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Toward a Deeper Understanding of Embodiment

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This article sets the stage for a debate, played out in two subsequent articles in this issue by Glenberg and by Mahon, regarding the role of embodied conceptual representations in cognitive operations such as language understanding and object identification. On an embodied view of cognition, championed by Glenberg, conceptual knowledge and thought are necessarily grounded in sensorimotor representations. The contrary position, advocated by Mahon, is that symbolic thought is the foundation for cognition and is independent of such representations, although it may coincidentally evoke them. I review a few of the many available demonstrations showing that cognition is influenced by sensorimotor representations. Then, taking Mahon's perspective, I illustrate how examples from various classes of these demonstrations can be explained by mechanisms other than embodiment of conceptual representations. I close with an example of what can be taken as evidence for the representation of a behavioural goal that is abstract in the sense that it is not coded directly as an embodied action.

Keywords: action representations, embodied cognition, language understanding, object identification

The proposal that conceptual meaning must somehow be grounded in representations of sensorimotor experience (e.g., Barsalou, 1999; Barsalou, Kyle Simmons, Barbey, & Wilson, 2003; Glenberg, 1997) was revelatory for many of us who were schooled in a brand of cognitive science that characterised meaning in abstract, symbolic form (e.g., Anderson, 1983, 1993; Burgess & Lund, 1997; Collins & Quillian, 1969; Landauer & Dumais, 1997). On this traditional view, electronic devices such as computers are seen as viable models of human information processing. The notion that core principles of knowledge representation and cognitive computation are intimately tied to the neural systems that provide sensory input and generate motor activity raises serious doubts about whether that traditional view can be sustained. These aspects of biological systems are not part of prototypical computer models of cognition, but perhaps they must be if we are to succeed in our aim to construct accurate computational accounts of embodied mental processes.

What, then, is the nature of embodiment, and what role does it serve in cognition? This question is at the heart of the debate played out in the articles in this issue by Glenberg (2015) and Mahon (2015). A strong version of embodied representations, as espoused by Glenberg, holds that conceptual knowledge is closely integrated with sensorimotor experiences and even constrained by what our perceptual and motor systems are capable of experiencing and producing (Barsalou et al., 2003; Glenberg, 1997). Two branches of evidence have made substantial contributions to supporting an embodied view of conceptual knowledge, one based on behavioural evidence, the other on neuroimaging and related techniques.

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On the behavioural side, numerous demonstrations have shown that sensorimotor representations make contributions to cognitive tasks such as object identification and language comprehension. For example, time taken to verify that a pictured object was mentioned in a preceding sentence is reduced if the object is posed in a manner compatible with what is described in the sentence (Zwaan, Stanfield, & Yaxley, 2002). Thus, verifying that the target object *eagle* was mentioned in a sentence such as *The eagle soared across the sky* took less time when the eagle was pictured flying compared to perched on a branch. Comprehending sentences appears to involve generation of a specific perceptual version of its constituents, constrained by sentence context so that if a closely matching physical instantiation of this version is then presented for verification, little time is needed to make a response. Similarly, Pecher, Zeelenberg, and Barsalou (2003) showed that when verifying properties of objects (e.g., *leaves rustle*), subjects were faster if the item on the previous trial implied the same rather than a different perceptual modality (e.g., *blender is loud* vs. *toast is warm*). This result suggests that subjects relied on a form of sensory-perceptual simulation because the observed switch cost is analogous to similar costs observed when modality switches are made in perceptual tasks (Spence, Nicholls, & Driver, 2001).

In the motor domain, Glenberg and Kaschak (2002) introduced the action-compatibility effect, whereby classifying sentences as meaningful by making a hand movement toward or away from the body is done more rapidly if the movement is consistent with the action described by the target sentence (e.g., moving the hand away from the body to classify *You gave the brick to the workman* as sensible). This outcome is consistent with the proposal that understanding language is dependent on a mental simulation of the message (see also Zwaan & Taylor, 2006). Furthermore, semantic classification of objects apparently evokes motor representations compatible with those objects, suggesting that conceptual knowledge about objects includes action representations. Tucker and Ellis (2001) had subjects make power or precision grasps to classify objects as natural or manufactured. Even though the classification response did not logically require consulting knowledge of actions associated with the objects, responses were made faster if the size of the object (and therefore its associated typical grasp) was congruent with the physical classification response made by the subject (e.g., small object, precision grasp; large object, power grasp).

The second branch of evidence that is consistent with an embodied account of knowledge representation and language processing involves neuroimaging methods. One of the earliest examples of this evidence is the finding (Chao & Martin, 2000) that activation of the left ventral premotor cortex and left posterior parietal cortex, as measured by functional MRI (fMRI), is elevated when observers view pictures of manipulable objects (e.g., hammer) relative to objects that are not typically manipulated (e.g., human faces, animals). Chao and Martin (2000) proposed that this selective activation indicates that identification of manipulable objects may "depend" on their stored sensorimotor attributes (p. 482). Language processing also appears to be strongly connected to areas of premotor cortex. Experiments using fMRI have shown that when processing sentences or action words referring to particular body regions (leg, arm, face), corresponding areas of the motor and premotor cortex are especially active (Hauk, Johnsrude, & Pulvermüller, 2004; Tettamanti et al., 2005). For instance, listening to the sentence *I kick the ball* activated the leg region of premotor cortex to a greater degree than premotor regions associated with hands/arms or face. In a related demonstration, Pulvermüller, Hauk, Nikulin, and Ilmoniemi (2005) showed that application of transcranial magnetic stimulation (TMS) to hand or leg motor areas in the left hemisphere of right-handed subjects led to faster responses in a lexical-decision task for words related to hand or leg movements, respectively. These results were not seen when a sham TMS procedure was used. Pulvermüller et al. took these findings to indicate the existence of functional links between action and language systems.

As indicated by the foregoing summary, the available behavioural and neuroimaging evidence provides substantial support for a sensorimotor contribution to conceptual knowledge. Indeed, this evidence is consistent with Glenberg's (2015) claim that embodied aspects of experience are tightly integrated into conceptual knowledge and make necessary contributions to activities such as object identification and language comprehension. Mahon's (2015) counterpoint, however, is that we must also consider what findings might be expected under a viable alternative hypothesis. His position (see also Mahon & Caramazza, 2008) is that evidence for the involvement of embodied representations can be explained by activation spreading between brain regions (e.g., conceptual and motor systems). Jackendoff (2012) provides a similar account from a linguistic perspective on the relationship between spatial representations (which include sensorimotor experience) and language comprehension. Although the interactions proposed in these non-embodied accounts mean that sensorimotor representations can contribute to cognitive performance, those representations do not necessarily play central functional roles in that performance. A signal observation from neuropsychological studies is the finding that patients with apraxia, who suffer from an impairment in using objects despite having no perceptual or motor deficits, nevertheless are able to name those objects and to recognise pantomimed actions representing the use of those objects (Negri et al., 2007). If conceptual knowledge about objects were embodied, one might have expected that impairment or elimination of sensorimotor knowledge would produce measurable deficits in perceptual and language processing.

Let us examine how some of the evidence for the embodied nature of conceptual representation might be viewed from the alternative perspective proposed by Mahon (2015). The striking neuroimaging evidence for activation of motor and premotor areas during tasks such as identifying objects or understanding language (e.g., Chao & Martin, 2000; Tettamanti et al., 2005) has an important shortcoming. Namely, the poor temporal resolution available with these methods means that we do not know when this activation occurs, relative to other cognitive operations. It is not clear, for instance, whether activation in premotor cortex occurs early enough to make contributions to conceptual operations responsible for achieving identification and comprehension. Moreover, even if it were demonstrated that there is a temporal overlap between motor and premotor area activation and other cognitive processes, this correlation would not logically require a causal connection.

Although behavioural studies have provided evidence of the influence of sensorimotor representations on the online performance of cognitive tasks, they also have a set of drawbacks of their own. First, in many cases, behavioural results consist of some form of *priming* effect, in which faster responding occurs when successive stimuli are compatible on some dimension. Benefits can arise proactively, as when encountering a stimulus creates a mental state that enables more efficient processing of the next stimulus (Collins & Loftus, 1975; Masson, 1995; Neely, 1977), or retroactively, whereby current processing of a stimulus is supported by recruitment of an earlier processing event (Neely, Keefe, & Ross, 1989; Ratcliff & McKoon, 1988; Whittlesea & Jacoby, 1990). The potential for retroactive mechanisms in priming is particularly important because it offers an alternative interpretation of some behavioural effects taken as evidence for embodied conceptual representations. For example, consider the Zwaan et al. (2002) evidence for mental simulation of concepts mentioned in a sentence (e.g., *The eagle soared across the sky*) mentioned earlier. It is possible that subjects did not initially imagine the object mentioned in a sentence as being in a specific pose (e.g., an eagle with its wings spread). Instead, upon seeing the object in a particular pose, perhaps subjects more readily elaborated their understanding of the sentence to incorporate the pictured version of the object when it matched the sentence's details than when it did not match.

A second difficulty in the interpretation of compatibility effects is that they may arise from sources other than congruent action representations. In the Tucker and Ellis (2001) study showing compatibility effects between object size and type of manual response (pinch vs. power grasp), for example, the basis of the congruency between objects and actions was simply size. It is possible that the effect of congruency on response time was due to this more abstract type of compatibility (size), rather than being driven by action representations associated with the objects. This idea might be tested by having subjects use their preferred hand to press a large or a small button to make their classification responses or by replicating the original experiment with large and small objects that are not typically manipulated with the hands. I mention these options to illustrate the plausibility of alternative explanations of key results (see also Cho & Proctor, 2011, for a similar reinterpretation of the Tucker & Ellis, 1998, demonstration of action priming).

Another challenge regarding the interpretation of congruency effects between actions and target stimuli, such as the action-compatibility effect reported by Glenberg and Kaschak (2002), is that the task requirement to make a manual response (e.g., moving the hand toward or away from the body) may potentiate action representations in a manner that would not normally occur when overt manual actions are not produced. This is essentially a variant of Heisenberg's (1927) uncertainty principle and is very difficult to overcome. One recently reported study, not using manual responses, comes as close to escaping this conundrum as any behavioural study of which I am aware. To test the idea that subjects use mental simulation as an aid to comprehension, Gunraj, Drumm-Hewitt, and Klin (2014) had subjects read either silently or aloud a passage describing a character who was either reading or speaking at either a slow or a hurried pace. Gunraj et al. measured time taken to read the section of the text that quoted what the character was reading or speaking. When the subjects' activity (reading silently or aloud) matched the character's action (reading or speaking), their reading rates were modulated by the character's speed. No modulation was observed when the actions did not match. These results imply that comprehending text content (a character's linguistic actions) includes a form of sensorimotor simulation. This experiment has the advantage of not using an appended behaviour, like moving the hand (Glenberg & Kaschak, 2002) or turning a knob (Zwaan & Taylor, 2006), that might be suspected of artificially inducing mental simulation while comprehending sentences. Nevertheless, the results do not convincingly show that the observed modulation of reading speed reflects functional dependence of comprehension on mental simulation.

On the specific question of whether mental simulation of actions described by text is required for successful comprehension, a number of indications suggest the inadequacy of straightforward mental simulation. Recent results suggest important limitations on the finding that manual actions are made faster when they are congruent rather than incongruent with text content. One example, reported by Bergen and Wheeler (2010), is the finding that the action-compatibility effect established by Glenberg and Kaschak (2002) was replicated when sentences were presented using the progressive syntactic form (e.g., *John is closing the drawer*) but was not found when the perfect syntactic aspect was used (e.g., *John had closed the drawer*). Although both sentence types were successfully understood as being meaningful, the latter apparently did not evoke a mental simulation of the described action. Perhaps some other, unmeasured, action had been simulated in the case of the perfect aspect sentences, but it is not clear what action that would be. The question then arises as to whether such mental simulation is indeed required for comprehension.

Another relevant result was reported by my colleague, Daniel Bub, and me in a series of experiments that involved listening to sentences while being cued to make hand actions (Masson, Bub, & Lavelle, 2013). These hand actions were either volumetric (lifting) actions or functional actions applied when using an object. Cued actions were completed in less time if they were compatible with the actions described in the context sentences. For example, being cued to make a volumetric action consisting of a vertically oriented power grasp just after hearing the term *spray can* in the sentence *Joey lifted the spray can to clear the shelf* led to a faster response than making an unrelated volumetric action such as a vertical precision grasp. Note that in this sentence, the goal of the action (clearing the shelf) occurs late in the sentence, after mention of the target object. When we placed the goal at the beginning of the sentence, followed by mention of a volumetric action (e.g., *To clear the shelf, Joey lifted the spray can*), the relevant volumetric hand action performed by the subject no longer showed a priming effect. Instead, the functional action associated with the object mentioned in the sentence (for a spray can, a power grasp with forefinger extended upward) was primed. This outcome is not consistent with the idea that subjects understood the sentences by constructing a literal mental simulation of the described action (e.g., lifting a spray can). Rather, action representations associated with the functional use of the objects were evoked, even though the sentence made no mention of such actions. This phenomenon can be understood in the context of goal hierarchies, as explained in the Masson et al. (2013) article.

Finally, recall the TMS results reported by Pulvermüller et al. (2005), showing enhanced lexical decision speed when stimulation was applied to the motor area relevant to the action associated with the target word. This finding might mean only that there is a "downstream" link between action representations and word processing. Rather than making a necessary contribution to identifying target words, action representations may serve only to supplement ongoing processes that could run almost as efficiently without such input. A more recent result using TMS indicates that action representations may indeed not make contributions to the early stages of word identification. Papeo, Vallesi, Isaja, and Rumiati (2009) applied TMS to left primary motor cortex and measured evoked potentials in the right hand. In this paradigm, the TMS pulse, coupled with the measured muscle potential in the hand, can be interpreted as a probe that reveals the degree of motor cortex activation at the time the TMS pulse is applied. Subjects judged whether verbs were action related, and TMS was applied at different time points after word onset. As Figure 1 shows, enhanced motor cortex activity when a hand-action verb (e.g., *stir*) was presented, relative to a nonaction verb (e.g., *wonder*), was not found during the first few hundred milliseconds after word onset. Only 500 ms after word onset was differential motor cortex activation for hand-action versus nonaction verbs obtained, well after lexical-semantic processing would have occurred, according to data from event-related potential studies (Pulvermüller, Harle, & Hummel, 2001; Sereno, Rayner, & Posner, 1998). See Fleming et al. (2015) for another example of late influences of motor activity on target processing, as revealed by TMS. A more convincing result that would support a causal role for action representations in language comprehension or object identification would be a demonstration using TMS to disrupt motor activity (e.g., Siebner, Hartwigsen, Kassuba, & Rothwell, 2009), leading to impairment of language comprehension or object identification. No such demonstration has yet been provided as far as I know.

Two interesting undercurrents in the articles by Glenberg (2015) and Mahon (2015) are the allegorical use of the medieval notion of a flat Earth (Glenberg) and the view that human cognition is special (Mahon). The latter of these two conjured for me an additional allegory, one that harkens to the Victorian reaction to publication of Darwin's (1871) *The Descent of Man, and Selection in Relation to Sex*. Many were desperate to preserve the notion that

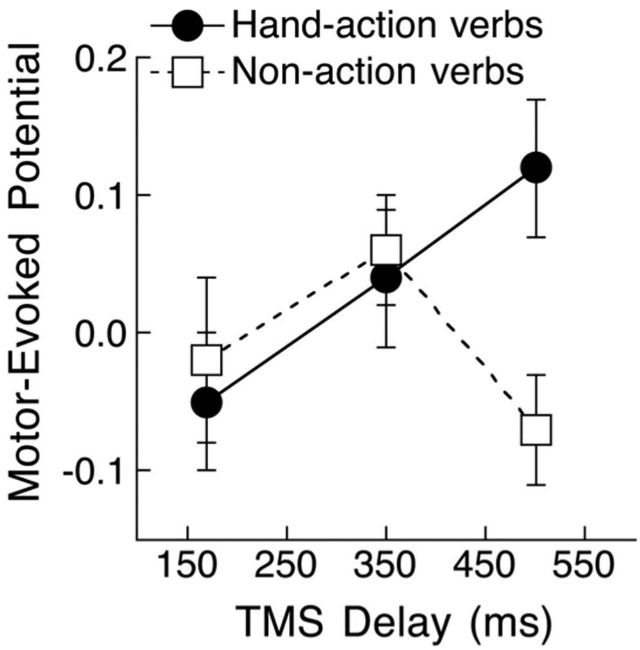

Figure 1. Mean motor-evoked potential for hand-action and nonaction verbs as a function of delay between word onset and transcranial magnetic stimulation (TMS) pulse. Error bars correspond to one standard error of the mean. Adapted from Papeo et al. (2009).

humans somehow are special creatures. I would like to argue that there is no need to postulate specialness of human cognition and at the same time to offer a glimpse of what an abstract, but not necessarily human, cognitive process might be like.

Some years ago, I was impressed with a single-cell recording study with monkeys (Ochiai, Mushiake, & Tanji, 2005) and its implication for claims about action representations coded in premotor cortex. Ochiai et al. (2005) recorded activity in individual cells of premotor cortex while a monkey moved its hand from a start position to a location indicated by a light. A majority of the measured cells responded selectively to either a left- or a rightward movement. The critical feature of the experiment was that the monkeys viewed their hand on a video monitor, rather than being able to view it directly. This allowed the researchers, in a second phase of the experiment, to present a mirror-reversed image of the monkey's moving hand. Now, a rightward hand movement, for example, caused the hand image on the monitor to move left to reach the target light located on the left. The central question was whether cell populations active during the rightward hand movement under normal viewing would continue to be activated in the mirror-reversed condition when the actual hand moved right, but the viewed image showed a hand moving left to reach the target location. Crucially, the cell populations were activated in accordance with the viewed display, not the actual hand movement. Thus, the coding of these premotor cortex cells reflected the relatively abstract goal or intention of reaching a target location in either the left or right of visual space; they did not code a physical movement to the left versus right.

A human analogue of the Ochiai et al. (2005) result was recently reported in a behavioural study by Osiurak and Badets (2014), who had subjects use normal or modified pliers. Normal pliers closed to grasp an object when the hand gripping them closed, and they opened when the hand opened. The modified pliers operated in the reverse manner (e.g., closing the hand opened the pliers). Just before being cued to open or close the normal pliers, subjects viewed an animation symbolizing opening or closing. A form of action-compatibility effect was found, whereby the action was made faster if the animation was congruent with that action. Note the ambiguity of this result. Was the compatibility effect driven by the overt hand action (open vs. close) or by the effect achieved by the action of the pliers? This question was answered by testing subjects with the reverse pliers. Consistent with the Ochiai et al. study, compatibility was determined not by the hand action but by that action's goal—the movement of the pliers.

In my view, then, there is reason to retain some degree of skepticism regarding strong claims about the embodiment of conceptual representations. A potentially useful direction in which this skepticism points is toward a consideration of goals, particularly goals associated with behaviourally induced manipulations of the environment. There is evidence to suggest an underlying commonality between human and primate tendencies to represent at least modestly abstract goals that are somewhat removed from the embodied actions that are enacted to achieve them.

Résumé

Cet article ouvre la porte à un débat, mené dans deux articles subséquents du présent numéro par Glenberg et Mahon, traitant du rôle des représentations conceptuelles incarnées dans les opérations cognitives telles la compréhension du langage et l'identification d'objets. Dans une perspective incarnée de la cognition, avancée par Glenberg, les connaissances et pensées conceptuelles sont obligatoirement ancrées dans les représentations sensorimotrices. La position contraire, défendue par Mahon, stipule que la pensée symbolique est à la base de la cognition et indépendante de telles représentations, bien qu'elles puissent, par pure coincidence, les évoquer. J'examine une sélection des nombreuses démonstrations disponibles illustrant que la cognition est influencée par les représentations sensorimotrices. Ensuite, en utilisant la perspective de Mahon, je montre comment des exemples de diverses classes de ces représentations s'expliquent par des mécanismes autres que l'incarnation de représentations conceptuelles. Je conclus avec un exemple de ce qui pourrait être considéré comme preuve pour la représentation d'un but comportemental qui est abstrait dans le sens où il n'est pas codé directement comme une action incarnée.

Mots-clés : représentations d'actions, cognition incarnée, compréhension du langage, identification des objets.

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