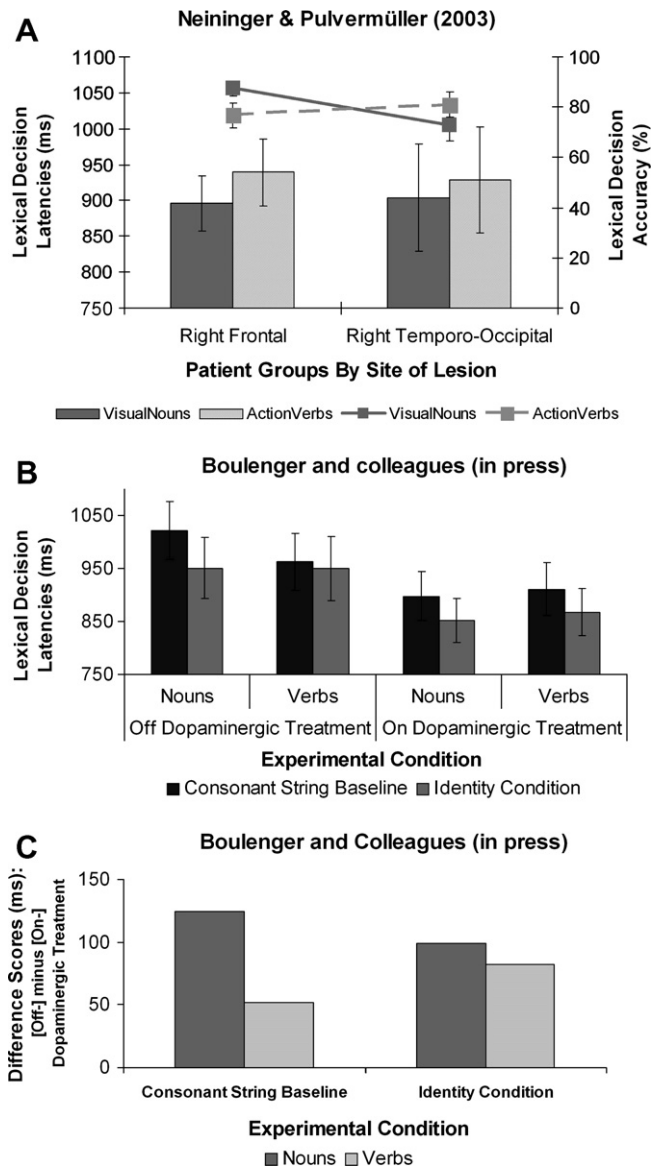


Fig. 1. (A) Depiction of a subset of the findings from Neininger and Pulvermüller (2003), demonstrating the interaction between patient group (i.e., those with right frontal versus right temporo-occipital lesions) and word type (verb versus noun). (B) Depiction of the findings from Boulenger and colleagues (2008), for those eight patients who were tested both on and off dopaminergic treatment (from Tables 3b and 3c, Boulenger et al., 2008). (C) Depiction of the differential modulation for verbs compared to nouns, of the consonant string baseline condition in the off- and on-dopaminergic treatment conditions (from Boulenger et al., 2008).

Taken together, the studies of Neininger and Pulvermüller (2003) and Boulenger and colleagues (2008) suggest that patients with compromised motor systems (of various etiologies) may exhibit ‘deviant’ performance for action verbs compared to nouns. That said neither study tested the performance of the patients on other types of verb stimuli. An important issue for future research is to distinguish between potential grammatical class specific impairments, and truly semantic impairments (see also Bak et al., 2001; for review and discussion, see Shapiro and Caramazza, 2003).

There are also aspects of the findings observed in both studies that invite replication. In Neininger and Pulvermüller’s (2003) study, the (to-be-expected) effect on response times was not obtained. As the patients were, overall, well above chance in performing the task, it may be the case that the observed effects in accuracy were carried by a few items that the patients consistently

failed to judge correctly (see [Neininger and Pulvermüller, 2003](#), for more fine-grained analyses of the patient groups). In [Boulenger and colleagues' study \(2008\)](#), the critical interaction on which the authors' conclusion is based is carried by the consonant string baseline. As can be seen in [Fig. 1C](#), the condition that is differentially affected, comparing nouns and verbs, across the off- and on-dopaminergic testing sessions, is the consonant string baseline. On the view that the observed interaction is driven by 'deviant' semantic processing, the expectation would be for the interaction to be carried by modulations in the identity condition, rather than the consonant string baseline condition.

Setting the above empirical and methodological issues aside we believe that the type of data reported by [Neininger and Pulvermüller \(2003\)](#) and [Boulenger and colleagues \(2008\)](#) is particularly strong. The theoretical conclusions derived by the respective authors of those two studies share the view that the observed effects indicate that motor-relevant information is involved in the semantic analysis of action verbs. That conclusion must be situated within the context of the experimental task that participants were asked to perform: lexical decision. While semantic influences in lexical decision are well documented, it is not obvious how (and indeed why) semantic variables affect a task that, strictly speaking, does not depend on semantic analysis. Any (embodied or disembodied) account of the findings must therefore make reference to a decision mechanism that promiscuously uses information that, on a logical analysis of the task requirements, would not be necessary. A theory of the decision mechanism is needed that articulates why the state of the conceptual system is relevant for lexical decision. Only subsequent to the articulation of such a theory does the question arise as whether the activation of the motor is mediated by the prior retrieval of 'abstract' and 'symbolic' conceptual content.

The version of the disembodied cognition hypothesis that is falsified by the types of data reported by [Neininger and Pulvermüller \(2003\)](#) or [Boulenger and colleagues \(2008\)](#) maintains that the state of the motor cortex is irrelevant to lexical/conceptual processing. Thus, (and bracketing the above methodological concerns) it is the case that versions of the disembodied cognition hypothesis that include strong restrictions on 'cross-talk' between sensory/motor systems and the conceptual system, are falsified by the types of findings reported by [Neininger and Pulvermüller](#), and [Boulenger and colleagues](#). As noted above, this does not mean that the above discussed findings constitute evidence for the embodied cognition hypothesis. It may (merely) mean that it is necessary to reconsider the assumptions that are made about the dynamics of activation flow within and between cognitive systems. For instance, it may be the case that suppression of relevant motor areas feeds back to areas where conceptual and lexical representations are stored/computed. This is, of course, an open issue: however, it is also one alternative hypothesis that must be rejected before findings such as those reported by [Neininger and Pulvermüller \(2003\)](#) or [Boulenger and colleagues \(2008\)](#) can be taken as evidence for the embodied cognition hypothesis.

3. The disembodied cognition hypothesis: Is motor system activation during conceptual processing merely Pavlovian?

There are other findings from neuropsychology, and in particular, Apraxia, that provide some leverage on the issue of whether or not important aspects of some concepts are embodied. Apraxia is an impairment for using objects that cannot be explained by basic sensory or motor impairments. There are now a number of studies, from different research groups, using different materials and scoring methods, that converge on two empirical facts: patients can be

impaired for using objects despite being unimpaired for: (1) naming the same objects, and (2) recognizing the pantomimes associated with the uses of those objects (for reviews, see [Johnson-Frey, 2004](#); [Mahon and Caramazza, 2005](#); [Rothi et al., 1991](#)). Examples of each of these dissociations are represented in [Fig. 2](#) (data from [Negri et al., 2007](#)). These data indicate that the integrity of motor processes, as indexed by object-use tasks, is not necessary in order for object naming and action recognition to be in the normal range. On the basis of these facts, the strong form of the embodied cognition hypothesis can be rejected.

However, it is important to apply the same criteria consistently: Do these neuropsychological data *add* to a theory of concepts? Not really. Imagine a patient, such as one of the patients depicted in [Fig. 2B](#), who when presented with a hammer, cannot demonstrate how to use the hammer. The same patient, while not being able to demonstrate the use of the object, may be able to say that the object in hand is a hammer, and that it is used together with nails. From this, one may conclude that possessing the ability to actually use an object is not constitutive of other ways of cognizing about that object (e.g., naming). And from this one can conclude that the concept HAMMER is not reducible to just sensory and motor information. However, we cannot at present know whether the concept HAMMER in this patient is different in subtle but important ways from the concept HAMMER the patient possessed before sustaining brain damage. Note, however, that none of the evidence reviewed above, and which has been cited in favor of the embodied cognition hypothesis, provides specific clues about which aspects of the concept HAMMER may be (subtly) impaired in that patient.

The challenge within the disembodied cognition hypothesis is: (1) to develop a model of the computations and representational content that mediate between perceptual processing and motor activation, and (2) to specify the conditions under which those computations are deployed. There are a number of theoretical possibilities that remain unaddressed and which would be consistent with the available evidence. One possibility (which we do not endorse – see below), is that motor activation is entirely irrelevant for semantic analysis. Consider the Pavlovian dog, which salivates when it hears the bell. One may ask: How does all of the nervous system machinery that results in the conditioned response in the dog become 'activated' by the bell? Does all of that activation constitute 'recognizing the bell' – or is it all activated rather only after the bell is recognized as such?

3.1. Objections to the foregoing

In the course of discussing the arguments presented above with colleagues we have had the opportunity to receive critical feedback. Discussion of some of those objections within the present context is, in our view, productive for exploring the theoretical options that are currently available. Here we take the opportunity to list several of the more forceful objections that we have heard voiced, and to outline some responses to them.

(a) *The embodied cognition hypothesis predicts the observed patterns of activation evidence, while the disembodied hypothesis does not predict those data.*

It is false to maintain that a theory that assumes a strict separation between abstract conceptual content and sensory/motor information does not predict the observed findings that have been argued to support the embodied cognition hypothesis. Such a theory is silent with respect to such predictions; the predictions that follow from such a theory depend entirely on further assumptions that are made about the dynamics of activation flow between (and/or within) cognitive systems.

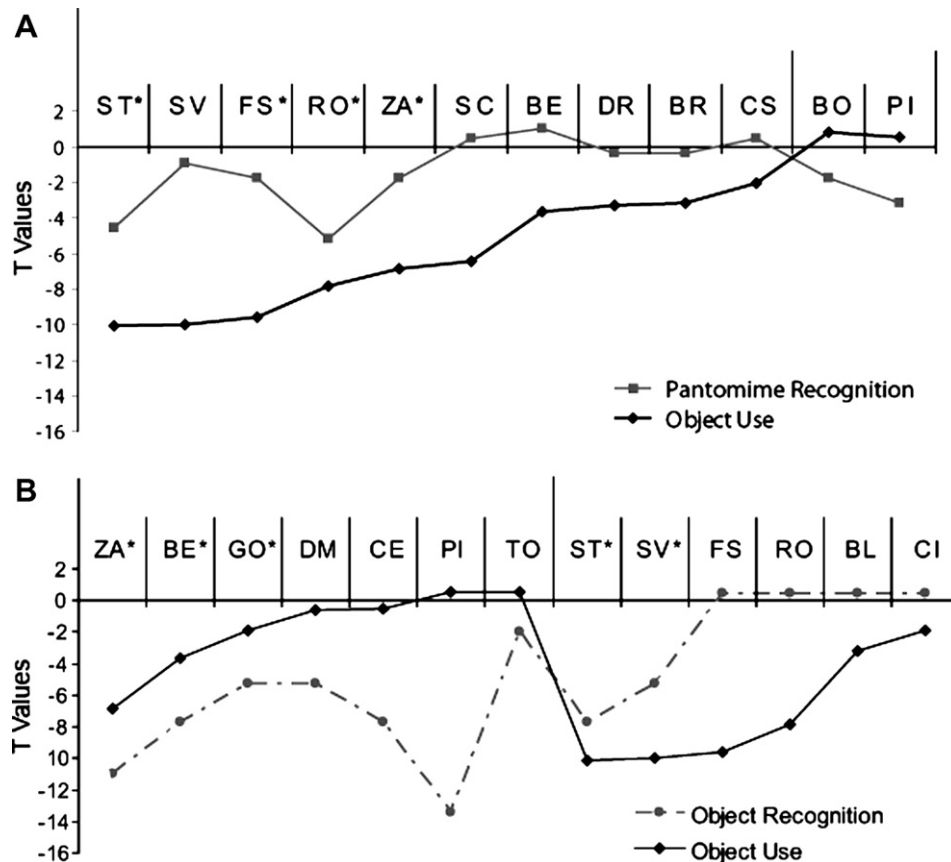


Fig. 2. Double dissociations between object use and pantomime recognition (A) and object use and object recognition (B). On the y-axis of each graph, t -values (Crawford and Garthwaite, 2006) are plotted comparing the performance of each patient (considered individually) to a matched control group ($n = 25$). The asterisk (*) indicates that the patient's performance for both tasks differs significantly from the normal control mean, but that performance between the two tasks is also dissociated for the same patient. The absence of the asterisk () indicates that performance of the patient on the spared task is not different from controls. All patients were tested for object naming/recognition, object use, and pantomime recognition using the same set of 29 manipulable objects. See Negri and colleagues (2007) for details. Figure reproduced (with permission) from Negri and colleagues (2007).

A theory of concepts would have to address not only the issue of how information is represented and what that information consists in, but also how information is retrieved at various levels of processing within the system. A theory of the former must therefore be developed in the context of a theory of the latter. Any particular empirical observation occurs in the context of a particular task; a theory of the paradigm in which the data are obtained must go along with any cognitive interpretation of the observed effects.

(b) You guys (Mahon and Caramazza) are arguing for the hypothesis of disembodied cognition: What is the evidence for that view? There is all of this evidence for the embodied cognition hypothesis, but there is no evidence for the disembodied cognition hypothesis.

We have not, and have not elsewhere, argued for the parody of the disembodied cognition hypothesis that is falsified (see above) by the available activation evidence. We have argued that the available evidence can be accommodated by the disembodied cognition hypothesis if specific assumptions, that are independently motivated by other aspects of cognitive processing, such as cascaded activation, are made about the dynamics of activation flow between (and/or within) cognitive systems. It follows that the embodied cognition hypothesis is without empirical support relative to other viable theories. We have also argued that, in the measure to which the embodied cognition hypothesis is an empirically testable claim, it is at variance with the available neuropsychological evidence.

As noted in the Introduction to this article, the logic of our argument has been to provide an account of the evidence from the perspective of the disembodied cognition hypothesis in order to remove the empirical support for the embodied cognition hypothesis. Below we sketch our own view of the roles of sensory and motor information in semantic processing.

(c) The existence of neuropsychological dissociations between impaired action production and spared naming, as well as impaired action production and intact action recognition do not constitute evidence for 'a modular perspective'. This is because computational simulation studies have proven that double dissociations can be explained by distributed interactive systems approaches. Such neuropsychological dissociations, although important, are neutral with regard to the critical question at stake in the discussion in this article. Mahon and Caramazza are not entitled to conclude that "strong forms of the embodied hypothesis are at variance with the neuropsychological evidence."

This objection has two components. The first component concerns the attribution of a 'modular' view of cognitive architecture to our argument. For instance, Pulvermüller and colleagues (e.g., Pulvermüller, 2005) use the term 'modular' to refer to the types of cognitive processes that might be postulated in place of 'distributed interactive systems' (for a similar construal see also Gallese and Lakoff, 2005; for discussion, see Mahon and Caramazza, 2005, footnote 2, for discussion). There are two implications of the use of the term 'modular' in this context (see Fodor, 1983, for

a more strict deployment of the term). The first is that a 'modular' cognitive process is, in some way, compartmentalized or separated from other processes. (That is, it is 'modular' in the way that 'modular homes' are 'modular'). The second implication is that, if a process is 'modular', then activation cannot 'escape from' or 'leak out of' that process to other 'modular' processes.

We have chosen (here and elsewhere) to not use the term 'modular' in relation to the debate about whether cognition is embodied. The reason why, is that the modularity of cognitive processes is not what is at stake in the discussion about whether cognition is embodied: concluding that cognitive processes are not modular does not imply that they are therefore embodied. Confusion on this point is, we believe at the heart of a popular argument which begins with a demonstration of motor system activation in tasks that purportedly implicate conceptual processing and concludes that concepts are embodied. The argument goes through only if one (implicitly) accepts premises that, in our view, misrepresent the available hypothesis space. The implicit premises are that: (1) two cognitive systems must either be modular or dynamically interactive; and (2) within one's theory of the mind/brain, one must assume either 'modular' processes or embodied processes. The argument then takes the form:

Empirical fact: The motor system is automatically activated during conceptual and/or perceptual processing (i.e., activation automatically spreads from conceptual and/or perceptual levels of processing to the motor system).

Conclusion: Because conceptual representations (/perceptual processes) and the motor system interact, they are not 'modular', and because they are not 'modular' cognition must be embodied.

Seen in this way, it is clear that the crux of the 'disagreement' concerns the implicit premises that are made before the argument for embodied cognition is even presented. We believe those premises overly restrict (and thus misrepresent) the available hypothesis space. This is because there is no real disagreement about the direct interpretation of the empirical facts as indicating that activation flows between conceptual and/or perceptual processes and the motor system. Thus, the central theme of this article: a disembodied cognition hypothesis can account for the empirical facts if explicit assumptions are made about the way in which activation spreads between (and/or within) cognitive systems.

We may thus set aside the issue of 'modularity' in order to focus on the substantive issue raised in the above objection. That issue is whether computational simulation studies in fact 'prove' that neuropsychological double dissociations are not problematic for the embodied cognition hypothesis. The answer is clear: if anything, simulation studies are existence proofs that representations can dissociate only in the measure to which they occupy non-overlapping regions of a network. If two representations (e.g., the concept HAMMER, and the motor information required to use hammers) are represented over the same sets of nodes in a network, then they cannot strongly dissociate.

Stated another way, the only way in which two representations within a common network can dissociate due to damage to the network is if: (a) there is duplication of one of the representations somewhere else in the network, and/or (b) the two representations do not overlap to a relevant extent. Both (a) and (b) are contrary to the spirit of the embodied cognition hypothesis. Thus, we conclude that strong forms of the embodied cognition hypothesis are at variance with the available neuropsychological evidence.

4. Interim summary

The embodied cognition hypothesis cannot be true as a general theory of human cognition (think of representations/concepts such

as '300,012,' incredulous, astute, theory, embodied, false and on and on). Experiments are not required to demonstrate that the scope of the embodied cognition hypothesis is sharply limited up front. Nevertheless, the issue of whether the embodied cognition hypothesis offers a cogent and empirically valid account of the representation of concrete objects and actions is in itself interesting. Furthermore, that issue has served as a microcosm for exploring broader issues, such as whether cognitive processes are symbolic or non-symbolic.

The argument for the embodied cognition hypothesis has been principally based on three types of findings: (I) the motor system can be automatically activated during perceptual and conceptual processing; (II) activation in the motor system can spread to conceptual and perceptual levels of processing; and (III) linguistically processed input can result in activation of the motor and sensory systems. We have shown that the disembodied cognition hypothesis can accommodate the empirical findings that have been argued to uniquely support the embodied cognition hypothesis. Our argument has been the same throughout: the evidence adduced in support of the embodied cognition hypothesis can be explained by a disembodied view of cognition if appropriate (and independently defensible) assumptions are made about the dynamics of activation flow between (and/or within) cognitive systems.

At the same time, the currently available evidence from apraxia falsifies strong forms of the embodied cognition hypothesis. There are now a number of published cases in which patients with impairments for using objects are able to name the same objects that they cannot use (for references, see Johnson-Frey, 2004; Mahon and Caramazza, 2005). This conclusion is strengthened by computational simulation studies that indicate that processes dissociate in the measure to which they are represented over separate regions of an interactive network (e.g., Pulvermüller and Preißl, 1991). At the same time, the neuropsychological evidence in no way resolves the issue of how concepts of concrete objects and actions are represented in the brain, beyond establishing that sensory and motor information plays, at best, a supportive but not necessary role in representing concepts.

From the foregoing, one thing is clear: the goal of developing a theory of concepts will not be served by collecting more of the same data. One more fMRI experiment demonstrating that the motor cortex is activated during action observation or sentence processing does not make the embodied cognition hypothesis more likely to be correct. One more patient showing that an impairment to motor processes does not affect action or object recognition will not make the disembodied cognition hypothesis more likely to be correct.

In our view, the way in which the hypothesis space is currently cast does not productively serve the development of a theory of concepts that resonates with the available evidence. Part of the cause of this situation is a conflation of claims about the dynamics of activation flow with claims about the structure and format of representations. As long as the hypothesis space is cast in this way, as is now standard in the field, we do not think that progress in developing positive claims about concepts will be forthcoming. To reiterate: this is not because of a shortage of data. We believe it is because the agreed-upon hypothesis space does not acknowledge alternatives that are consistent with all of the data and which have not to date been explored. In the remainder of this article we sketch one such alternative.

5. Grounding by interaction

Consider the hypothetical apraxic patient with whom one might have a conversation about hammers. The patient might be able to recount the history of the hammer as an invention, the

materials of which the first hammer was made, or what hammers typically weigh. The patient may even look at a hammer and name it without apparent difficulty. But when presented with a hammer, the patient is profoundly impaired at demonstrating how the object is physically manipulated to accomplish its function. This impairment is not due to a peripheral motor deficit, as the patient may be able to imitate meaningless gestures without difficulty. What is the functional locus of damage in the patient? Has the patient 'lost' part of his/her concept HAMMER?

On one level, the patient clearly does retain the concept HAMMER and in this sense, the concept HAMMER is 'symbolic', 'abstract', and 'qualitatively different' from the motor 'knowledge' that is compromised in the patient. On another level, when the patient instantiates the 'abstract' and 'symbolic' concept HAMMER, that instantiation occurs isolated from sensory/motor information that, in the normal system, would go along with the instantiation of the concept.

Thus, on the one hand, there is a level of representation of meaning that is sufficiently general and flexible that it may apply to inputs from diverse sensory modalities, and be expressed in action through diverse output modalities. The 'abstract' and 'symbolic' representation of HAMMER could be accessed from touch, vision, or audition; similarly, that representation could be 'expressed' by pantomiming the use of a hammer, producing the sounds that make up the word 'hammer', writing the written word 'hammer', and so on. In short, there is a level of conceptual representation that is 'abstract' and 'symbolic' and which is not exhausted by information that is represented in the sensory and motor systems.

On the other hand, conceptual information that is represented at an 'abstract' and 'symbolic' level does not, in and of itself, exhaust what we know about the world. What we know about the world depends also on interactions between 'abstract' conceptual content and the sensory and motor systems. As discussed in the Introduction, there are two ways in which such interactions may come about. First, 'abstract' and 'symbolic' concepts can be activated by events in the world that are processed by the sensory systems, and realize changes in the world through the motor system (see Jeannerod and Jacob, 2005 for relevant discussion). Second, the instantiation of a given 'abstract' and 'symbolic' concept always occurs in a particular situation; as such, the instantiation of that concept in that situation may involve highly specific sensory and motor processes.

Within the grounding by interaction framework, sensory and motor information colors conceptual processing, enriches it, and provides it with a relational context. The activation of the sensory and motor systems during conceptual processing serves to ground 'abstract' and 'symbolic' representations in the rich sensory and motor content that mediates our physical interaction with the world. Another way to state this is that sensory and motor information constitutes, in part, the 'mental stuff' over which specific instantiations of a concept are realized. Of course, the specific sensory and motor information that is activated may change depending on the situation in which the 'abstract' and 'symbolic' conceptual representation is instantiated.

5.1. How is 'grounding by interaction' different from the so-called 'disembodied cognition hypothesis'?

The two views are similar in that they both assume that there is an 'abstract' and 'symbolic' level of conceptual content that is not constituted by sensory and motor information. However, the two views diverge in an important respect. According to the disembodied cognition hypothesis, 'abstract' and 'symbolic' conceptual knowledge is *all that is important* for appreciating what we know (conceptually) about the world. On the disembodied cognition

hypothesis, activation of the motor system in tasks that do not 'require' motor system activation must be regarded as ancillary to, and inconsequential for, semantic analysis. Such motor system activation would be akin to the role that the activation of the 'salivary system' in the Pavlovian dog plays in recognizing the bell – i.e., nothing.

In contrast, according to 'grounding by interaction', the instantiation of a concept includes the retrieval of specific sensory and motor information. Within the 'grounding by interaction' framework, 'removing' the sensory and motor systems (as in brain damage) would result in impoverished or 'isolated' concepts. Sensory and motor information on that view, contributes to the 'full' representation of a concept. The activation of sensory and motor processes during conceptual processing is not necessarily 'ancillary to' or 'inconsequential for' conceptual processing. The activation of specific sensory and motor representations complements the generality and flexibility of 'abstract' and 'symbolic' conceptual representations.

5.2. On the grounding by interaction view, is specific sensory and motor information constitutive of conceptual content?

There are detailed positions (most notably, Barsalou, 1999) that begin with the assumption that conceptual content is represented in terms of (or constituted by) specific sensory and motor information; more and more abstract levels of representation are then added to the system, in order to arrive at a level of 'meaning' representation that is sufficiently abstract as to be compositional. The result is a theory of concepts in which the actual 'concepts' are no longer embodied – they are removed (representationally) from the sensory and motor information of which they are claimed to be constituted.

In contrast, we have begun with the assumption that concepts are represented at a level that abstracts away from the specific sensory and motor events that have gone along with the instantiation of those concepts in the past (and which will go along with them in the future). The question is whether such sensory and motor events are nevertheless constitutive of the concept. So consider the concept DOG. And consider that one sees on Monday a Rat Terrier, and then on Tuesday, a Rodesian Ridgeback. On both Monday and Tuesday, the concept DOG has been instantiated. However, the particular sensory information that went along with the instantiation of the concept DOG on Monday and Tuesday was different. So, the question arises: Did the observer instantiate the same concept DOG on Monday and Tuesday? If the specific sensory and motor information that 'goes along' with instantiations of a concept is understood as being 'constitutive' of that concept, then different people cannot have the same concepts, and even the same person may not instantiate the same concept at different points in time.

On the grounding by interaction view, the specific sensory and motor information that goes along with the instantiation of a concept is not constitutive of that concept. Of course, that does not mean that that specific sensory and motor information is not important for the instantiation of a concept, in a particular way, at a given point in time. Indeed, such sensory and motor information may constitute, in part, that instantiation. A useful analogy in this regard is to linguistic processing. There is no upper limit (in principle) on the number of completely novel sentences that a speaker may utter. This fact formed one of the starting points for formal arguments against the behaviorist paradigm (Chomsky, 1959). If one were to consider the (indefinite) set of sentences that a person may utter in their life: those sentences can have syntactic structures that are in no way specifically tied to the particular words through which the expression of those syntactic structures were realized. The syntax of a sentence is not exhausted by an account of the words of which it is composed; this is the case even

though it may be the first time that that syntactic structure has ever been produced, and even though the expression of that particular syntactic structure clearly depended (de facto) on the presence of those particular words. To close the analogy: concepts 'wear' sensory and motor information in the way that the syntax of a sentence 'wears' particular words.

To make the point more concrete, consider the view advanced by Zwaan and colleagues (e.g., Zwaan, 2004). On that view, the explicit assumption is made that "...comprehension involves [i.e., consists in] action and perceptual representations and not amodal representations" (Zwaan, 2004, p. 6). Thus, consider the concept DOG in the two sentences: (1) the dog easily jumped over the chair; or (2) the dog could easily walk under the chair. The 'image' of a dog that is evoked by sentence (1) is of a large dog, while the image of a dog that is evoked by sentence (2) is of a small dog. On an account such as Zwaan's, the concept DOG, as retrieved in understanding sentence (1) is therefore distinct from the concept DOG that is retrieved in understanding sentence (2). In contrast, on the grounding by interaction view, the sensory construct of the imagined 'dog' is different in the two cases; however, the same 'abstract' concept DOG is retrieved in both cases.

5.3. How does the hypothesis of grounding by interaction deal with more abstract concepts?

This question requires clarification, because on one level, *all* concepts on the grounding by interaction view are represented (at least as types) at an 'abstract' level. Thus, the concept HAMMER has an abstract representation that would be the relevant mental unit on any formal analysis of the concept HAMMER. However, the referent of that concept is a concrete entity in the world, and thus the instantiation of that concept is often dressed in specific sensory and motor information. On the other hand, there are innumerable abstract concepts, in the sense that the referents of those concepts are not concrete entities or events. For such concepts, there may be no significant sensory or motor correlates to their instantiation. At the same time, there may be, sometimes, sensory or motor correlates.

Consider the concept BEAUTIFUL. There is no *consistent* sensory or motor information that corresponds to the concept BEAUTIFUL. The diversity of sensory and motor information that may be instrumental in the instantiation of the concept BEAUTIFUL is unlimited: the mountains can be beautiful, or an idea, or the face of the beloved. The 'abstract' and 'symbolic' representation BEAUTIFUL is given specificity by the sensory and/or motor information with which it interacts in a particular instantiation. Of course, this claim could be interpreted as indicating that anything that 'happens' to be activated in the mind/brain when a given concept is instantiated is 'part of' that concept. In this regard, the analogy to spreading activation during lexical access in speech production is relevant. So for instance, when a person says to another – *you are beautiful* – the activation of the phonological encoding system is not, in any sense, 'part' of the concept BEAUTIFUL. On the other hand, one may be inclined to say that the perception of the setting sun behind the beloved, is in a relevant sense, part of the instantiation of the concept BEAUTIFUL in the utterance – *you are beautiful*.

5.4. The domain-specific sensory-motor hypothesis

The grounding by interaction view of concept representation is part of a larger framework on the organization and representation of concepts that we are developing. We refer to the broad framework as the Domain-Specific Sensory-Motor Hypothesis. The central aspect of that hypothesis is that the way in which concepts are organized and represented is determined by the use to which those classes of mental representations have been, and are, put

(Caramazza and Shelton, 1998). Within this framework, we have argued that the organization of higher order visual object recognition processes in ventral temporal cortex is due (in part) to innate functional connectivity between regions of the ventral stream and regions of the brain that receive the outputs of ventral stream processing (Mahon et al., 2007). In the present context, we have argued that there is structure that relates abstract conceptual content to sensory and motor processes. That structure provides the conduit for both freeing cognition from the specifics of the body, as well as allowing cognition to interface with the world through the body.

6. Conclusion

It is one of the most important insights of cognitive neuroscience that processes are activated that 'go beyond' the 'logical' requirements of the task. Those findings have provoked major revisions to classical views about how the mind works. We have suggested that while the spirit of those revisions is welcome, the specific conclusions that have been reached are not supported, relative to other viable theories, by the empirical evidence. Recognition of this point is, we believe, important in order to preserve a productive balance between theory and evidence. Preserving that balance is necessary for developing a theory of concepts with a firm empirical footing.

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