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

Gilles Vannuscorps [a,b], Michael Andres [b,c], Agnesa Pillon [a,b,*]

[a] Institute of Psychological Sciences and Institute of Neuroscience, Université catholique de Louvain, Place du Cardinal Mercier 10, 1348 Louvain-la-Neuve, Belgium
[b] Fonds de la Recherche Scientifique-FNRS, Belgium
[c] Department of Experimental Psychology, Faculty of Psychology, Ghent University, Henri Dunantlaan 2, 9000 Ghent, Belgium

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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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* Corresponding author. Address: Institut de recherche en sciences psychologiques, Université catholique de Louvain, Place du Cardinal Mercier 10, 1348 Louvain-la-Neuve, Belgium. Fax: +32 10 473774.
E-mail address: agnesa.pillon@uclouvain.be (A. Pillon).

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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 information regarding spoken name frequency (New, Brysbaert, Veronis, & Pallier, 2007), concept familiarity, imageability, and age of acquisition (Alario & Ferrand, 1999; Bonin et al., 2003a, Bonin, Peereman, Malardier, Meot, & Chalard, 2003b) were available in French lexical databases. An artifact was deemed manipulable (1) when it can be picked up and moved with one or both hands and (2) if it is associated with a specific hand action involving either grasping the artifact to use it as a tool or manipulating it in order to achieve a result (Saccuman et al., 2006). Authors (e.g., Mahon et al., 2007) have proposed to make a further distinction, within the class of manipulable objects, between those that are associated with motor movements that unambiguously allow their identification (e.g., hammer, scissors, toothbrush) and those that are associated with motor movements that are less predictive of their identity (e.g., frying pan, suitcase, candle). Involvement of motor knowledge in object identification, if any, could mainly concern the first kind of manipulable artifacts, hereafter, the "strongly manipulable" (SM) artifacts. In order to identify a subset of SM artifacts within our set of 110 items, we followed the procedure of Magnié and colleagues (Magnié, Besson, Poncet, & Dolisi, 2003). We presented the name of the 110 artifacts to 20 subjects (mean age: 26; 6 males) who did not participate in the main experiment and we asked them to judge on a five-point scale how easily (1 = very difficult; 3 = easy; 5 = very easy) they could pantomime the action usually associated with each artifact so that any person watching this action could identify the artifact. The artifacts with a manipulability rating equal or larger than 3 ($N = 69$) were considered as SM artifacts. All data analyses were performed on the whole set of artifacts and on the subset of SM artifacts.

The 110 photograph stimuli were displayed on a computer screen with a size of 400×400 pixels, on a white background. The participants were asked to name each photograph as fast and as accurately as possible. In each trial, a fixation point was presented in the centre of the screen for 200 ms; then the screen was cleared for 500 ms and the stimulus was displayed until the voice key was triggered. The next trial began after an interval of 1000 ms. The experiment was controlled by the E-Prime software (Psychological Software, 2002, Pittsburgh, PA). The participants were equipped with a sensitive built-in microphone connected with an RT-measuring PST (Psychology Software Tool) serial response box. Malfunctioning of the voice key and participants' responses were registered on-line by the experimenter.

Once the naming task was completed, the artifact photographs were presented again to each participant, who was asked to tell whether he had already used the artifact. From the 110 artifacts, only those that all control participants had already used ($N = 92$) were included in the analyses. These stimuli were then divided into two sets according to their having been used (Set 1) or never used (Set 2) by DC. The number and characteristics of items in each set is provided in Table 1 (see the item list in Appendix). Stimuli in Sets 1 and 2 did not significantly differ in terms of spoken word frequency, imageability, and manipulability. However, concept familiarity was significantly higher and age of acquisition significantly lower in Set 1 in comparison to Set 2.

We also checked that DC uses the artifacts of Set 1 for their conventional purpose (i.e., not only for grasping or moving them). We presented him the name of each of these artifacts and asked him to describe for what purpose and how (i.e., with what effector and movements) he usually uses them. This questionnaire showed that DC uses all the artifacts of Set 1 for their conventional purpose. Thus, he uses keys to open doors, clothespins to hang the laundry, an eraser to erase pencil marks, a screwdriver to drive screws, a computer keyboard to write e-mails, and so forth. He uses most (81%) of these artifacts (e.g., keys, cameras, rulers, matches, lighters, combs, etc.) with his feet only, some others (16%) with both his mouth and feet (e.g., pipe) or, alternatively his month or his feet, depending on the circumstances (e.g., clothespins), and some others (3%) with another means (e.g., he pushes on "flat" light switches with his shoulder).

3. Results

Trials with voice key failures (0.4% of control participants' trials, no trial in DC) and with exceptionally long naming latencies (i.e., trials with latencies of 6048 ms in Control 1, 6057 ms in Control 2, and 16,559 ms in Control 4, no trial in DC) were excluded from the analyses. No other trimming of the data was applied. Response latency analyses were carried out over correct responses only. Distinct analyses were performed with the whole set of manipulable artifacts and with the set of SM (strongly manipulable) artifacts only. Fig. 1 displays error rate, mean response latency, and mean efficiency score in DC and each control participant for both sets of items, separately for the whole set of artifacts and for SM artifacts only. The efficiency score (expressed in ms) was computed for each participant by dividing the mean response latency by the proportion of correct responses in a given condition (thus, the higher the score the poorer the performance). This score allows combining the measures of accuracy and speed into a single measure of processing efficiency; also, it allows between-group comparisons unbiased by potential speed-accuracy tradeoffs (Townsend & Ashby, 1978, 1983).

We computed Crawford and Garthwaite's (2005) Revised Standardized Difference Test (RSDT) over each dependent variable (error rate, response latency, and efficiency score) in order to test whether the discrepancy in DC's naming performance between Sets 1 and 2 of manipulable artifacts significantly differed from the discrepancy between both sets in control participants. Considering the whole set of manipulable artifacts, the analyses revealed that the discrepancy in DC's performance between Sets 1 and 2 did not significantly differ from that found in control participants, whether error rate [$t\ (4) = .83$, $p = .45$], response latency [$t\ (4) = .03$, $p = .98$], or efficiency score [$t\ (4) = .70$, $p = .52$] was considered as the dependent variable. When only SM artifacts were analyzed, similar results emerged. The discrepancy in DC's naming performance between Sets 1 and 2 did not significantly differ from that found in control participants, whether in terms of error rate [$t\ (4) = .89$, $p = .42$], response latency [$t\ (4) = .09$, $p = .94$], or efficiency score [$t\ (4) = .38$, $p = .72$].

We then carried out a by-item analysis of variance with covariates (ANCOVA) over the response latencies of DC and control participants for each item. The aim of this analysis was threefold: (1) increasing statistical power for testing the interaction between Group (DC vs. controls) and Set of items (Set 1 vs. Set 2), by considering items ($N = 84$ or $N = 64$) as the random factor; (2) controlling for the potential effect of the variables of concept familiarity and age of acquisition, which were not matched between Sets 1 and 2 (see Section 2.2); and (3) testing whether concept familiarity and age of acquisition, which are known to be important determinants of picture naming times in healthy participants (e.g., Alario et al., 2004), significantly interacted with Group; a significant interaction between Group and conceptual-lexical variables might suggest the existence of qualitatively different conceptual-lexical representations in DC and control participants. The ANCOVA was thus carried out with response latency as the dependent variable, items as the random factor, Group (DC vs. Controls) as within-item factor, Set of items (Set 1 vs. Set 2) as between-item factor, and concept familiarity and age of acquisition as covariates. For each item, we entered into the analysis the response latency of DC and the median of the response latencies of control participants. These data were then inverse transformed for satisfying ANCOVA's normality assumptions. When the whole set of artifacts were

Table 1
Distribution of the stimuli in the various sets of items used in the picture naming task (Set 1 = Already used by DC; Set 2 = Never used by DC) and mean (and standard deviation) values of lexical and conceptual variables in each set.

Whole set of manipulable artifacts (*N* = 92)	Set 1 (*N* = 64)	Set 2 (*N* = 28)	*t*	*p*
Spoken word frequency[a]	19.31 (34.14)	14.49 (32.58)	0.63	0.53
Age of acquisition[b]	2.57 (0.66)	2.95 (0.65)	2.53	<0.01
Concept familiarity[b]	3.47 (1.06)	2.50 (2.90)	4.19	<0.01
Imageability[c]	4.35 (0.45)	4.18 (0.70)	1.34	0.18
Manipulability[d]	3.61 (0.82)	3.75 (0.91)	0.72	0.47
Subset of strongly manipulable artifacts (*N* = 69)	**Set 1 (*N* = 48)**	**Set 2 (*N* = 21)**		
Spoken word frequency[a]	21 (37.62)	10.19 (10.06)	1.29	0.20
Age of acquisition[b]	2.47 (0.60)	2.84 (0.57)	2.37	<0.05
Concept familiarity[b]	3.5 (1.11)	2.47 (0.86)	3.72	<0.01
Imageability[c]	4.41 (0.38)	4.46 (0.37)	0.46	0.65
Manipulability[d]	3.97 (0.56)	4.17 (0.58)	1.34	0.18

[a] Number of lemma occurrences per million in a corpus of subtitles of films (New et al., 2007).
[b] From Alario and Ferrand (1999) and Bonin et al. (2003b).
[c] From Bonin et al. (2003a).
[d] See Section 2.

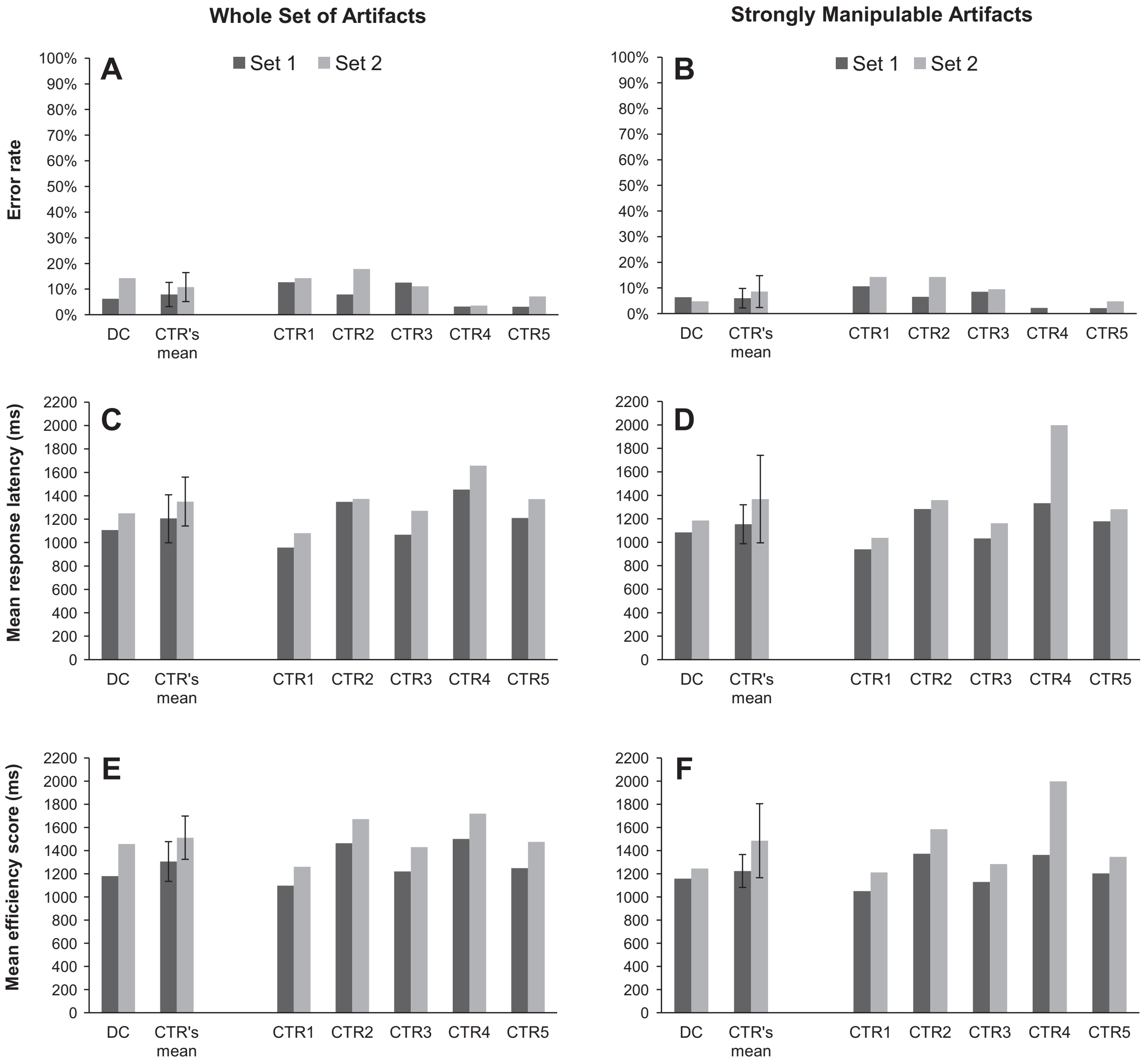

Fig. 1. DC's and control participants' error rate (A and B), mean response latency (C and D), and inverse efficiency score (E and F) in the picture naming task, for manipulable artifacts that were used (Set 1) or never used (Set 2) by DC, when considering the whole set (*left*) or only strongly manipulable (*right*) artifacts. Error bars represent 1 S.D. from the mean.

considered, the analysis disclosed no significant effect of Group [F (1, 80) < 1], Set of items [F (1, 90) < 1], or Group x Set interaction [F (1, 80) < 1]. As for the continuous variables, the analysis yielded a significant effect of age of acquisition [F(1, 80) = 12.10, $p < .001$] and no significant effect of concept familiarity [F (1, 80) < 1]. Importantly, neither age of acquisition [F(1, 80) = 1.16, $p = .29$] nor concept familiarity [F (1, 80) < 1] significantly interacted with Group. The ANCOVA performed with SM artifacts yielded similar results, namely, no significant effect of Group [F (1, 60) = 1.55, $p = .22$], Set of items [F (1, 60) < 1], or Group × Set interaction [F (1, 60) < 1]. The analysis also revealed a significant effect of age of acquisition [F (1, 60) = 5.11, $p < .05$] and no significant effect of concept familiarity [F (1, 60) < 1]. Age of acquisition [F(1, 60) = 1.77, $p = .19$] or concept familiarity [F(1, 60) < 1] did not significantly interact with Group.

These results of by-item analyses confirmed those obtained with RSDT analyses, which are in essence by-subject analyses, by showing that the discrepancy in the naming performance between the artifacts of Sets 1 and 2 was not significantly different in DC and control participants, and this was true also for SM artifacts. To obtain positive evidence that the effect of Set of items was equivalent in DC and control participants, we conducted a Bayesian analysis (Wagenmakers, 2007) to estimate the likelihood of the null hypothesis being true for the Group × Set of items interaction. We applied the method recently described by Masson (2011) to compute the posterior probabilities for H_0 (interaction absent) and H_1 (interaction present) using the sum of squares for the interaction effect from the by-item ANCOVA. For the whole set of artifacts, this analysis indicated that the posterior probabilities were .90 for H_0 (i.e., the null hypothesis has a 90% chance of being true) and .10 for H_1; with SM artifacts, the probabilities were .86 for H_0 and .14 for H_1. According to Raftery's (1995) classification of evidence into «weak» (.50–.75), «positive» (.75–.95), «strong» (.95–.99), and «very strong» (>.99), the probability values obtained for the whole set and for the subset of SM artifacts both provide positive support for H_0 (interaction absent) hypothesis.

It is also worth noting that the results showed no evidence for any naming difficulties in DC compared to control participants whether for artifacts of Set 1 or those of Set 2. Actually, Crawford and Howell's (1998) modified t-test performed with each dependent variable indicated that DC's performance in naming the whole set of manipulable artifacts was not significantly different from controls' performance whether for Set 1 [error rate: t (4) = −0.32, $p = 0.77$; response latency: t (4) = −0.45, $p = 0.67$; efficiency score: t (4) = −0.67, $p = 0.54$] or Set 2 [error rate: t (4) = 0.56, $p = 0.60$; response latency: t (4) = −0.44, $p = 0.68$; efficiency score: t (4) = −0.26, $p = 0.80$]. The same results were found when only SM artifacts were considered [Set 1: error rate: t (4) = 0.09, $p = 0.93$; response latency: t (4) = −0.38, $p = 0.72$; efficiency score: t (4) = −0.42, $p = 0.69$. Set 2: error rate: t (4) = −0.56, $p = 0.60$; response latency: t (4) = −0.44, $p = 0.67$; efficiency score: t (4) = −0.68, $p = 0.53$].

Finally, we sought positive evidence that DC's naming performance, that is, both his naming accuracy and speed, was influenced by variables that also influenced naming accuracy and speed in control participants. With this aim, we performed regression analyses with imageability, concept familiarity, and age of acquisition as predictors of DC' naming accuracy (correct/incorrect) or response latency and, in separate analyses, of control participants' naming accuracy (percentage of correct responses per item) or response latency. The results showed that imageability was the only significant predictor of both DC's accuracy [Model: chi-square = 3.85, $p < .05$; Imageability: Wald = 4.19, $p < .05$, Exp(B) = 2.97] and response latency [Model: F (1, 82) = 17.26, $p < .001$, Adjusted R square = .16; Imageability: Beta = −0.42, $t = -4.16$, $p < .001$] when the whole set of artifacts was considered, and the only significant predictor of DC's accuracy when SM artifacts were considered [Model: chi-square = 3.81, $p = .05$; Imageability: Wald = 4.02, $p < .05$, Exp(B) = 8.36]. The same variable emerged from the regression analyses performed over the data of control participants. Imageability was the only significant predictor of both controls' accuracy [Model: F (1, 90) = 13.15, $p < .001$, Adjusted R square = .12; Imageability: Beta = .36, $t = 3.63$, $p < .001$] and response latency [Model: F (1, 90) = 34.38, $p < .001$, Adjusted R square = .27; Imageability: Beta = −0.53, $t = -5.86$, $p < .001$] when the whole set of artifacts was considered, and the only significant predictor of both controls' accuracy [Model: F (1, 66) = 22.61, $p < .001$, Adjusted R square = .24; Imageability: Beta = .51, $t = 4.75$, $p < .001$] and response latency [Model: F (1, 66) = 19.75, $p < .001$, Adjusted R square = .22; Imageability: Beta = −0.48, $t = -4.44$, $p < .001$] when SM artifacts were considered.[1]

In light of the outcomes of these regression analyses, it appears that the significant effect of age of acquisition found in the ANCOVA analyses, in which imageability was not introduced, was likely due to age of acquisition being correlated with imageability. The important point, however, is that both types of analyses showed that the naming performance of DC and control participants was predicted by the same variables. This finding gives no support to the view that DC's conceptual representations of manipulable artifacts presented some qualitative difference with those of control participants.

4. Discussion

Manipulable artifacts that, in DC, benefited from being associated with motor experience and, thereby, motor knowledge of how using and manipulating them, were not identified more accurately or rapidly than manipulable artifacts that were not associated with motor experience. If motor knowledge indeed enriched the conceptual representation of manipulable artifacts, then their identification should have been facilitated compared to manipulable artifacts whose conceptual representation lacks motor features. Thus, the present findings are at odds with the view that the concepts of manipulable artifacts include motor knowledge of how they are used.

An objection that can be raised against this conclusion is that it is based on a negative result. In this context, it is foremost important to note that Bayesian analyses of the data provided positive support for the hypothesis that DC's performance was not different for the artifacts he already used compared to those he never used. Still, one may ask whether the picture naming task used in this study was appropriate and sensitive enough to disclose a significant effect of the presence of motor features in the conceptual representation of artifacts on DC's naming accuracy or speed. We have reasons to believe that the picture naming task was indeed appropriate for that purpose. First, there is ample evidence that naming a visually-presented object entails retrieving its core and distinctive conceptual features (for recent review, see Taylor, Devereux, Acres, Randall, & Tyler, 2012) and that performance in this task is sensitive to even subtle, real (e.g., Woollams, Cooper-Pye, Hodges, & Patterson, 2008) or temporary virtual (e.g., Pobric, Jefferies, & Lambon Ralph, 2007) damage to conceptual representations. Second,

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[1] As Fig. 1 shows, response latencies of control participants for the SM artifacts included in Set 2 present more variability than other measures, which might have reduced the probability to observe a significant difference between DC and controls in this case. However, this higher variability was only due to a particularly long average response latency of Control 4 for this set of items. This averaged value was itself mostly due to 4 exceptionally slow responses (3912, 4112, 4891, and 4932 ms), which were indeed far outside the range of the control's other responses (all >5 standard deviations from the mean of the set when these items are excluded). None of the statistical analyses presented above yielded different outcomes when performed after excluding these 4 data points or all the data from Control 4.

we found positive evidence that the naming performance of both DC and control participants was significantly affected by the degree of imageability of the items. To our knowledge, the imageability effect is unanimously assumed to reflect conceptual processing. According to Plaut and Shallice (1993), imageability in fact indexes the richness of a conceptual representation, i.e., the number of conceptual features it is composed of. The higher processing efficiency for concepts with richer representations would be due to the system being able to settle faster into a stable pattern of activation when more semantic features are activated. In this view, the imageability effect found in both DC's and control participants' naming performance indicates that the picture naming task was indeed able to disclose an effect of conceptual richness—and hence, a facilitation effect of the presence of motor features in the concepts of manipulable artifacts, if any. That DC's naming accuracy and speed was sensitive to imageability—and not to the presence of motor features—therefore provides positive support to the view that motor features are *not* constitutive of the concepts of manipulable artifacts.

This finding corroborates the conclusion previously drawn from the pattern of performance of brain-damaged patients who were able to name artifacts for which they were unable to demonstrate the use (e.g., Negri et al., 2007; Rapcsak et al., 1995; Rumiati et al., 2001). However, in these studies, the amount of patients' residual motor knowledge about the artifacts they were able to name was unknown and only naming accuracy, not speed, was measured. The empirical approach taken in this study allowed us to show further that having no motor knowledge *at all* for manipulable artifacts does not yield any detectable processing disadvantage in comparison with manipulable artifacts associated with motor knowledge. This finding thus constitutes stronger support for theories of artifact concept representation that posit two distinct representational levels for conceptual and motor knowledge, the first being involved in categorization and identification of artifacts and the latter in planning their actual use (e.g., Humphreys et al., 1988; Rothi et al., 1991).

This conclusion is in line with evidence obtained in studies using a variety of paradigms with healthy participants. For instance, Bub and colleagues (Bub, Masson, & Bukach, 2003) asked participants to learn associations between colors and gestures (i.e., pinch, poke, closed grasp, and open grasp). The participants were then presented with colored photographs of artifacts and asked to produce the gesture previously associated with the color in which the artifact is displayed (Experiment 2) or to name the artifact (Experiment 3). The color in which each artifact was displayed corresponded to gestures that were either congruent or incongruent with the gesture naturally associated with the artifact. A strong congruency effect was found in response latency when the task of the participants was to produce the gesture associated with the color but not when their task was to name the artifact. This suggests that motor knowledge of how an artifact is manipulated is indeed activated upon the visual presentation of the artifact but this activation has no detectable impact on object naming. In a recent rTMS study (Pelgrims, Olivier, & Andres, 2011), it was found that virtual lesions of the anterior part of the left supramarginalis gyrus interfere with the performance of participants in a task in which they had to decide whether two objects are used by adopting the same hand posture, but not with their performance in determining whether two objects are normally used in the same context or have a similar function. Thus, interfering with the functioning of a brain region critically involved in processing motor knowledge associated with artifacts did not hamper conceptual processing of those artifacts.

Moreover, it is important to note that this conclusion does not conflict with previous evidence showing that motor representations are automatically activated when participants simply observe manipulable artifacts or listen to their name. Evidence for such motor activation is compelling; it was consistently found in both functional neuroimaging (for review, see Martin, 2007) and behavioral studies (e.g., Bub et al., 2008). For instance, Chao and Martin (2000) found that viewing or naming pictures of tools selectively activated the left posterior parietal and left ventral premotor cortices, two regions that are assumed to store information about hand movements associated with the use of manipulable artifacts. Findings from behavioral studies confirmed that motor activation is related to the retrieval of motor knowledge of how an artifact is used. Bub and colleagues (Bub et al., 2008), for instance, found that, upon the visual presentation of the picture of a manipulable artifact or of its name, the response latencies for performing a given gesture were longer when the gesture was not compatible with the gesture typically associated with the artifact. This result indicated that artifacts or names of artifacts automatically evoke motor knowledge of how they are used (see also Bub & Masson, 2012). Within a theory of artifact concepts that ascribes conceptual and motor knowledge to two distinct representational levels (e.g., Humphreys et al., 1988; Rothi et al., 1991), automatic motor activation is viewed as the consequence of activation spreading and cascading from the pre-conceptual (object or word recognition processes) to the conceptual and then to the motor level of representation. Because of the cascading flow of information between the conceptual and motor levels, motor representations are activated while conceptual processing is not completed.[2] In that way, even if information derived from the motor level of representation is not relevant for the task in hand, it is nevertheless available and can affect, under some circumstances or experimental manipulations, the accuracy or speed of the participants' responses in that task.

Given these assumptions, the results of an eye-tracking experiment (Myung et al., 2006; Experiment 2), which were presented as compelling evidence that motor knowledge is part of the concept of an artifact, are in fact consistent with an alternative explanation. In this experiment, participants were presented with an array of four object pictures and asked to point to the one matching a simultaneously presented spoken word. When the object picture shared manipulation features with the target word (i.e., the picture of a typewriter and the word "piano"), it was fixated more often by participants than unrelated or visually-matched object pictures. Within a theory positing two distinct representational levels for conceptual and motor knowledge, this effect would result from both conceptual and motor features being automatically activated from the target word and the object picture while participants perform the word-to-picture matching task. Thus, during the matching process, both kinds of information are available, which caused interference (i.e., more eye fixations) for rejecting the object sharing motor features with the named object.

In this study, the contrast that was critical to test the hypothesis that the conceptual representation of a manipulable artifact includes motor knowledge was the intra-individual contrast, in DC, between the performance in identifying artifacts that were associated to motor experience and those that were not. This contrast revealed that the identification of artifacts associated to motor experience was not facilitated compared to those that were not, which is consistent with the view that motor knowledge is not part of an artifact concept. A somewhat distinct finding of this study, namely, that DC was as efficient as normally-limbed participants in identifying *both kinds* of manipulable artifacts, also provides some insight into how congenitally altered sensorimotor

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[2] In dual route models of object identification (e.g., Rumiati & Humphreys, 1998), motor features associated with a manipulable artifact are, in addition, directly activated from the structural properties of the visually-presented artifact. This direct source of activation may also produce activation of motor features before conceptual processing is completed.

experience impacts on conceptual development. Indeed, this finding suggests that motor experience does not make an essential contribution to the acquisition of concepts of manipulable artifacts. Thus, although DC was deprived of upper-limb motor interactions with artifacts from birth, which prevented him to manipulate familiar objects or led him to engage in idiosyncratic body-object interactions to use them (i.e., with his feet, mouth, or shoulders), the conceptual representations he acquired are seemingly as rich and/or as efficient as those acquired by normally-limbed individuals. DC's atypical development and interactions with his environment certainly had an impact on brain organization. Previous neuroimaging studies with bilateral upper-limb aplasic individuals who, like DC, have acquired fine foot motor skills early in life to compensate the lack of hand function, have shown not only functional reorganization but also structural changes in the motor and somatosensory cortices. For instance, functional magnetic resonance imaging and transcranial magnetic stimulation of primary motor cortex revealed that, in these individuals, the foot was represented in the normal "foot area" of the primary motor cortex but also in an additional, nonadjacent area in the vicinity of the normal "hand area" (Stoeckel, Seitz, & Buetefisch, 2009). Likewise, when compared to controls, individuals with compensatory foot use showed better stimulus localization on the toes and enhanced representation of the foot in the medial somatosensory cortex (Stoeckel, Pollok, Schnitzler, Witte, & Seitz, 2004). Moreover, increased grey matter values were found in medial motor areas in individuals with skilful foot use when compared to controls (Stoeckel, Morgenroth, Buetefisch, & Seitz, 2012). Although this has not been investigated so far, the brain networks subserving visual-motor integration should also be subjected to changes compared to controls. Even so, DC has acquired concepts for a category of objects that are supposed to be learned partly if not mainly through visual-motor interactions, i.e., manipulable objects, and these concepts proved to be as rich and efficient as those acquired by normally-developed individuals, when tested in a timed identification task. This study thus confirms the relative autonomy of conceptual development vis-à-vis idiosyncratic sensory-motor experiences, as already evidenced by studies having investigated object and action concepts in congenitally blind individuals (for review, see Bedny & Saxe, 2012).

It remains an open question, though, as to what extent the content of artifact concepts and their neural representation differ according to the nature of motor experience. Future studies are needed to elucidate this question with the help of neuroimaging methods, among others. Indeed, even if the absence or peculiarity of motor experience does not prevent the acquisition of rich and efficient concepts of manipulable artifacts, their content may not be identical to those acquired in normal conditions (see, for discussion, Bedny, Caramazza, Pascual-Leone, & Saxe, 2012; Bedny & Saxe, 2012). Based on recent advances in developmental research, we predict no differences in the content and neural representation of artifact concepts in case of atypical motor development. Indeed, we hypothesize that the acquisition of artifact concepts and, thereby, their content is structured around a quite abstract property of artifacts, namely, their function or purpose (e.g., Kemler Nelson, Russell, Duke, & Jones, 2000) or even their *intended* function, i.e., not the current function but what the artifact was designed for (e.g., Asher & Kemler Nelson, 2008). For instance, it has been shown that infants, as young as 11–12 months of age, use functional information conveyed by a short demonstration with a given set of objects as a cue to later categorize a different set of objects (Träuble & Pauen, 2007). Moreover, the function of objects overrides object similarity in terms of shape or salient perceptual features (e.g., Diesendruck, Markson, & Bloom, 2003) or in terms of how they are manipulated (Zinchenko & Snedeker, 2011) when preschool children (or adults) categorize or name novel artifacts (see for review, Hernik & Csibra, 2009). Under the assumption that artifact function may be inferred from observation of others' goal-directed actions and demonstrations, or learned from others by verbal communication (Csibra & Gergely, 2009), atypical motor development should have little impact, if any, on the acquisition and content of artifact concepts.

In conclusion, this study adds new evidence to the view that motor knowledge is not part and parcel of the concepts of manipulable artifacts. This view does not preclude automatic activation of motor knowledge when manipulable artifacts are identified. However, it urges greater effort in developing and testing fresh hypotheses on why motor knowledge of artifacts is automatically activated if it is not for the purpose of identification.

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Appendix A

See Table A1.

Table A1
List of the manipulable artifacts in Set 1 (already used by DC) and Set 2 (never used by DC). The subset of strongly manipulable artifacts are marked with "*".

Modal name in French	Modal name in English	Modal name in French	Modal name in English
Set 1			
**Agrafeuse*	*Stapler	**Ciseaux*	*Scissors
**Aiguille*	*Needle	**Clavier*	*Keyboard
**Allumette*	*Match	**Clef*	*Key
**Ampoule*	*Bulb	**Cloche*	*Bell
**Appareil photo*	*Camera	**Clou*	*Nail
**Aspirateur*	*Vacuum	⁎*Compas*	*Compass
**Bague*	*Ring	**Couteau*	*Knife
**Balai*	*Broom	**Crayon*	*Pencil
**Barre*	*Tiller	**Cuillère*	*Spoon
**Briquet*	*Lighter	**Enveloppe*	*Envelope

Table A1 (*continued*)

Modal name in French	Modal name in English	Modal name in French	Modal name in English
*_Brosse_	*Brush	*_Eventail_	*Fan
*_Brosse à dent_	*Toothbrush	*_Gomme_	*Gum
*_Calculatrice_	*Calculator	*_Jumelles_	*Binoculars
*_Chronomètre_	*Stopwatch	*_Cigarette_	*Cigarette
*_Cigare_	*Cigar	*_Maracas_	*Maracas
*_Loupe_	*Magnifying glass	*_Fermeture éclair_	*Zipper
*_Micro_	*Microphone	_Bouée_	Buoy
*_Peigne_	*Comb	_Prise_	Plug
*_Pipe_	*Pipe	_Pince à linge_	Clothespin
*_Poêle_	*Frying pan	_Canif_	Penknife
*_Râteau_	*Rake	_Clé anglaise_	Wrench
*_Règle_	*Ruler	_Bougie_	Candle
*_Salière_	*Salt shaker	_Ecrou_	Screw nut
*_Sifflet_	*Whistle	_Grille-pain_	Toaster
*_Stylo_	*Pen	_Interrupteur_	Switch
*_Tampon_	*Stamp	_Spatule_	Spatula
*_Téléphone_	*Telephone	_Magnétophone_	Tape recorder
*_Tétine_	*Nipple	_Trombone_	Trombone
*_Toupie_	*Top	_Equerre_	Set square
*_Tournevis_	*Screwdriver	_Cocotte_	Casserole
*_Yoyo_	*Yoyo	_Verrou_	Lock
*_Volant_	*Steering wheel	_Bouton_	Button
Set 2			
*_Boomerang_	*Boomerang	*_Guitare_	*Guitar
*_Carabine_	*Rifle	*_Hache_	*Ax
*_Cerf-volant_	*Kite	*_Haltères_	*Dumbbell
*_Epée_	*Sword	*_Klaxon_	*Horn
*_Fer à repasser_	*Iron	*_Lime à ongle_	*Nail file
*_Flèche_	*Arrow	*_Marteau_	*Hammer
*_Rouleau à pâtisserie_	*Rolling pin	*_Raquette de tennis_	*Tennis racquet
*_Piano_	*Piano	_Punaise_	Thumbtack
*_Poignée_	*Handle	_Ciseau à bois_	Chisel
*_Perceuse_	*Drill	_Binette_	Hoe
*_Scie_	*Saw	_Pince_	Clamp
*_Revolver_	*Revolver	_Cadenas_	Padlock
*_Fouet_	*Whip	_Truelle_	Trowel
*_Raquette de ping-pong_	*Ping-pong racket	_Cor_	Horn

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