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Is motor knowledge part and parcel of the concepts of manipulable artifacts? Clues from a case of upper limb aplasia

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ABSTRACT

The sensory-motor theory of conceptual representations assumes that motor knowledge of how an artifact is manipulated is constitutive of its conceptual representation. Accordingly, if we assume that the richer the conceptual representation of an object is, the easier that object is identified, manipulable artifacts that are associated with motor knowledge should be identified more accurately and/or faster than manipulable artifacts that are not (everything else being equal). In this study, we tested this prediction by investigating the identification of manipulable artifacts in an individual, DC, who was totally deprived of hand motor experience due to upper limb aplasia. This condition prevents him from interacting with most manipulable artifacts, for which he thus has no motor knowledge at all. However, he had motor knowledge for some of them, which he routinely uses with his feet. We contrasted DC's performance in a timed picture naming task for manipulable artifacts for which he had motor knowledge *versus* those for which he had no motor knowledge. No detectable advantage on DC's naming performance was found for artifacts for which he had motor knowledge compared to those for which he did not. This finding suggests that motor knowledge is not part of the concepts of manipulable artifacts.

1. Introduction

What are the constituents of the conceptual representation of manipulable artifacts? What is there in the concept of a hammer? According to an influential theory developed within the framework of cognitive neuropsychology (Rothi, Ochipa, & Heilman, 1991), the conceptual representation of a manipulable artifact includes knowledge of its typical physical features (shape, texture, weight, etc.) and knowledge of what it is used for, its purpose or function. Such conceptual representation is conceived of as amodal or "symbolic" and is connected to input and output modality-specific representations. Input modality-specific representations provide the perceptual description of the visual object or of the visual motion of the body parts interacting with it. Once the conceptual representation of the artifact is accessed from this perceptual description, it activates output modality-specific representations that encode the phonological form associated with the artifact (for naming) or the learned motor programs associated with its use. What is important for the purpose of this study is that, within this view, motor knowledge of how an artifact is used is *not* constitutive of its conceptual representation (see also Humphreys, Riddoch, & Quinlan, 1988).

In contrast, the sensory-motor theory of conceptual representations assumes that conceptual knowledge of a manipulable artifact is distributed over modality-specific sensory and motor representations that are encoded during one's body sensorimotor interactions with the artifact. In this view, conceptual knowledge of an artifact thus *includes* motor knowledge of how it is used (e.g., Allport, 1985; Damasio, 1990; Martin, Ungerleider, & Haxby, 2000). Evidence cited in support of this theory refers to functional neuroimaging (e.g., Chao & Martin, 2000; Gerlach, Law, & Paulson, 2002; Saccuman et al., 2006) and behavioral (e.g., Bub, Masson, & Cree, 2008; Myung, Blumstein, & Sedivy, 2006) studies that showed that motor representations are automatically activated when manipulable artifacts are viewed, named, or identified, even when there is no intention to act upon them. However, that motor knowledge is automatically activated when manipulable artifacts are viewed or identified is not evidence that motor knowledge is *part of* their conceptual representation (Mahon & Caramazza, 2008).

In favor of the functional independence of conceptual and motor knowledge, there are reports of brain-damaged patients with apraxia who can recognize and name artifacts while they cannot demonstrate how to use them (e.g., Negri et al., 2007; Rapcsak, Ochipa, Anderson, & Poizner, 1995; Rumiati, Zanini, Vorano, &

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Shallice, 2001; for review, see Mahon & Caramazza, 2005). However, such evidence is not compelling either. Difficulties in manipulating artifacts might arise from damage to motor implementation processes that operate *after* spared motor knowledge has been retrieved. Moreover, even if access to motor knowledge was indeed degraded in these cases, the patients seldom made omission errors when asked to manipulate artifacts, or content errors, like using a toothbrush like a comb. Their errors mostly consisted in executing the appropriate manipulation movements but with temporal and spatial inaccuracies, which suggests that some residual motor knowledge has been accessed, which may suffice to support identification.

Be it as it may, evidence that patients can identify artifacts without being able to correctly use them is problematic only for variants of the sensory-motor theory that feature motor knowledge as indispensable (e.g., Gallese & Lakoff, 2005) or most diagnostic for identifying a manipulable artifact (e.g., Warrington & McCarthy, 1987). Under these theoretical variants, lack or degradation of motor knowledge indeed should prevent the identification of manipulable artifacts. However, the sensory-motor theory in itself is not committed to that strong prediction. If motor knowledge is part of manipulable artifact concepts, without being the central piece of these concepts, lack or degradation of such knowledge should somewhat hamper or delay the identification of manipulable artifacts—not necessarily *prevent* it. To our knowledge, this somewhat weaker prediction has never been tested in patients unable to manipulate artifacts, since only accuracy, not easiness (i.e., speed) or efficiency of processing, was recorded when identification was assessed.

In this study, we tested this prediction by investigating the identification of manipulable artifacts in an individual, DC, who was totally deprived of hand motor experience due to bilateral upper limb aplasia. This condition prevents him from interacting with most manipulable artifacts, for which he thus has no motor knowledge at all. However, DC had developed exceptional skills in using some artifacts with his feet (e.g., writing with a pen) and, thereby, had fine motor knowledge for some of them. This allowed us to assess the status of motor knowledge vis-à-vis the conceptual representation of manipulable artifacts in a within-subject design. Thus, we contrasted DC's performance in a timed picture naming task, for two sets of manipulable artifacts—those with which he had motor experience (Set 1) *versus* those with which he had no motor experience *at all* (Set 2). Given that both sets of items may differ in terms of potentially confounding variables, we also recorded the performance of typically developed control participants for both sets of manipulable artifacts and used it as a baseline for the analysis of DC's difference in performance between both item sets (Cf. Case-controls design in neuropsychology; Crawford & Garthwaite, 2005).

Before going farther, and in order to avoid misunderstandings, it may be useful to clarify what we mean by DC having «no motor knowledge at all» for a series of manipulable artifacts. Actually, both the term «motor» and the term «knowledge» are important in this phrase. By «motor knowledge», we mean motor programs and skills that an individual acquires through his actual and repeated use of an object in its conventional function. These acquired motor programs related to object use have to be distinguished from two other kinds of manipulation-related information that can be accessed when viewing an object. First, an individual may access some knowledge of how an object is usually used even if he never used it himself and, hence, does not have any learned motor patterns associated with it. For example, he may *know* how a saw is to be used and how hands and arms moved when people use it, just because he already saw someone else using it or because he already read instructions describing how to use it. Such visual or declarative knowledge is to be distinguished from *motor* knowledge acquired through the actual use of the object. Second, viewing any object with its specific shape, structure and volume, even if it was never encountered before, may cue specific motor interactions with it («affordances»). Such on-line, form-derived motor programs are also distinct from *acquired* motor programs, which represent conventional manipulation patterns linked to the conventional function of familiar objects. Thus, due to upper limb aplasia, DC could not acquire any *motor knowledge* of how using most manipulable artifacts although he is presumably able to access the two other kinds of manipulation-related information when viewing manipulable artifacts, whether he already used them or not, just like normally-developed individuals.

We reasoned that, within the sensory-motor theory, the inclusion of motor knowledge in the content of the conceptual representation of manipulable artifacts should make this representation richer than that of manipulable artifacts that were not associated with motor experience and, thereby, lacks motor features. Semantically rich stimuli, that is, stimuli with high numbers of semantic features, are processed faster in tasks involving object identification (e.g., semantic categorization) than stimuli with low numbers of features (Pexman, Holyk, & Monfils, 2003) and such higher processing efficiency can also be observed in hemodynamic responses (Pexman, Hargreaves, Edwards, Henry, & Goodyear, 2007). Therefore, we predicted that if motor knowledge was constitutive of the conceptual representation of manipulable artifacts, DC should identify (name) more rapidly artifacts for which he has motor knowledge compared to those for which he has no motor knowledge at all (everything else being equal). On the contrary, if motor knowledge was not constitutive of the conceptual representation of manipulable artifacts, having motor knowledge associated with them should not make the concepts richer and, therefore, should not facilitate the identification of these manipulable artifacts.

2. Method

2.1. Participants

DC is a 51 year-old man with a Master's Degree in Psychology, with a bilateral upper limb aplasia due to thalidomide-related embryopathy. The left extremity is completely aplasic; on the right side, the radius is aplasic and a partial ($\approx$12 cm) humerus or ulna and two fingers (the small and the ring finger) had developed. The shoulder and elbow/wrist joints are absent or not functional. Finger mobility is too limited to allow him a precision or palm grip. DC had never experienced any phantom limb sensation and never had any prosthesis similar to biological hands or arms. Given the lack of hand function, DC had developed exceptional foot dexterity from early life so that he routinely uses his feet for grasping and manipulating a series of artifacts to achieve daily life activities (e.g., he writes with a pen, types on a computer keyboard, and eats with a fork); in fact, he lives by himself and is able to achieve most daily life activities in total autonomy. However, he reported being unable to use a large range of other familiar objects (e.g., a hammer or a saw).

Five right-handed normally developed control subjects, matched with DC for gender, age (mean = 53.8; range = 48–56), and number of years of education (mean = 17.2; range = 16–19), also participated in the study. All participants gave written informed consent prior to the study. The study was approved by the biomedical ethic committee of the *Cliniques universitaires Saint-Luc*, Brussels, and all participants gave their written informed consent prior to the study.

2.2. Material and procedure

The stimuli consisted in 110 color photographs of manipulable artifacts. These items were selected among items for which