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Features of Planned Hand Actions Influence Identification of Graspable Objects

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Abstract

We demonstrate that constituents of motor actions associated with handled objects play a role in identifying such objects. Subjects held in working memory action plans for reaching movements; these action plans specified both the hand to be used (left or right) and a wrist orientation (vertical or horizontal). Speeded object identification was impaired when a pictured object matched the action on only one of these two categorical dimensions (e.g., a beer mug with its handle facing left, an action plan involving the right hand and vertical wrist orientation), relative to when the object matched the action on both dimensions or neither dimension. This result implies that identification of a manipulable object leads to automatic retrieval of matching features of a planned action along with nonmatching features to which they are bound. These discrepant features conflict with those of the target object, which results in delayed identification.

Keywords

action representations, object identification, theory of event coding, motor processes

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Tasks that require attention to handled objects automatically evoke a representation of action in the motor cortex. Functional imaging studies have demonstrated that motor cortical regions are activated when subjects view graspable objects (e.g., Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Martin, Wiggs, Ungerleider, & Haxby, 1996). Behavioral evidence also indicates that visual attention to a handled tool can elicit a mental representation of the action afforded by the handle (for a review, see Sumner & Husain, 2008). According to one view, activation of the motor system is merely an automatic by-product of perception (Mahon & Caramazza, 2008). Recently, however, intriguing evidence has suggested that actions associated with the function of objects form an integral part of their meaning. Thus, the mental representation of an action associated with a manipulable object should play a causal role in identification of that object. For example, Campanella and Shallice (2011) have shown that in a speeded picture-word matching task, it is harder to distinguish between a pair of objects requiring similar hand actions than between a pair of objects sharing only visual similarity. These authors inferred that knowledge of how an object is manipulated is encoded as part of the object's conceptual representation (also see Helbig, Graf, & Kiefer, 2006; Kiefer, Sim, Liebich, Hauk, & Tanaka, 2007).

In this article, we present striking evidence that sheds light on the nature of the motor representations implicated in the identification of everyday objects like beer mugs and frying pans. Handled objects, under certain task conditions, will automatically trigger a representation of both the hand and the grasp posture induced by the spatial location and orientation of the handle (Bub & Masson, 2010). The results of the experiment we report show that these components of an action are not merely elicited as a consequence of attending to the object but play a causal role in semantically driven perceptual tasks.

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Our methodology draws on the influential observation that a prepared action interferes with the perception of an object when the action and object share features (Hommel, 2009; Hommel, Müsseler, Aschersleben, & Prinz, 2001). A surprising but repeatedly observed result is that performance is impaired only when such feature overlap is partial; complete matching of features across a perceptual and a motor task has no particular impact (Hommel, 2004). The reason behind the cost is as follows. Assume that stimulus A generates an event in working memory that demands the temporary integration of a set of activated motor features (e.g., left hand and vertical grasp). Now consider stimulus B, a perceptual event requiring the integration of visuomotor features, one of which has already been conscripted by A. Feature overlap between competing events is disadvantageous; the presence of a single shared visuomotor feature in B (say, a visual feature associated with a left-handed response) will evoke, by spreading activation, the feature combination (left hand and vertical grasp) assigned to event A in working memory. This reactivated feature combination conflicts with and hence delays integration of the correct combination of target features representing event B. In contrast, no interference should be observed between the two events if they have all or none of their features in common. A recurrence of the same combination of features or a complete mismatch of features does not entail any particular coding or selection problem. Hommel (2005) pointed out that the evidence implies not so much a benefit from the repetition of event files as a cost incurred when there is a partial overlap in their features (for additional theoretical details, see Hommel, Proctor, & Vu, 2004; Stoet & Hommel, 2002).

Consider, then, the effect of preparing an action comprising two motor features (left or right hand and vertical or horizontal wrist orientation) on a task that requires the identification of a handled object. If these motor features are indeed recruited by the visual object as part of its semantic representation, one should see the distinctive pattern of interference effects generated when the integrated constituents of two events hold a feature in common. Interference between the action and the target object should occur if they share one or the other (but not both) of the two features. For example, a left-handed action requiring a horizontal wrist posture should specifically interfere with the speeded naming of an object like a beer mug (which demands a vertical posture) when the handle also faces left and with an object like a frying pan (which demands a horizontal posture) if the handle faces right. The same action should not affect the naming of objects that share both of these motor features (e.g., a frying pan with the handle on the left) or neither of them. We present clear evidence confirming this prediction. Our experimental results establish that motor features like grasp orientation and choice of hand are included in the procedures that map the visual form of a handled object onto a semantic representation.

Method

Subjects

Twenty students at the University of Victoria participated in the experiment in return for extra credit in an undergraduate psychology course. Three subjects were left-handed, but this was not a factor in the design of the experiment.

Materials

Ninety-six digital photographs of handled objects were selected for use as critical stimuli. There were three different instances of each of 32 object types (e.g., 3 different teapots, 3 different flashlights; see Table 1). Half of the objects were positioned so that the handle was oriented vertically (e.g., beer mug) and invited a vertical grasp, and half were positioned so that the handle was oriented horizontally (e.g., frying pan) and invited a horizontal grasp. Two versions of each photograph were generated, one with the handle facing to the right and one with the handle facing to the left. Five hand postures (e.g., power grasp, flat palm, precision grip) were selected and digitally photographed, both with the palm oriented vertically and with the palm oriented horizontally. Each of these 10 photographs was then rendered in a left-hand and a right-hand version.

Table 1. Names of the Objects Used in the Experiment

Horizontally oriented handle	Vertically oriented handle
can opener	beer mug
chisel	blow dryer
flashlight	coffee mug
frying pan	coffeepot
garden shears	drill
iron	garden sprayer
kettle	hairbrush
knife	hammer
pliers	handsaw
saucepan	joystick
screwdriver	measuring cup
scrub brush	megaphone
spatula	pitcher
strainer	teapot
vacuum	water gun
wrench	watering can

Design

Five pairs of hand postures were formed, with two different postures in each pair and each posture included in two different pairs. Each of these pairs was rendered in four different versions defined by the factorial combination of orientation (vertical or horizontal) and side of the body (left or right); that is, within each version, both hands had the same orientation and the same side of the body. In combination, the hand posture, orientation, and side of the body specified a particular hand action that a subject could perform.

Each of the 96 objects was shown to subjects once in each of two blocks, for a total of two presentations, in an object-naming task. The alignment of a given object (handle facing left or right) varied across the two blocks. Each presentation of an object was coupled with a pair of hand actions (which matched one another on alignment and orientation) that was held in working memory. This coupling resulted in one of four possible relationships between the object and the actions, defined by their congruency or incongruency with respect to orientation and alignment. Examples of object-action couplings corresponding to these four relationships are shown in Figure 1a. Assignment of a given object to a combination of orientation and alignment congruency of the hand actions was counterbalanced across subjects. The posture feature of the hand actions was pseudorandomized across items with the constraint that each posture was used about equally often in each of the four congruency combinations. Each subject received 12 trials with each of the 16 possible combinations of object features (vertical or horizontal orientation, left- or right-facing handle) and hand-action features (congruent or incongruent with respect to the object's orientation and handle). Assignment of objects to these 16 conditions was counterbalanced across subjects.

Procedure

Subjects were tested individually using an Apple Mac Pro desktop computer. They were first trained to pantomime each of the five hand postures using either hand and using both a vertical and a horizontal orientation of the

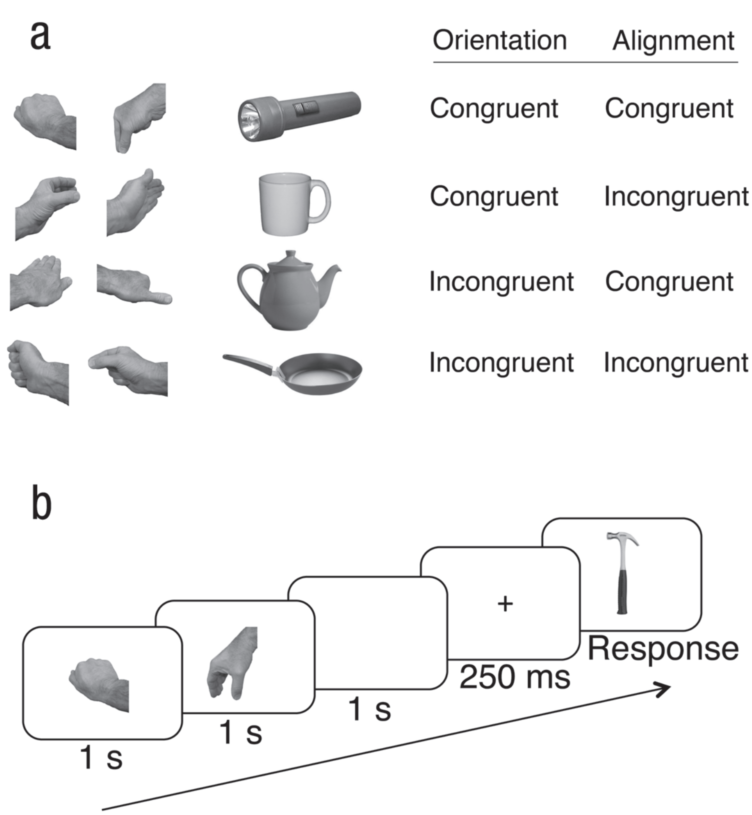

Fig. 1. Examples of hand-action pairs and objects used in the experiment (a) and illustration of the stimulus sequence on each trial (b; the target object was displayed until a response was made). On each trial, the orientation (vertical or horizontal) of the object's handle could be either congruent or incongruent with the orientation of the wrist, and the alignment (left or right) of the object's handle could be either congruent or incongruent with the hand's side of the body, respectively.

palm. Performance of a particular action was cued by presentation of a picture of a hand posture (like the hand images shown in Fig. 1b), which the subject then mimicked. Each action (combination of posture, orientation, and hand) was performed twice, for a total of 40 trials. Subjects were then familiarized with the set of 96 object photographs. Each photograph was presented with the name of the pictured object appearing below it, and the subject read the name aloud.

Next, two blocks of 96 critical object-naming trials were presented. At the beginning of each trial, a pair of pictured hand postures was presented sequentially. Each picture was shown for 1 s. After a delay of 1 s, a fixation cross appeared for 250 ms and was then replaced by the photograph of a target object, which remained in view until the subject made a naming response by speaking into a microphone mounted as part of a headset. This sequence of events is illustrated in Figure 1b. Subjects were instructed to respond as quickly and accurately as possible. The experimenter, viewing a separate monitor that indicated the object's name, recorded the accuracy of the response by a key press. At the end of 25% of the trials, selected at random, subjects were instructed to produce the two hand actions presented at the start of the trial, which they did by pantomiming the actions, attempting to generate the correct hand shape and wrist orientation using the correct hand. This requirement ensured that subjects attempted to hold the hand actions in working memory while performing the object-naming task. We had subjects maintain the representation of two actions, rather than one, to maximize the possibility that the memory load would influence object-naming performance. Breaks were provided after every 32 trials.

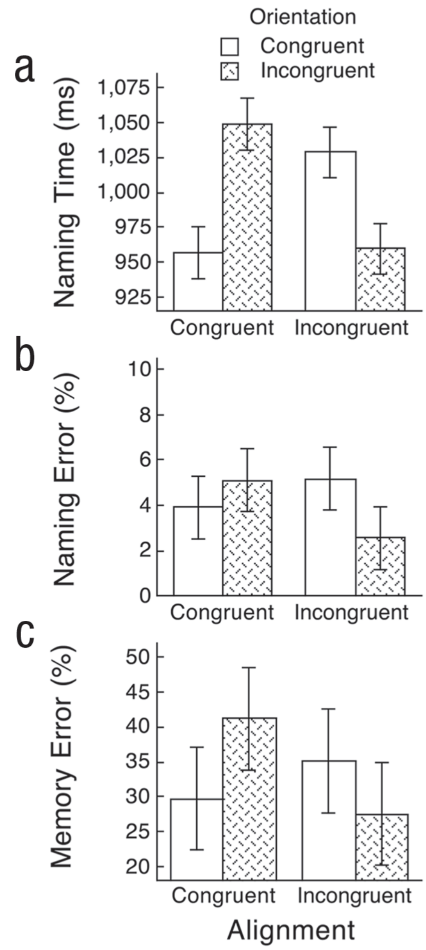

Fig. 2. Mean naming time (a) and percentage error (b) in the object-naming task and mean percentage error in report of the hand postures held in working memory (c) as a function of the presented hand actions' congruency/incongruency with the object's orientation and alignment. Error bars are 95% within-subject confidence intervals (Loftus & Masson, 1994).

Results

Response times in the object-naming task were considered outliers if they exceeded 2,400 ms. This cutoff was established so that fewer than 0.5% of correct responses would be excluded (Ulrich & Miller, 1994). For each subject, the mean response time for correct responses in each of 16 conditions was computed. These conditions were defined by the factorial combination of object orientation, object alignment, and congruency/incongruency of the hand-action orientation and alignment relative to the object (2 × 2 × 2 × 2). A repeated measures analysis of variance (ANOVA) applied to these data yielded two significant effects ($F < 1.8$ for all other effects). First, there was an interaction between congruency of orientation and congruency of alignment, $F(1, 19) = 84.49$, $MSE = 6,157$, $p < .0001$, $\eta_p^2 = .82$. The pattern of this interaction is shown in Figure 2a. The interaction produced a crossover pattern in which faster naming occurred when the hand postures were either congruent with the object on both orientation and alignment or incongruent with the object on both of these dimensions. Naming was slower when the hand postures were congruent with the object on only one dimension. This crossover pattern explains why none of the main effects were significant.

Second, there was a three-way interaction of orientation congruency, alignment congruency, and object orientation, $F(1, 19) = 15.91$, $MSE = 8,671$, $p < .001$, $\eta_p^2 = .46$. The pattern shown in Figure 2 held more strongly for vertically oriented objects (e.g., beer mug, teapot) than for horizontally oriented objects (e.g., frying pan, flashlight; see Fig. 3). However, the pattern was not qualitatively different between these two object sets, and the interaction effect was significant when tested separately for vertical objects, $F(1, 19) = 97.61$, $MSE = 6,117$, $p < .0001$, $\eta_p^2 = .84$, and horizontal objects, $F(1, 19) = 7.02$,

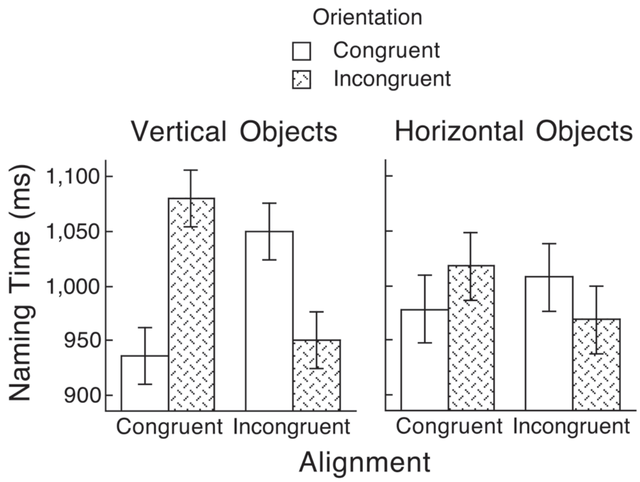

Fig. 3. Mean naming time as a function of the presented hand actions' congruency/incongruency with the object's orientation and alignment, separately for vertically and horizontally oriented objects. Error bars are 95% within-subject confidence intervals (Loftus & Masson, 1994).

MSE = 8,712, $p < .02$, $\eta_p^2 = .27$. The robustness of the Object Orientation × Alignment Congruency interaction was assessed separately for each of the two blocks of trials, and separately for trials on which one of the hand postures held in working memory involved a closed power grasp (there were two such postures in the set of five, although one had a protruding thumb, as shown in Fig. 1a) and trials on which neither posture was a grasp of that type. In all cases, the interaction was highly reliable (*p*s < .001).

The average error rate on the object-naming task was 4.2%. Errors included false starts and inability to name an object. An ANOVA indicated that the interaction of orientation congruency and alignment congruency had a significant effect on the error rate, $F(1, 19) = 8.03$, *MSE* = 35.4, $p < .02$, $\eta_p^2 = .30$. This interaction is illustrated in Figure 2b, which shows the same pattern as found in the naming-time data.

Production of the hand actions at the end of randomly chosen trials was scored as either correct or incorrect. To be correct, the subject had to duplicate both hand actions with the correct hand, hand shape, and orientation, but the order in which the two actions were generated was not considered. Small variations in hand shape were not counted as errors. Because memory for the hand actions was probed on only 25% of the trials, the accuracy data were very sparse across the 16 conditions. Therefore, we collapsed the conditions into the four that fit the two-way interaction found in the object-naming data: congruent alignment and congruent orientation, congruent alignment and incongruent orientation, incongruent alignment and congruent orientation, and incongruent alignment and incongruent orientation. The mean percentage error in these four conditions is shown in Figure 2c. The relatively high error rate (33.4% overall) may seem surprising, but it should be remembered that only five hand shapes (each appearing in four versions) were used in different pairings over the course of nearly 200 trials, which created substantial proactive interference (Wickens, Born, & Allen, 1963). Once again, the crossover interaction pattern is apparent, as with the object-naming measures. An ANOVA found this interaction to be significant, $F(1, 19) = 7.24$, *MSE* = 249.49, $p < .02$, $\eta_p^2 = .28$.

Discussion

Conventional use of a handled object requires the choice of the left or right hand, depending on the position of the object's handle, and a vertical or horizontal closed grasp, depending on the handle's orientation. We examined the claim that these motor constituents, evoked automatically when handled objects are attended (Bub & Masson, 2010), also play a role in their perceptual identification. Our results establish that when people name images of handled objects, a striking pattern of interference occurs if planned actions are concurrently held in working memory. Naming was slowed when a single motor feature was shared between the actions in working memory (left- or right-handed, vertical or horizontal grasp orientation) and the grasp associated with the target object. Latencies were faster and equivalent when the planned action and perceived object shared both or neither of these features. The effects of orientation and alignment were not restricted to planned actions resembling the closed power grasp afforded by handled objects. Though one or two of the five postures serving as tokens for the planned actions resembled this grasp, these postures had no special impact on naming performance. The influence of planned actions depended on the overlap between generic constituents of the planned actions (the orientation of the wrist and the choice of hand) and the corresponding features of grasp afforded by the target object.

Remarkably, the object-naming and motor tasks showed reciprocal interference with exactly the same characteristic pattern of effects. Not only did the planning of actions disrupt the ability to name handled objects, but in addition, retrieval of the actions themselves was compromised by feature overlap with the target objects. Actions were reproduced less accurately after the naming response when they required either the same hand or the same wrist orientation as the grasp associated with the object. Performance was better if the handled object and the planned actions shared both or neither of these features.

The evidence we have obtained goes well beyond previous demonstrations that a concurrent motor task can affect the identification of graspable objects (for a critique of this evidence, see the Supplemental Material available online). Witt, Kemmerer, Linkenauger, and Culham (2010) found that squeezing a rubber ball interfered with naming a tool when the tool's handle was aligned rather than misaligned with the hand squeezing the ball. No analogous effect of alignment occurred when participants named animals. Witt et al. speculated that motor simulation plays a role in the identification of tools, but made no claims about the nature of the relationship between actions and the semantic representation of objects. Clearly, naming was affected by the spatial alignment between the handles of the objects and the hand engaged in the motor task. Beyond this fact, however, it is not clear which components of the hand action interfered with perception, nor indeed whether the task of repeatedly clenching the left or right hand was responsible for the interference, or whether sensory feedback from the action drew attention to one or the other side of the body.

We emphasize the novel and counterintuitive nature of our findings. Planning left-handed actions that require a vertical palm orientation, for example, interferes with naming an object like a beer mug or a teapot when the handle is aligned with the right (but not the left) hand, and interferes with naming an object like a frying pan or flashlight when the handle is aligned with the left (but not the right) hand. Similarly, recalling the form of an intended left-handed action with a vertical palm is more difficult if a perceived object affords a grasp with the right hand and a vertical wrist posture or a grasp with the left hand and a horizontal posture. The reciprocity of interference effects between actions in working memory and the speeded naming of handled objects is additional evidence supporting the assumption that performing these working memory and naming tasks involves at least some access to common representational codes. Furthermore, we have obtained strong evidence that motor features like wrist orientation and choice of hand are recruited during the identification of manipulable objects.

It may seem puzzling, as Stoet and Hommel (2002) have observed, that feature overlap between an action and target object has a definite interfering effect, given that other research indicates positive compatibility effects when two stimuli share features (for a review, see Hommel & Prinz, 1997). As Stoet and Hommel pointed out, however, allowing subjects enough time to plan and memorize an action sequence that is not carried out until completion of a perceptual task temporally separates the critical underlying processes. The features of the action are fully integrated before the visual object is presented, and competition takes place because the object shares a feature with the action. A shorter interval between the action and object may not allow enough time for planning to be completed before perceptual processing. In that situation, feature overlap will produce positive priming effects (Stoet & Hommel, 2002). The individual features of the action plan are activated (though not yet integrated) and facilitate the processing of an object that enlists the same constituents.

There is more, however, to the issue of cost versus benefit associated with sharing of features between motor and perceptual events. Thomaschke, Hopkins, and Miall (2012) noted that there are many reports of either a gain or a loss in perceptual sensitivity following the preparation of an action (e.g., Deubel, Schneider, & Paprotta, 1998; Hommel & Schneider, 2002), and that these opposing effects can occur on roughly the same time scale. They made the interesting claim that two different mechanisms are responsible for visuomotor priming. One mechanism is the binding of categorical features into a stable representation when an action is planned. The other is a shift in attention to the metric dimensions of representational space for movement control. Performance on a perceptual task involving categorical features that partially overlap with the features bound to an active motor plan will show impairment relative to performance on a task in which there is no overlap, whereas performance on a perceptual task that requires the analysis of metric information will show facilitation whenever features of the motor task prime matching features of the object to be identified.

The fact that an action plan has a negative rather than a positive impact on naming performance offers an additional clue about the nature of the motor representations that contribute to the identification of handled objects. If the argument by Thomaschke et al. (2012) is correct, then the visuomotor features recruited for naming are indeed categorical, as we have assumed in defining their relationship to the constituents of a planned action (i.e., left or right side, vertical or horizontal grasp orientation). Other high-level tasks that involve the perception of manipulable objects might well require the processing of metric information. For example, if subjects were asked to imagine the details of the grasp action afforded by an object in an unusual orientation, performance might show a benefit rather than a cost from an active motor plan. Our results suggest, though, that the metric properties of an object are not attended when the task simply requires the naming of canonically viewed objects. If the naming task had required attention to the metric properties of the target objects, we would have observed an advantage when features partially or even fully overlapped relative to the condition in which no features overlapped.

The striking pattern of reciprocal interference effects we have documented is fully consistent with the view that a common representational format underlies the processing of perceived objects and intended actions. The most influential theory consistent with this viewpoint, the theory of event coding (Hommel et al., 2001), is intended as a framework for understanding the functional relationship between higher-level stages of perception and action planning. It is important to note that this framework provides a set of metatheoretical principles covering a wide range of potential interactions between motor and perceptual processes, and does not in itself constitute a detailed theoretical account of the relationship between the motor features of handled objects and their perceptual identity. In contrast to this general framework, some recent theories of semantic memory (e.g., Kiefer & Pulvermüller, 2012) assume that motor actions associated with manipulable objects are an essential part of their conceptual representation, so that this class of objects is particularly susceptible to the influences of actions held in working memory.

It is indeed of great interest that the task of simply naming a manipulable object demands what appears to be an obligatory retrieval of both the hand and the wrist orientation afforded by the position of the object's handle. Yet neither of these constituents of a grasp action is diagnostic of an object's identity; a right-handed grasp with a vertically oriented wrist, for example, is afforded by a great variety of different tools. Why, then, should the details of an action afforded by the handle of an object have such a potent effect on identification? What is unique about a vertical or horizontal grasp applied to a particular handled object is the outcome of the action, which in turn depends on the object's proper function. Wierzbicka's (1984) definition of "mug," for example, includes the fact that "[mugs] are rounded and open at the top so that one can drink easily from them by tipping the top part slightly towards the mouth without any of the liquid going outside" (p. 225).

Recent theory views object function as a property that emerges through context-specific interactions between multiple features of an object and the observer (e.g., Barsalou, Sloman, & Chaigneau, 2005). Learning about an object's functional properties requires an understanding of the relationship between specific actions afforded by that object and their outcomes (Perone, Madole, & Oakes, 2011). We contend that for any visual instance of a given object, action-outcome pairings provide a direct route to functional knowledge. Thus, although we remain neutral on the question of whether sensorimotor information is a necessary part of semantic representation in general (for a recent judicious review of this contentious issue, see Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012), our results suggest that the grasp action applied to the handle of an object is an automatically evoked component of its perceptual identity.

Author Contributions

D. N. Bub and M. E. J. Masson contributed equally to the study concept. All authors contributed to the study design. Testing and data collection were performed by T. Lin under the supervision of D. N. Bub and M. E. J. Masson. Parts of the manuscript were drafted by T. Lin, and other parts were drafted by D. N. Bub and M. E. J. Masson, who also provided critical revisions. All the authors approved the final version of the manuscript for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

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