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 with the left or right hand requiring either a horizontal or vertical wrist orientation. When a pictured object matched only one of these two categorical dimensions (e.g., beer mug with its handle facing left, action plan involving the right hand and vertical wrist orientation), speeded object identification was impaired relative to when the planned action and the target object matched on both or neither dimension. This result leads to the surprising conclusion that features of a planned action integrated in working memory are made available in an all or none manner when identifying a manipulable object. Partial overlap between features of the planned action and those associated with the object requires time consuming resolution of the conflict generated by the non-overlapping feature.

Keywords

action representations, object identification, theory of event coding

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 tool or utensil 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 suggests that actions associated with the function of objects form an integral part of their meaning. As such, the mental representation of an action should play a causal role in identifying a manipulable 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 an object pair sharing only visual similarity. These authors infer 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). We will 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.

Our methodology draws on the influential observation that a prepared action interferes with the perception of an object when features are shared between action and object (Hommel, Müsseler, Aschersleben, & Prinz, 2001). A surprising but repeatedly observed result is that performance is impaired only when such feature overlap is partial; the complete matching of features across two tasks has no particular impact (Hommel 2004). The reason behind the cost is as follows. Assume stimulus A generates an event in working memory that demands the temporary

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integration of a set of activated motor features (e.g. left hand/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 visuomotor feature in B (say, a visual feature associated with a left handed response) will evoke by spreading activation the feature combination (left hand/vertical grasp) assigned to event A in working memory. This re-activated feature combination now conflicts with and hence delays integration of the correct combination of target features representing event B. 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 between two events does not entail any particular coding or selection problem. Hommel (2005) points out that the evidence implies not so much a benefit in 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/right hand; vertical/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, we 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 their 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 (demanding a vertical posture) when the handle also faces left, and with an object like a frying pan (demanding a horizontal posture) if the handle faces right. The same action should not affect the naming of objects that share both (e.g., a frying pan with the handle on the left) or neither of these motor features. We present clear evidence confirming this prediction. The 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.

Table 1. Names of Objects Used in the Experiment

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

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 half so that the handle was oriented horizontally (e.g., frying pan). Two versions of each photograph were generated, one with the handle facing to the right and one with the handle facing to the left. A set of 5 hand postures (e.g., power grasp, flat palm, precision grip) was selected and digitally photographed with the palm oriented vertically or horizontally. Each of these 10 photographs was then rendered in a left-hand and a right-hand version.

Design

Five pairs of hand postures were formed with two different postures in each pair and each posture included in two different pairs. Within a pair, both hands had the same orientation (vertical or horizontal) and the same side of body (left or right). Each of these pairs was rendered in four different versions defined by the factorial combination of orientation and side of body. In combination, the hand posture, orientation, and side of 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 the object (handle facing right or left) varied across the two blocks. Each presentation of an object was coupled with a pair of hand actions that was held in working memory. Assignment of particular objects to an orientation and alignment combination of hand actions in each block was counterbalanced across subjects. The posture feature of the hand actions was pseudo-randomized across items with the constraint that each posture was used about equally often in each condition

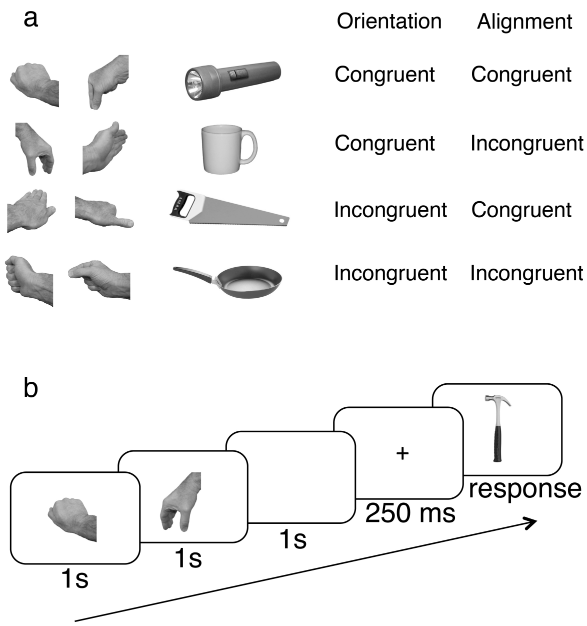

Fig. 1. (a) Examples of hand action pairs and objects used in each condition representing congruent or incongruent wrist orientation (horizontal, vertical) and handle alignment (left, right) and (b) an example of the stimulus sequence on each trial (the target object was displayed until a response).

of the experiment. The coupling of an object with a pair of hand actions resulted in one of four possible relationships between the object and hand actions, defined by the congruency or incongruency between these stimuli with respect to orientation and alignment. Examples of object/hand couplings corresponding to the four conditions are shown in Figure 1a. For each subject, 12 trials were experienced with each of the 16 possible combinations of object features (vertical or horizontal orientation, right- or left-facing handle) and hand pair (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 a Apple Mac Pro desktop computer. They were first trained to pantomime each of the 5 hand postures using either hand and using both a vertical and a horizontal orientation of the palm. Performance of a particular action was cued by presentation of a picture of a hand posture (as in Figure 1b) which the subject then mimicked. Each action was performed twice for a total of 40 trials. Next, subjects were 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.

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 a naming response was produced. The subject named the object, 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 which indicated the object's name, recorded the accuracy of the response by a key press. On 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. Subjects maintained the representation of two actions, rather than one, to maximize the possibility that the memory load would influence the object-naming performance. Breaks were provided after every 32 trials.

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 were excluded (Ulrich & Miller, 1994). For each subject, the mean correct response time 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 x 2 x 2 x 2). A repeated-measures analysis of variance (ANOVA) applied to these data yielded two significant effects (all other effects had $F < 1.8$). 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. It can seen that the interaction is a cross-over in which faster naming occurs when the hand postures are either congruent with the object on both orientation and alignment or incongruent on both dimensions. Naming is slower when the hand postures are congruent with the object on only one dimension. This cross-over pattern explains why none of the main effects were significant.

The only other significant effect was the three-way interaction between orientation and alignment congruency and object orientation, $F(1, 19) = 15.91$, $MSE = 8{,}671$, $p < .001$, $\eta_p^2 = .46$. This interaction

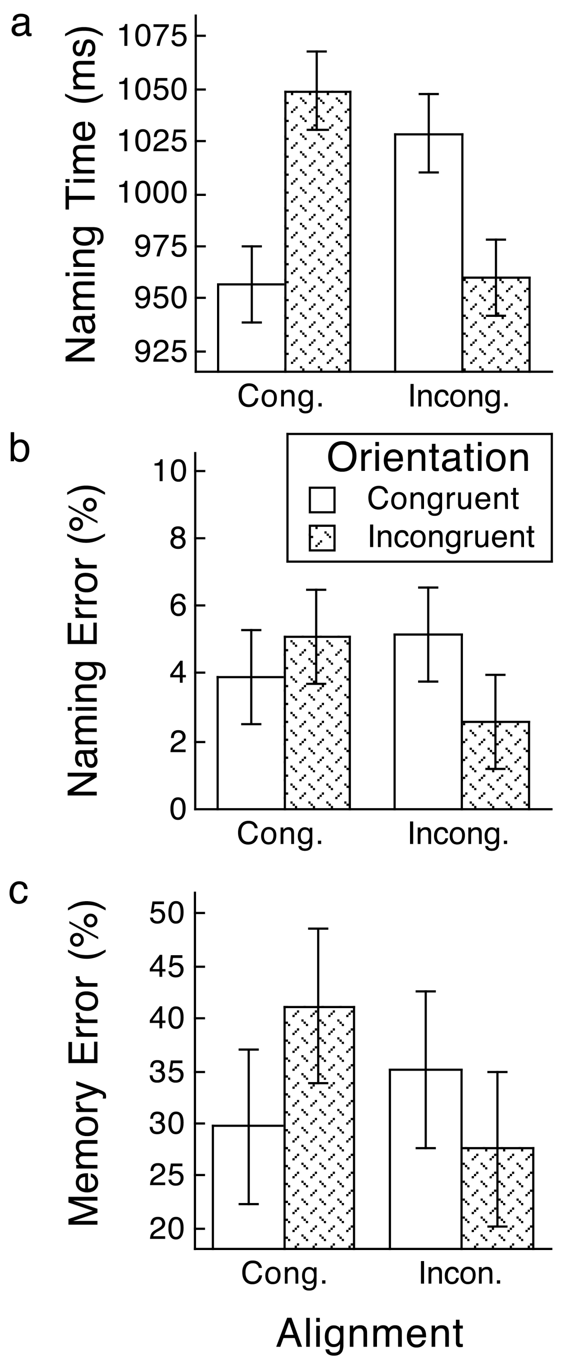

Fig. 2. (a) Mean naming time and (b) percent error in the object-naming task and (c) mean percent error in report of the hand postures held in working memory as a function of horizontal/vertical orientation and left-right alignment congruency between actions held in working memory and the object being named. Error bars are 95% within-subject confidence intervals (Loftus & Masson, 1994).

indicated that 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), and is depicted in Figure 3. The pattern of the interaction was not qualitatively different for the two object sets and the interaction effect was significant when tested separately, $F(1, 19) = 97.61$, $MSE = 6{,}117$, $p < .0001$, $\eta_p^2 = .84$ for vertical objects, and $F(1, 19) = 7.02$, $MSE = 8{,}712$, $p < .02$, $\eta_p^2 = .27$ for horizontal objects. The robustness of the orientation by alignment congruency interaction was also 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 Figure 1a) or 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% and the mean for each condition is shown in Figure 2b. Errors included false starts and occasions where subjects were not fully acquainted with the name of an object they did not frequently use. An ANOVA indicated that the interaction between congruency of orientation and congruency of alignment between hand actions and target object was significant, $F(1, 19) = 8.03$, $MSE = 35.4$, $p < .02$, $\eta_p^2 = .30$. This interaction is shown in Figure 2b, where it can be seen that it shares the same pattern as the corresponding interaction that was seen in the naming-time data.

Production of the hand actions at the end of randomly chosen trials was scored as either as 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 only 25% of trials were probed for report of the hand actions, the accuracy data were very sparse across the 16 possible conditions. Therefore, we collapsed the conditions into the four that fit the two-way interaction found in the object-naming data, namely, congruency between hand actions and the object with respect to orientation and alignment. Mean percent 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, creating substantial proactive interference (Wickens, Born, & Allen, 1963). Once again, the cross-over 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

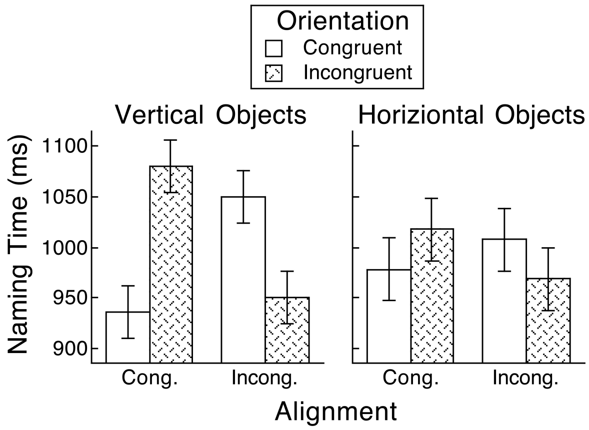

Fig. 3. Mean naming time as a function of orientation and alignment congruency shown separately for vertically and horizontally oriented objects. Error bars are 95% within-subject confidence intervals.

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 naming 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 (left- or right-handed action; 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 do not require that the planned action resembles the closed power grasp afforded by handled objects. Though one or two of the five postures serving as tokens for the planned action resembled this grasp, it had no special impact on naming performance. The influence of planned actions depended on the overlap between generic consituents 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, we observed reciprocal interference between object naming and motor tasks that revealed 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 object. Actions were less accurately reproduced after the naming response when they either required the same hand or the same wrist orientation as the grasp associated with the object. Better performance occurred if both or neither of these features were shared between the handled object and the planned actions.

The evidence we have obtained goes well beyond previous demonstrations that a concurrent motor task can affect the identification of graspable objects (see supplemental on-line material). Witt, Kemmerer, Linkenauger and Culham (2010) found that squeezing a rubber ball interfered with the naming of tools when the handle was aligned rather than misaligned with the response hand. No analogous effect of alignment occurred when participants named animals. These authors 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 handle of the object and the hand engaged in the motor task. Beyond this fact, however, we do not know which components of the hand action interfered with perception, nor indeed whether it was the task of repeatedly clenching the left or right hand that was responsible for the interference, or sensory feedback from the action that drew attention to one or the other side of the body.

We emphasize the novel and counterintuitive nature of our findings. Planning actions with the left hand that require a vertical palm orientation, for example, interferes with the naming of an object like a beer mug or a teapot when the handle is aligned with the right (but not the left) hand, and with 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 these intended actions (in the present example, left handed, palm vertical) is more difficult if the perceived object affords a grasp with the right hand and a vertical wrist posture, or 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 in support of the assumption that performing these 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 the action and target object has a definite interfering effect, when other research indicates positive compatibility effects between two stimuli that share features (for a review, see Hommel & Prinz, 1997). As these authors point out, however, allowing subjects enough time to plan and memorize an action sequence A which is not carried out until completion of perceptual task B, temporally separates the critical underlying processes. The features of the action are now fully integrated, and competition takes place because a subsequent visual object requires a feature in common to both events. A shorter interval between action A and object B may not allow enough time for planning to be completed before perceptual processing. In that situation, it has been shown that 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 features shared between motor and perceptual events. Thomaschke, Hopkins, and Miall (2012) noted 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. The planning of an action requires that categorical features are bound into a stable representation. Concurrently, there is a shift in attention to the metric dimensions of representational space for movement control. A perceptual task that involves categorical features bound to an active motor plan, such as object naming, will show impairment, whereas a perceptual task that requires the analysis of metric information will show facilitation.

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 visual-motor features recruited for naming are indeed categorical, as we have assumed in defining their relationship to the constituents of a planned action (left/right; horizontal/vertical 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 may indeed 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 an object, we would have observed a benefit rather than a cost in performance.

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 argument 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 meta-theoretical principles covering a wide range of potential interactions between motor and perceptual tasks, 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 object 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 consultation of both the hand and wrist orientation afforded by the position of the 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 afforded by a handle is the same for a great variety of different tools and utensils. Why then should the details of an action afforded by the handle of an object have such a potent effect on identification? What is nonetheless 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 (1985) definition of "mug", for example, includes the fact that "...a person raises it to the mouth so part of it touches the lip then tips the top part towards the mouth so a little liquid moves down inside the mouth" (Goodard, 1998; p. 236).

Recent theoretical considerations view 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 functional properties requires an understanding of the relationship between specific actions afforded by an 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 can remain neutral on the question of whether sensory and motor 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.

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Supplementary On-Line Material

A substantial number of reports have shown that motor representations affect the time to identify words or pictures denoting manipulable objects. Although these reports advocate the idea that action representations are part of the meaning of manipulable objects, they all face an alternative interpretation. Namely, that there is spreading activation between object meaning and the motor system so that when a word or picture is identified, its associated motor representations are automatically evoked and interact in some way with a language or perceptual task (Mahon & Caramazza, 2008). Moreover, proposals that motor representations play a causal role in word or object identification seldom make *a priori* claims as to the expected pattern of results given action overlap between objects or events. Indeed, some studies have produced interference effects due to action similarity, and others have obtained facilitation. An organizing principle that appears to distinguish these two classes of outcome is that facilitation arises when a target stimulus is primed by a preceding stimulus having similar versus dissimilar motor representations (e.g., Helbig, Graf, & Keifer, 2006; Helbig, Steinwender, Graf, & Kiefer, 2010; Kiefer, Sim, Helbig, & Graf, 2011; Myung, Blumstein, & Sedivy, 2006). Interference occurs when a motor task is engaged while identifying a target object (e.g., Witt, Kemmerer, Linkenauger, & Culham, 2010; Yee, Chrysikou, Hoffman, & Thompson-Schill, in press).

A further difficulty, however, is that action-based features of similarity used to bolster the claim that motor representations are implicated in the meaning of objects or words are often left implicit or undefined. For example, Helbig et al. (2006) simply say that pairs of pictures "… differed only with regard to the similarity of the actions typically carried out with the two objects" (p. 223). Inspection of the accompanying figure containing examples of related and unrelated pairs reveals inconsistency in the extent to which pairs in a given condition overlap in similarity. For example, pliers and a horseshoe were classified as incongruent, even though they both involve a power grasp, whereas two objects that appear to be designed for grinding are used as a congruent pair, but require different orientations of the hand (Helbig et al., 2006; Fig. 1). This lack of specification leaves uncertain the kind of relationship between actions and objects that modulate object identification. In Helbig et al. (2010), a video prime showing the two hands with wrists oriented horizontally (a rolling-pin action) were deemed congruent with the action required to use a wheelbarrow (where a vertical orientation of the wrists is required). Similarly, in Myung et al. (2006), the actions associated with a clothes iron and a cello bow were deemed related, as were piano and typewriter. In the former case, it is the movement of the whole arm and not the hand posture (power grip and precision grip for iron and bow, respectively) that is related, but in the latter case it is the shape of the hand that is related, not the movement of the arms.

Finally, if motor representations indeed play a functional role in accessing object meaning, the literature has not progressed to the point where the details of this role are explicated. For example, Witt et al. (2010) showed that squeezing a ball interferes with naming a tool when its handle was aligned with the occupied hand. They inferred that the effect is due to motor simulation of acting on the tool, which plays a "functional, but not necessary, role in tool recognition" (p. 1217). Presumably the implication is that multiple routes are available from vision to meaning, one of which includes action representations, though the authors provide no details about these routes.

Our contribution adds substantively to the literature on actions and object identification in the following ways. First, we have an explicit definition of the overlap between action features in working memory and the actions associated with a target object. We restricted our examination to two dimensions: hand used (left vs. right) and wrist orientation (vertical vs. horizontal). Second, the interference effects we document are explicitly derived from a theoretical framework (the Theory of Event Coding; Hommel, Müsseler, Aschersleben, & Prinz, 2001) that predicts a counterintuitive pattern: complete feature overlap between a planned action and a target object produces no benefit relative to non-overlapping pairs, whereas partial feature overlap generates a cost. This pattern occurs when categorical features are bound in working memory and are shared with the target object. A different pattern is predicted when the object and the features of an action are represented metrically (i.e., as when full parametric specification of a reach and grasp action is needed). Under these conditions, full, and even partial, feature overlap are expected to produce facilitation (Thomaschke, Hopkins, & Miall, 2012) relative to no overlap.

The evidence that we have obtained suggests that action representations do indeed play a causal role in object identification. Consider the alternative claim, namely, that action representations follow (through spreading activation), rather than contribute to, object identification (Mahon & Caramazza, 2008). Let us assume that the contents of working memory are re-evoked by the target object such that the similarity between the planned action and the actions associated with the object causes interference. Then we should expect that a match between the target object and the planned action on both action features should yield longer response times than either a partial or a full

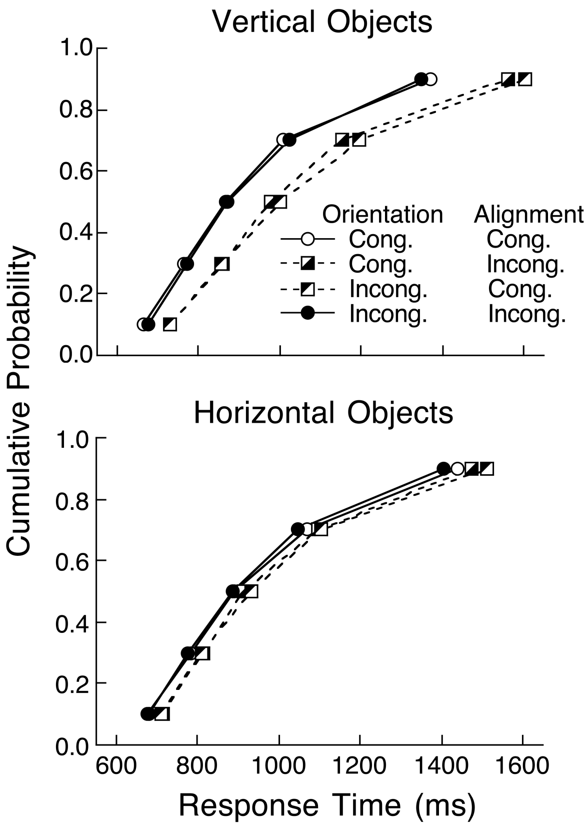

Fig. S1. Cumulative density functions for response time distributions for object naming.

mismatch. Our results, by contrast, show that slowing occurs only when there is a partial match between features, relative to either a full match or mismatch. The shared feature would appear to be an obligatory part of the naming process. Recruitment of that feature triggers the integrated representation of features already in working memory as part of the planned action. This representation includes one feature that matches the target object and one that conflicts with it. The result is a delay in assembling the motor representation used in the naming process. We can show that this delay occurs even for the fastest set of naming responses. An analysis of the cumulative response time functions shows that the partial match effect holds across the full range of response time bins (see Figure S1)[1]. Recruitment and integration of action features appear to be ineluctable elements of object naming and are not confined to slow naming responses. This finding rules out the possibility that the effects we obtained are confined to responses that are slow enough to generate an evoked action as a consequence of (rather than as a contributor to) successful object identification.

In addition, we found that reporting the actions held in working memory was also susceptible to the partial mismatch between action features. This outcome provides further support for the idea that naming the object enlists a motor feature that is part of the planned action. The consequence is that the integrated representation of the planned action is disrupted.

The claim that the details of an action plan have a causal role in object identification raises questions about the specifics of the relationship between the meaning of an object and its associated actions. We have argued that action-outcome pairings represented by visual instances of an object provides a modality-specific route to meaning. In other words, the functional properties of an object can be accessed by considering the relationship between specific actions afforded by a particular form of the object and the outcomes of those actions. We do not claim, however, that this route is the only one for object recognition. An object can also access meaning independently of the actions evoked by its particular structural form and orientation. This distinction implies that in cases of neurological impairment of the mechanism that derives the function of an object from its perceived action-outcome pairings, successful naming may take place via the alternative route. We would not expect, then, that apraxic patients who fail to perform or recognize the actions associated with an object would necessarily show impaired naming performance (see Mahon & Caramazza, 2005).

Note

1. An analysis of variance of the binned response time data for vertical objects shown in Figure S1 indicated that the signature interaction between congruency for alignment and orientation was significant, $F(1, 19) = 64.79$, $MSE = 26{,}083$, $\eta_p^2 = .77$, and the size of this effect increased with longer response times, $F(4, 76) = 12.68$, $MSE = 6{,}512$, $\eta_p^2 = .40$. Nevertheless, the interaction was significant even in the shortest response time bin, $F(1, 19) = 49.45$, $MSE = 1{,}389$, $\eta_p^2 = .72$. For the horizontal objects, the congruency interaction was significant, $F(1, 19) = 9.11$, $MSE = 20{,}278$, $\eta_p^2 = .32$, and did not interact with response time bin, $F < 1$.

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