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Language-based access to gestural components of conceptual knowledge

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We report two experiments in which production of articulated hand gestures was used to reveal the nature of gestural knowledge evoked by sentences referring to manipulable objects. Two gesture types were examined: functional gestures (executed when using an object for its intended purpose) and volumetric gestures (used when picking up an object simply to move it). Participants read aloud a sentence that referred to an object but did not mention any form of manual interaction (e.g., *Jane forgot the calculator*) and were cued after a delay of 300 or 750 ms to produce the functional or volumetric gesture associated with the object, or a gesture that was unrelated to the object. At both cue delays, functional gestures were primed relative to unrelated gestures, but no significant priming was found for volumetric gestures. Our findings elucidate the types of motor representations that are directly linked to the meaning of words referring to manipulable objects in sentences.

Keywords: Action representations; Embodied cognition; Sentence comprehension.

Specific hand actions are required when using manipulable objects like a calculator or thumbtack. A great deal of theoretical speculation has emerged on the conceptual role that these motor representations might play in language tasks (Barsalou, 1999; Zwaan & Taylor, 2006; see also papers in this issue). To what extent does the meaning of the word "calculator", expressed in isolation or as part of a sentence, depend on knowing the physical actions required to use the corresponding object? This question receives some of its force from neuroimaging experiments establishing that motor-related cortical activity occurs when normal subjects judge the meaning of words referring to manipulable objects (Boronat et al., 2006; Lewis, 2006; Phillips, Humphreys, Noppeney, & Price, 2002). Motor activation appears to reflect the topographic organization of the motor system. Words that refer to actions or objects associated with particular limbs or body parts (e.g., arm, leg, mouth) yield activation in corresponding regions of premotor cortex (Pulvermüller, Shtyrov, & Ilmoniemi, 2005; Tettamanti et al., 2005). In addition, evidence

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from brain-damaged patients indicates that difficulty in identifying the function of tools is associated with a number of impairments, all having to do with the manipulation of objects. These patients tend to be apraxic (they are unable to accurately imitate hand gestures despite showing adequate dexterity in other respects), and they make errors when determining the hand actions needed to execute the functions of manipulable artifacts (Buxbaum & Saffran, 2002).

These and other provocative results (e.g., Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996) indicate that motor representations are accessed during the semantic processing of manipulable objects. Yet the evidence thus far does not permit any further theoretical claims about the relationship between the meaning of words and knowledge of the actions associated with object use. The actions pertinent to objects require specific hand postures (e.g., a stapler is used by pressing down with a flat palm or a closed fist on the top). We do not know whether the activation seen in neuroimaging studies includes detailed representations of hand postures or merely the general body part used to interact with the object.

In addition, what exactly do we mean when we talk of hand actions in regard to the *function* of an object? Artifacts have a particular form and weight distribution that guide the shape and positioning of our hand during manual interactions. The hand posture that we must adopt to pick up a calculator or thimble is presumably part of the knowledge we possess about using these objects. We refer to such interactions as *volumetric*, and we distinguish them from manual interactions needed to enact the conventional function of an object. For some actions, the hand movements for volumetric interactions are the same as those for functional interactions. For example, we adopt the same hand posture to pick up or move a glass and to drink from it. For other objects, the volumetric gesture is quite different from the functional gesture. The hand posture we use to pick up a calculator is very different from the posture we use to carry out numerical computations with the object.

Both functional and volumetric types of actions may be implicated in the claim that motor-based knowledge is recruited during semantic judgements of words denoting manipulable objects. But the two kinds of gestures are not formally the same in all cases, nor does the evidence suggest that they share the same neural substrate. Neuropsychological research indicates a double dissociation between the two gesture types. Patient L.L. (Sirigu et al., 1995) showed impairment in the hand movements required to utilize familiar objects (functional actions) but no such impairment when required to reach and pick up the very same objects (volumetric actions). Similarly, Buxbaum, Sirigu, Schwartz, and Klatzky (2003) found that functional grasps of patients with left inferior parietal damage were impaired, and patients reverted instead to intact volumetric grasps when attempting to demonstrate the conventional use of familiar objects. The reverse dissociation between functional and volumetric grasps can be seen in patients with optic ataxia, a disorder of visually guided reaching. Such cases are severely impaired when reaching for and grasping objects volumetrically but show no such impairment when the task requires a functional interaction with the object (Jeannerod, Decety, & Michel, 1994; Perenin & Vighetto, 1988).

Functional and volumetric gestural representations are valid components of the normal interaction with objects, and both types of knowledge may be recruited during the semantic processing of a word like *calculator*. But the possibility that they are computationally distinct raises questions about the way these representations are evoked in the course of reading a sentence. The relationship between sentence context and the gestural representations constructed during comprehension is a very complex matter that must surely involve the meaning of both the verb and its complement. Sentences can describe a variety of ways of interacting with manipulable objects, some of these interactions being volumetric, others being functional. In the experiments presented here we are specifically interested in the gestural representations evoked by the noun, rather than the much more complex issue involving dynamic interactions between verb and noun. Thus, we confine ourselves here to verbs that do not entail physical actions (i.e., we avoid verbs like *lift*, *pick up*, *use*, *open*), and we examine whether words referring to manipulable objects evoke motor representations in these neutral contexts. Consider the following examples.

John thought about the calculator.
Elaine wanted a new pencil.

These sentences do not selectively imply either functional or volumetric interactions, but instead describe rather abstract, mental contemplation of objects. Under these conditions, it might be expected that there would be little or no role for gestural representations to play. Rather, comprehension of the sentence, including the manipulable object, might go forward with consideration given only to abstract propositions that constitute the meaning of the object (e.g., a device for computing numerical quantities). Alternatively, if the core conceptual meaning of manipulable objects includes knowledge about manual interactions with those objects, then this knowledge might automatically be evoked, even when the object appears in an utterance that makes no reference to manual action.

Assuming that semantic attributes of a word like *calculator* include both volumetric and functional properties of the object, how do the gestural representations corresponding to these properties emerge over time in a sentence like *John thought about the calculator*? We argue that access to meaning for the noun can potentially involve either volumetric or functional properties, but that the default is functional when no motor action is implied in the verb. We agree with Jackendoff (2002) that function is a basic element of human understanding (see also Glenberg, 1997). Jackendoff noted that children will spontaneously ascribe function to a very wide range of objects, including lakes for swimming and the sun for keeping us warm (Kelemen, 1999). Moreover, as children develop, they increasingly rely on object function rather than shape when extending names to new artifacts (Kemler Nelson, Frankenfield, Morris, & Blair, 2000; Truxaw, Krasnow, Woods, & German, 2006). In addition, a sentence like *John enjoyed the calculator* is typically interpreted to mean that John enjoyed using the calculator. We hypothesize that the function of an object is readily accessible, even when not explicitly called on, and may be the modal point of entry to meaning given certain types of verbs. Thus, early evocation of functional knowledge should be marked by improved access to the parameters corresponding to the functional gesture after the relevant object name (e.g., *calculator*) in the sentence. An interesting question concerns the possibility that volumetric representations are also accessed during the comprehension process. In a sentence that makes no reference to manual interactions, we conjecture that any evidence for volumetric representations might be found later than the initial activation of functional knowledge. Volumetric gestures may depend on particular visual characteristics of an object including size and orientation. For example, the wrist orientation used to pick up a pen is very different depending on whether the pen is lying on a desk or positioned upright in a pen stand. With no visual depiction of the object available, potentially crucial parameters of the volumetric gesture are missing. It is plausible that under these circumstances, more time will be needed to develop a volumetric gestural representation of sufficient specificity to sustain a priming effect in our paradigm. Consistent with this proposal, we have shown that whereas functional gestures are primed by relevant object names (e.g., the word *calculator* primes the generation of a poke gesture) after just 300 ms of exposure to an object name, volumetric gestures do not show reliable priming (Bub, Masson, & Cree, in press). Volumetric gestures are clearly evident, however, when an object name is used to carry a colour that cues a specific gesture (Bub & Masson, 2006; Bub et al., in press). In this Stroop-like paradigm, on some trials the cued gesture matched the functional or volumetric gesture associated with the named object, whereas on other trials the gestures were incongruent. We observed a clear congruency effect when either the object's volumetric or functional gesture matched the colour-cued response. For example, if the word *calculator* appeared in the colour associated with a poke gesture (functional), then making that gesture was faster than making another gesture unrelated to the object. Similarly, if *calculator* appeared in a colour that cued a horizontal grasp (volumetric), then that gesture was faster than an unrelated one. Responses to colours in this task are substantially slower (by about 300 ms) than responses in the priming task, allowing more time for volumetric gestures to accrue. Clearly, volumetric gestural representations can be elicited by object names presented in isolation if sufficient time is allowed.

Detecting the evocation of functional and volumetric gestural knowledge

We wish to reveal the automatic evocation of gestural knowledge to words that denote manipulable objects when they appear in sentences. Previous behavioural research has been reported with a similar purpose, but the methods devised suffer a number of serious limitations. Chief among these is a lack of sensitivity to the crucial distinction that we have raised between functional and volumetric representations. For example, Tucker and Ellis (2004) required observers to judge whether individually presented words referred to natural or man-made objects. A two-choice response device comprised a cylinder (requiring a power grip) and a thin rod that required a precision grip. Observers made speeded judgements to each word (natural versus man-made) by manipulating one or the other of these response elements. The basic idea behind the experiment was that actions conventionally associated with the object denoted by the word should affect the speed with which observers initiated a particular grip: A precision or power response to the word should be faster if the object denoted was typically grasped in the same way. Many of the words used in this study referred to objects that required the same volumetric and functional grasps (needle, eraser, bottle, coin). We cannot know whether the effects of the words on reaction time (which in any case appear rather weak) are due to the shape of the object or their function. The fact that half the words referred to fruits and vegetables, most of which share common functional gestures (e.g., grasp and bring to mouth), suggests that the volumetric properties of the objects were the primary influence (see also Klatzky, Pellegrino, McCloskey, & Doherty, 1989, for a similar limitation).

Other behavioural research has sought compatibility effects between the direction of movement to signal a semantic decision and the directionality implied by the meaning of the word or sentence (e.g., Glenberg & Kaschak, 2002). It is easier to signal a judgement of the meaningfulness of a sentence using a movement toward the body than away from the body if the sentence also implies the same directionality. These spatial compatibility effects presumably are independent of the limb used to carry out the action. Indeed, it is unlikely that these effects are specific to manual responses and so cannot elucidate the nature of grasp representations evoked by words denoting manipulable objects (see, for a supportive example, Phillips & Ward, 2002).

Our purpose in this rather cursory review of the literature is not so much to produce a comprehensive evaluation of previous methodologies but to provide a clear motivation for our present enterprise. The logic behind our methodology is based on the assumption that if specific gestural representations are elicited by exposure to object names, then subjects should be able to manually generate actions based on those representations more quickly than they can unrelated actions. We provided precise definitions of target actions by requiring participants to respond by grasping a response apparatus in a specified manner. The response apparatus consisted of abstract shapes associated through training with particular hand actions, as shown in Figure 1. Participants were trained to make a target hand action when cued by a photograph of a hand posture. On critical trials, participants read a context sentence that mentioned a manipulable object prior to receiving a hand cue. The target gesture was either the

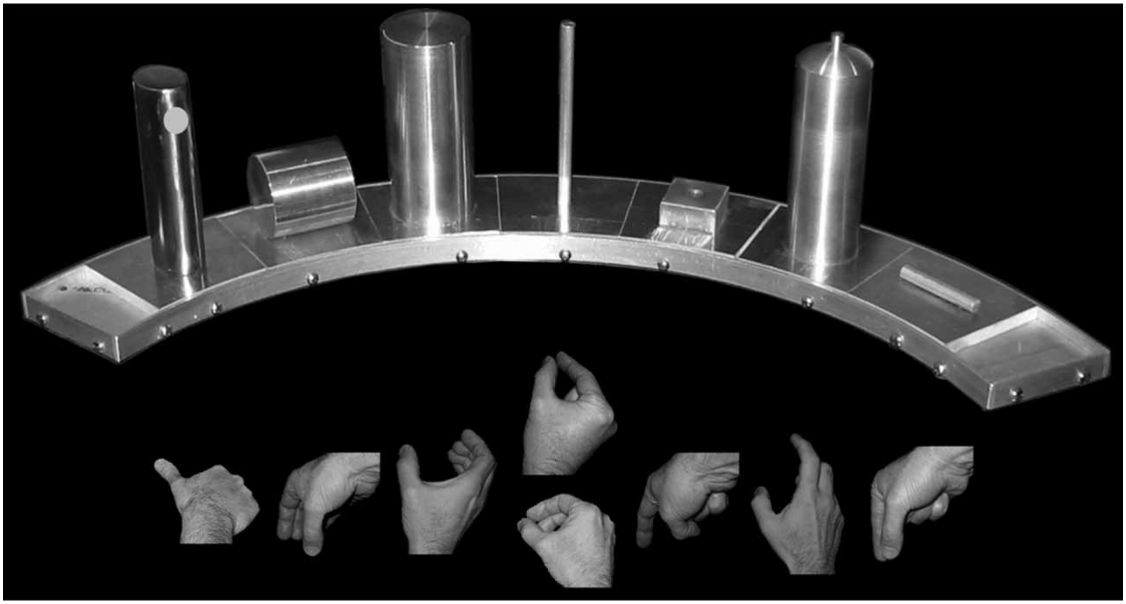

Figure 1. *The response device and the hand cues used in the experiments. The hand cues pictured here are aligned with the element of the response device to which they were assigned. Two gestures were assigned to the thin vertical rod. The gestures, from left to right, are thumb press, horizontal grasp, vertical grasp, vertical pinch, writing grip, poke, aerosol, and horizontal pinch.*

functional or volumetric gesture typically used with that object, or it was unrelated to the object.

We assume that if mental representations of actions are evoked by the mention of a manipulable object in a context sentence, then participants will respond more quickly when the hand cue requires them to generate one of these actions than when the hand cue denotes an unrelated action. For example, reading a sentence that mentions a calculator potentially evokes the action of pressing calculator buttons, and this mental activity should prime the production of a poking action made with the designated element of the response apparatus. Even though the mental representation of pressing calculator keys may not completely fit the action of poking an element of the response apparatus, the parameter sets that define these two activities should be sufficiently similar to yield a priming benefit. We note that the influence of semantic knowledge on motor tasks typically is confined to the early stages of preparation and response execution (Glover, Rosenbaum, Graham, & Dixon, 2004; Lindemann, Stenneken, van Schie, & Bekkering, 2006), with later movement stages affected more by the particular physical parameters of the object being grasped (Goodale, Milner, Jakobson, & Carey, 1991). With this constraint in mind, we measured response latency from the onset of the hand cue to the moment the participant lifted her or his hand to initiate the target gesture.

EXPERIMENT 1

In our first experiment, participants read aloud sentences that described a type of interaction with an object that did not involve manual interaction, such as seeing, forgetting, or thinking about. After reading each sentence, participants were cued to make a gesture that was either functionally or volumetrically related to the manipulable object mentioned in the sentence, or unrelated to it. By comparing response latencies on related versus unrelated trials, we were able to determine whether reading a context sentence led to the evocation of either functional or volumetric gestural knowledge. The signature of any such knowledge evocation should be a priming effect on response latency. In addition, we used two delay intervals between completion of sentence reading and presentation of the response cue, allowing us to discover whether each type of knowledge emerged relatively soon or late after sentence reading. In the Bub et al. (in press) experiment mentioned earlier, we demonstrated that a prime duration of 300 ms was adequate to reveal functional gestural representations. Based on this evidence, we expected that delays of 300 and 750 ms would be adequate for assessing which gestural knowledge, if any, is recruited during the final stages of sentence comprehension (short delay) and which continues to be active once comprehension processes have had time to be completed (long delay).

Method

Participants

A total of 30 undergraduate students from the University of Victoria participated for extra credit in an introductory psychology course.

Materials

Four pairs of gestures, each pair consisting of one functionally and one volumetrically related gesture, and one object associated with each pair of gestures were selected as the critical materials for the experiment. The objects and their corresponding gestures are shown in Table 1. A greyscale digital image of each gesture was created by photographing a hand posed in a position characteristic of the target gesture. The photographs were taken of a model's right hand. Left-hand versions were created by mirror reversal of those images on the vertical axis. These versions of the hand cues were used for left-handed participants.

Table 1. *Critical objects and related gestures used in the experiments*

Object	*Functional gesture*	*Volumetric gesture*
calculator	poke	horizontal grasp
hairspray	aerosol	vertical grasp
pencil	writing grip	vertical pinch
thumbtack	thumb press	horizontal pinch

For each of the four objects, a set of 75 sentences describing an abstract interaction with that object was generated. The interaction described in each sentence was abstract in the sense that the verb specified a mental or other notional activity (e.g., argue, forget, keep) rather than a direct physical or perceptual interaction (e.g., pick up, use, see). A total of 3 of the sentences associated with each object were used on practice trials, and the remaining 72 sentences in each set were used on critical trials. Within each set of 72 critical sentences, 24 abstract verbs were used in each of three different sentences. Each sentence was constructed so that the last word in the sentence was the name of the critical object. The following are two example sentences:

Hannah lied to her sister about the calculator.
In class Lucas remembered his thumbtack.

The 72 sentences associated with each object were randomly assigned for presentation in eight different conditions (9 sentences per condition), defined by the factorial combination of cue delay (300 ms or 750 ms), type of cued gesture (functional or volumetric), and relatedness condition (the gesture was related or unrelated to the manipulable object mentioned in the sentence). Random assignment was done independently for each participant. Across the four objects, this assignment provided for 36 trials in each of the eight conditions. Related gestures were defined by the object–gesture pairs shown in Table 1. The unrelated gesture used on a given trial was randomly selected from among the three other gestures of the same type (functional or volumetric).

Procedure

Sentences and hand cues were presented on a monitor controlled by a Macintosh G3 computer. A second monitor was used to display information to the experimenter regarding the correct response for each trial, allowing the experimenter to classify the participant's response as correct or incorrect at the end of each trial. A response box with a row of six keys mounted on its top surface was connected to the computer to provide response timing information. Participants made manual responses by lifting the forefinger of the dominant hand from a key and grasping an element of a response device designed to fit the cued gesture. The response device consisted of a curved base onto which seven aluminium elements were placed (see Figure 1). Each of the eight gestures was assigned to one of the elements (two gestures, writing posture and vertical pinch, were assigned to a single element—the thin vertical rod shown in the figure). The left-to-right order of the seven elements in the response device was varied across subjects. The response device was placed between the computer monitor and the participant so that the monitor could be clearly seen, and the elements of the response device were within easy reach.

Participants were first trained to make the eight responses using the assigned element of the response device when cued with the picture of a hand making one of the eight gestures. Participants were shown right- or left-hand versions of the hand cues, depending on their dominant hand, and made all responses with that hand. A total of 72 training trials were conducted (9 with each gesture). After response training was completed, participants were presented with a series of 300 sentences and hand cues (12 practice trials followed by 288 critical trials) in an independently determined random order. On each trial, a sentence appeared in the centre of the monitor, and the participant read it aloud. As soon as the final word had been enunciated, the experimenter pressed a key on the computer keyboard, which caused the sentence to be erased. After a delay of either 300 ms or 750 ms a hand cue was presented. The cued gesture was either functionally or volumetrically related to the object (henceforth, *functional* and *volumetric* gestures) or it was unrelated to that object. The participant's task was to carry out the gesture corresponding to the hand cue by lifting his or her forefinger from the response key and immediately making the gesture with the correct element of the response device. Participants were instructed to respond as quickly as possible while maintaining accuracy. Response latency was recorded as the time between the onset of the hand cue and lift-off from the response key. The hand cue was erased as soon as the participant's hand was lifted from the response key. After the response was made, the experimenter pressed a key to classify the response as correct or incorrect (e.g., making the wrong gesture or contacting an incorrect element on the response device).

Results and discussion

Mean correct response latency was computed for each of the eight conditions for each participant. Latencies were treated as outliers and were excluded from analyses if they were shorter than 250 ms or longer than 1,300 ms. These criteria were set so that no more than 0.5% of correct response latencies would be excluded (Ulrich & Miller, 1994). Using these limits led to exclusion of 0.46% of the observations.

Mean response latency for each condition is shown in Figure 2. The pattern of means indicated that there was a benefit for related functional gestures at both cue delays, but for volumetric gestures there was only a small priming effect that was restricted to the long cue delay condition. Data for functional and for volumetric gestures were analysed separately using repeated measures analyses of variance (ANOVA) with Type I error set at .05. The analyses included cue delay and relatedness as factors. The analysis of functional gestures revealed a main effect of relatedness, $F(1, 29) = 18.64$, $MSE = 267$, Cohen's $d = 0.15$, as related gestures were made 13 ms more quickly than unrelated gestures. The was no effect of cue delay nor an interaction, $F\text{s} < 1$. The ANOVA for volumetric gestures did not indicate a significant effect of priming, although the 6-ms effect approached significance, $F(1, 29) = 3.20$, $MSE = 301$, $p < .09$. Neither cue delay nor the interaction was significant, $F\text{s} < 1.7$. Estimated power for the test of priming among

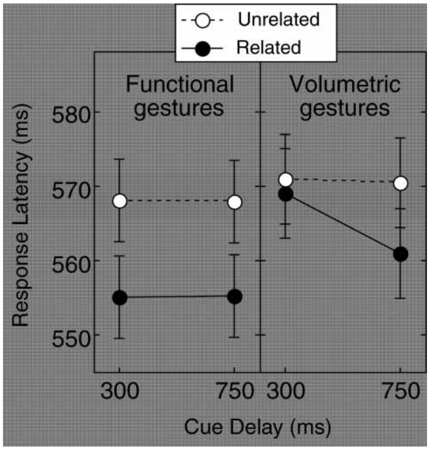

Figure 2. *Mean response latency in Experiment 1 as a function of gesture type, cued delay, and cuing condition. Error bars are 95% within-subject confidence intervals appropriate for comparing related and unrelated conditions (Loftus & Masson, 1994; Masson & Loftus, 2003).*

volumetric gestures to detect a significant effect of the magnitude seen for functional gestures was .99.

The overall mean error rate was 0.4% for functional gestures and 0.3% for volumetric gestures. These rates were very low and were made by fewer than 10 participants in each case, so we do not report statistical analyses of error rates.

These results indicate that functional but not volumetric gestural knowledge is available very shortly after reading the name of a manipulable object during the course of comprehending a sentence. This effect occurs despite the fact that the sentences used here described an abstract interaction with an object. There was no clear evidence that volumetric knowledge was elicited as well. The priming effect for functional gestures at the short delay suggests that knowledge about manual actions related to an object's function is recruited quickly and possibly automatically during the course of sentence comprehension.

EXPERIMENT 2

One might argue that in Experiment 1, participants were induced to recruit gestural knowledge because every sentence mentioned a manipulable object, even though the interactions described in the sentences did not feature manual actions. We therefore conducted a second experiment in an effort to obtain stronger evidence in favour of the automatic nature of the recruitment of gestural knowledge pertaining to an object's function. In Experiment 2, we included a large number of filler sentences that did not mention manipulable objects to discourage participants from intentionally recruiting gestural knowledge while reading sentences. As in Experiment 1, all sentences used abstract verbs rather than verbs referring to perceptual or specific physical interactions. The introduction of filler sentences meant that the proportion of trials on which the target gesture was related to a concept mentioned in the sentence was very low (about 10%), which was expected to discourage deliberate strategies involving expectations about which gesture would be cued. To keep the total number of trials at a reasonable number, we manipulated cue delay between subjects rather than within subjects as in Experiment 1. Given the results of Experiment 1, we were specifically interested in examining priming effects separately for functional and volumetric gestures. We expected to replicate the main results of Experiment 1: early and sustained priming of functional gesture, late and relatively weak or no priming of volumetric gestures.

Method

Participants

A total of 56 new participants were recruited from the same source as that in Experiment 1. Half of the participants were randomly assigned to each of the two cue delay conditions.

Materials

The same eight gestures and four manipulable objects were used as those in Experiment 1. A total of 64 critical sentences (16 for each of the four manipulable objects) were selected from the set used in Experiment 1. A set of 256 filler sentences using abstract verbs and not mentioning typical manipulable objects (e.g., *In the end,* *Melissa never agreed to the position*) was constructed. A set of 16 practice sentences was created as well. Each of the four manipulable objects was mentioned in one of the practice sentences. For the 64 critical trials, 16 were randomly assigned to each combination of gesture type (functional or volumetric) and relatedness (related or unrelated) with the constraint that each of the four objects was included equally often in each condition. This assignment was made independently for each participant. Across the practice, critical, and filler sentences, the cued gesture was related to an object mentioned in the context sentence on 34 of 336 or 10.1% of the trials.

Procedure

The same equipment and procedure was used as those in Experiment 1, except that for the critical trials only one cue delay was used: 300 ms for half of the participants and 750 ms for the other half. For filler trials, however, half were presented with a 300-ms cue delay, and half were presented with a 750-ms delay. Thus, across the full set of trials, participants experienced variation in the cue delay. A second difference in procedure from Experiment 1 was that there were 16 practice trials (instead of 12) immediately preceding the critical and filler trials.

Results and discussion

Outlier response latencies were defined as in Experiment 1, except that the upper bound was set at 1,400 ms, which led to the exclusion of 0.47% of the observations. Mean response latency for each condition is shown in Figure 3. The pattern of means was quite similar to that found in Experiment 1—namely, there was a clear relatedness effect for functional gestures at both cue delays, but little indication of a relatedness effect for volumetric gestures.

Separate ANOVAs with cued delay as a between-subject factor and relatedness as repeated measures factors were computed for functional and for volumetric gesture data. The ANOVA of functional gestures revealed a significant priming effect of 12 ms, $F(1, 54) = 9.07$, $MSE = 460$, Cohen's $d = 0.14$. The effect of cue delay and the interaction were not significant, Fs < 1. The analysis of volumetric gestures produced no significant effects, Fs < 1.1. The power of the analysis of volumetric gestures to find an effect of the size observed among functional gestures was estimated to be .89.

The mean error rate was 0.3% both for functional and for volumetric gestures. As in Experiment 1, these rates were very low, and errors were made by fewer than 10 participants, so no analyses of error rates are reported.

In Experiment 2, steps were taken to strongly discourage strategic recruitment of gestural knowledge. Nevertheless, there continued to be clear evidence of priming for functional gestures. In addition, there was no evidence for priming of volumetric gestures, although there was a trend toward such priming in the 750-ms delay condition of Experiment 1. That trend may have been due to strategic influences, given that there was no such trend in Experiment 2, which used a drastically reduced relatedness proportion. The contrast between functional and volumetric gestures with respect to the priming effect establishes a dissociation between these two gesture types, in that only functional gestures are primed soon

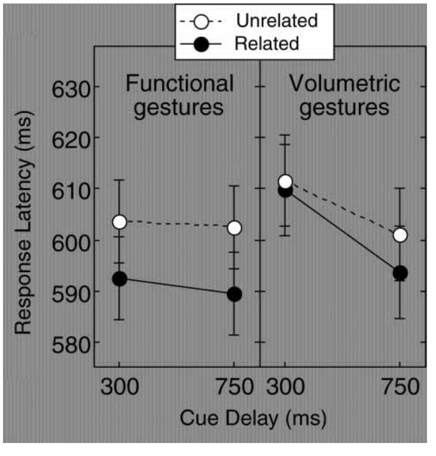

Figure 3. *Mean response latency in Experiment 2 as a function of gesture type, cued delay, and cuing condition. Error bars are 95% within-subject confidence intervals appropriate for comparing related and unrelated cue conditions.*

after reading sentences that depict abstract interactions with manipulable objects.[1] We view these priming effects as diagnostic of the differential evocation of two types of gestural knowledge. As such, the data suggest that functional and volumetric knowledge follow different time courses, with only functional gestural knowledge evoked during early stages of language comprehension when sentences do not mention physical interaction with the objects.

GENERAL DISCUSSION

We have shown that words referring to manipulable objects in sentences evoke specific hand actions appropriate to their use. The effects that we have observed are remarkable given that they occur even though the large majority of sentences referred to concepts that have no gestural associations. In addition, we used verbs, such as *think* and *discuss*, that do not invite manual action representations. Despite these constraints, sentences such as *John thought about the calculator* automatically evoke gesture representations. The time course of the activation of functional representations implies a relatively early access that includes only knowledge of how the object is manipulated to carry out its intended function.

These results go well beyond demonstrations that sentences about actions and objects (e.g., close the drawer) evoke spatial representations that influence the speed of responding when responses involve selecting the direction of an arm movement toward or away from the body (Glenberg & Kaschak, 2002). Other research (e.g., Myung, Blumstein, & Sedivy, 2006; Tucker & Ellis, 2004) shows evidence that hand actions appear to be activated by words but these studies do not provide evidence for the specificity and selectivity of volumetric and functional gestures that we have documented in an experimental context that strongly discourages strategic use of gestural knowledge.

It has been suggested by a reviewer that the priming effects we observed are in part due to visual representations of a hand posture generated by reading the name of a manipulable object. For example, reading the word *calculator* may invoke the visual form of a hand, forefinger extended, in the posture required to press a calculator key. This representation, in turn, may increase the efficiency with which a participant identifies a matching hand cue in our task. Although an influence of this kind is possible, we strongly suspect that if the visual form of a hand posture is generated, it is the product of motor representations initially evoked by the object name. It seems less plausible to us that the image of a hand posture is generated directly from reading a word without the involvement of motor representations. Nevertheless, this possibility could be tested by training participants to associate specific gestures with different colours, then cuing each gesture with its colour rather than with a picture of a hand posture. Priming effects seen under these circumstances would be entirely attributable to motor representations. For our present results, however, we acknowledge the possibility that some of the priming effect that we obtained may have been mediated by the visual form of a hand posture derived indirectly through motor representations or perhaps even directly from an object name.

Although we used only four different target objects in the experiments reported here, we have confidence that our results are generalizable to a wider set of objects. Bub et al. (in press) used 18 manipulable objects in a priming task in which object names were used to prime cued gestures. As discussed in the Introduction, with a 300-ms prime duration, they obtained priming effects for functional gestures but not for volumetric

[1] We also obtained completion time data for each trial in both experiments, in addition to response latency. Completion time was recorded using a device that detected the participant's initial contact with the response apparatus. An analysis of completion times produced the same pattern of results for the combined data set as did the reported analysis for response latency. We have found completion time data generally to be more variable than latency data and therefore prefer the latter for the sake of providing more powerful statistical tests of effects.

gestures, a pattern that fits with the results obtained here.

Given that the timing of the presentation of hand cues in our experiments was determined by the experimenter's reaction to the participant's completion of reading a sentence aloud, there was necessarily some variability in the synchronization of reading the object name and appearance of the hand cue. This method allowed only an approximate assessment of the time course of priming functional and volumetric gestures. Our approach, however, was adequate to show that priming of functional gestures occurred within a few hundred milliseconds of reading an object's name and that volumetric gestural knowledge was not reliably evoked, even more than half a second after reading was completed. In future experiments, we plan to use auditory presentation of sentences with presentation of hand cues exactly synchronized with selected target words.

Analysis of word meaning (Jackendoff, 2002) as well as developmental evidence (Kemler Nelson et al., 2000; Truxaw et al., 2006) indicates that the meaning of a word such as *calculator* is fundamentally rooted in the mental representation of its intended use. A crucial question concerns the relationship between abstract knowledge of function and the skilled movements required to properly use a manipulable object. We suggest that knowledge of the intended function of an object must minimally include a knowledge of the forces required on the relevant working components to produce the desired effect. For example, we assume that the meaning of *calculator* must include the fact that pressure has to be exerted in some way on the keys in the correct sequence for the device to actually calculate. Thus, knowing the correct function of an object must at least include some relatively abstract representation of the forces applied when operating it. The details of how to conventionally implement this function would be encoded in the motor system, but the functional knowledge is sufficiently abstract that the same forces can be correctly applied through other means (e.g., using one's nose to press a calculator's keys).

The full meaning of *calculator*, then, includes both an abstract description of the motoric forces that produce the intended goal in using the object and the details of the hand actions (functional gestures) that are typically used to generate those forces. Our results are entirely consistent with this assumption: A sentence like, *John thought about the calculator*, immediately activates gestural representations associated with the conventional use of calculator even though the meaning of the sentence does not imply any action on the object.

In addition to functional knowledge, knowing how to pick up an object must include a representation of the forces directed to relevant parts of an object's form. It is clear that these motor representations need not be the same as those enlisted for carrying out the function of the object. For example, picking up a calculator requires a completely different hand action than does using it. It is also important to note that another crucial distinction exists between motor representations associated with function and form. We have argued above that functional knowledge normally leads directly to actions associated with object use. This is not the case for volumetric gestural representations. Knowing the form of an object does not entail knowing the forces and actions required to pick it up. We are not saying, of course, that visual form does not recall from memory gestural representations associated with simply grasping an object under certain circumstances. Our claim is that this knowledge is not obligatory in the case of visual form, whereas functional gestural representations are automatically part of knowing the intended use of an object. Our results indicate that functional gestural knowledge can be evoked by words in sentences and in isolation without activating the corresponding representation of volumetric gestures. We have some evidence that volumetric gestures may be activated when responses are slower, and enough time is therefore available for them to show their presence (Bub et al., in press). These representations, we suggest, are separate from functional knowledge, not part of the core meaning of the object concept, and are activated over a longer time course during comprehension or perhaps when sentences specifically describe volumetric interactions with objects.

The relationship between knowing the abstract function of an object (e.g., that a calculator is used for numeric computation), the forces generated on the object to achieve this function, and the manual actions required to produce those forces remains an interesting question. Certainly, neuropsychological evidence indicates a complex organization that implies some degree of separability between these three aspects of object knowledge. The actions pertinent to implementing the function of an object can be triggered by the visual form, even though the core meaning (intended purpose) of the object is not accessible to the patient. An instance of the this kind of case was described by Sirigu, Duhamel, and Poncet (1991), in which the patient could still produce functional gestures to objects without relating these gestures to the correct intended use. Thus, for example, an iron evoked the correct mime of the typical motor action and the verbal response "you hold it in one hand and move it back and forth horizontally", but the avowed purpose of the object was "to spread glue evenly" (p. 2566). We can say that this patient did not understand the meaning of the object despite carrying out the relevant actions for its proper function because the actions did not relate to its typical use.

In cases of apraxia, patients may be able to state the intended function of an object even though lacking the details of the manner in which the action should be performed (Buxbaum, Veramonti, & Schwartz, 2000). Such patients, who are unable to manually demonstrate how an object is used, are often said to know what an object does without knowing how to use it (Mahon & Caramazza, 2003). Our view is that the nature of object representations allows for finer grained interpretations than this distinction implies. Patients may fail to know the details of how to interact with an object manually while clearly understanding the nature of the forces and their proper location required to implement the function. For example, using a pencil with a closed fist will not necessarily produce an ideal form of handwriting, but the intended purpose of the pencil is clearly understood.

It is not clear how the ability to name a visually presented object depends on the preservation of functional and motoric knowledge. The case described by Sirigu et al. (1991) indicates that patients may retain functional gestural knowledge without being able to name the object or identify its true purpose. Apraxic patients may be able to name objects without knowing the details of the associated functional gestures. We are unaware of any cases where naming is preserved but the patient has lost even a basic understanding of the force dynamics required to implement an object's function. This kind of dissociation, if observed, would imply that naming an object requires less than a complete specification of the function, at least in the sense of motoric forces typically applied to the object. It remains a matter of definition, then, whether one would infer that this putative case demonstrates that identifying an object does not require knowing the object's function. Naming an object is just one of a number of acts that we associate with our understanding of an object. To the extent that the understanding does not extend to the mechanisms of use, we can say identification is impaired, regardless of the preservation of a naming response. At the very least, our data show a very tight and automatic coupling between the process of understanding the meaning of a word that denotes a manipulable object and the evocation of precise parameters of hand actions dealing with the function of the object. There appears to be a close relationship between these action representations, the intentions typically associated with a manipulable object, and the meaning of a word referring to the object.

Finally, we consider the relationship between the gestural representations that we have measured to words in sentences and the distinction between dorsal and ventral streams and their contribution to action. Reaching for and grasping an object may, in certain cases of brain damage, be mediated entirely by the dorsal stream, which does not compute object identity (Goodale & Milner, 1992). In such cases, the grasp is not informed by functional knowledge, because this requires activity in the ventral system. Goodale and Milner (2004) described patient Dee, with damage to the ventral stream, who cannot identify objects, but who nevertheless directs a grasp correctly based on the size, shape, and orientation of an object. The grasp, however, is not determined by functional knowledge; Dee will reach out and grasp the shaft of a screwdriver when the handle is pointing away from her and gives no indication that she appreciates the function based on the visual percept. Normal participants behave similarly when reaching for objects under conditions of semantic interference produced by a memory-load task (Creem & Proffitt, 2001).

Although the evidence indicates that reaching for and grasping an object can be driven entirely by shape-based representations computed by the dorsal system, the planning of a hand posture for an intended interaction with an object is determined by a complex synergy between the ventral and dorsal streams. In the case of a word such as *calculator*, it is the meaning of the object and not merely its shape that is ultimately driving the influence that we observed on the earlier stages of the motor response. Our evidence indicates that reaching for and grasping a response element is affected by the meaning of a word shortly before launching the hand action. The aperture of the fingers during the later stages of the grasping response may be determined by aspects of object shape and size that are directly computed from visual representations (Kroliczak, Westwood, & Goodale, 2006). These visual attributes would be driven by the visual form of the response element. Earlier stages of the intended grasp show a strong influence of meaning, in particular the functional knowledge associated with the object referred to in the sentence context.

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REFERENCES

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*, 577–660.

Boronat, C. B., Buxbaum, L. J., Coslett, H. B., Tang, K., Saffran, E. M., Kimberg, D. Y., et al. (2006). Distinctions between manipulation and function knowledge of objects: Evidence from functional magnetic resonance imaging. *Cognitive Brain Research*, *23*, 361–373.

Bub, D. N., & Masson, M. E. J. (2006). Gestural knowledge evoked by objects as part of conceptual representations. *Aphasiology*, *20*, 1112–1124.

Bub, D. N., Masson, M. E. J., & Cree, G. S. (in press). Evocation of functional and volumetric gestural knowledge by objects and words. *Cognition*.

Buxbaum, L. J., & Saffran, E. M. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and nonapraxic subjects. *Brain and Language*, *82*, 179–199.

Buxbaum, L. J., Sirigu, A., Schwartz, M. F., & Klatzky, R. L. (2003). Cognitive representations of hand posture in ideomotor apraxia. *Neuropsychologia*, *41*, 1091–1113.

Buxbaum, L. J., Veramonti, T., & Schwartz, M. F. (2000). Function and manipulation tool knowledge in apraxia: Knowing "what for" but not "how". *Neurocase*, *6*, 83–97.

Creem, S. H., & Proffitt, D. R. (2001). Grasping objects by their handles: A necessary interaction between cognition and action. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 218–228.

Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences*, *20*, 1–55.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, *9*, 558–565.

Glover, S., Rosenbaum, D. A., Graham, J., & Dixon, P. (2004). Grasping the meaning of words. *Experimental Brain Research*, *154*, 103–108.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neuroscience*, *15*, 20–25.

Goodale, M. A., & Milner, A. D. (2004). *Sight unseen: An exploration of conscious and unconscious vision*. New York: Oxford University Press.

Goodale, M. A., Milner, A. D., Jakobson, L. S., & Carey, D. P. (1991). Perceiving the world and grasping it. A neurological dissociation. *Nature*, *349*, 154–156.

Jackendoff, R. (2002). *Foundations of language: Brain, meaning, grammar, evolution*. Oxford, UK: Oxford University Press.

Jeannerod, M., Decety, J., & Michel, F. (1994). Impairment of grasping movements following a bilateral posterior parietal lesion. *Neuropsychologia*, *32*, 369–380.

Kelemen, D. (1999). Beliefs about purpose: On the origins of teleological thought. In M. C. Corballis & S. E. G. Lea (Eds.), *The descent of mind* (pp. 278–294). Oxford, UK: Oxford University Press.

Kemler Nelson, D. G., Frankenfield, A., Morris, C., & Blair, E. (2000). Young children's use of functional information to categorize artifacts: Three factors that matter. *Cognition*, *77*, 133–168.

Klatzky, R. L., Pellegrino, J., McCloskey, B., & Doherty, S. (1989). Can you squeeze a tomato? The role of motor representations in semantic sensibility judgments. *Journal of Memory and Language*, *28*, 56–77.

Kroliczak, G., Westwood, D. A., & Goodale, M. A. (2006). Differential effects of advance semantic cues on grasping, naming, and manual estimation. *Experimental Brain Research, 175*, 139–152.

Lewis, J. W. (2006). Cortical networks related to human use of tools. *The Neuroscientist*, *12*, 211–231.

Lindemann, O., Stenneken, P., van Schie, H. T., & Bekkering, H. (2006). Semantic activation in action planning. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 633–643.

Loftus, G. R., & Masson, M. E. J. (1994). Using confidence intervals in within-subject designs. *Psychonomic Bulletin & Review*, *1*, 476–490.

Mahon, B. Z., & Caramazza, A. (2003). Constraining questions about the organization and representation of conceptual knowledge. *Cognitive Neuropsychology*, *20*, 433–450.

Masson, M. E. J., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology*, *57*, 203–220.

Myung, J.-Y., Blumstein, S. E., & Sedivy, J. C. (2006). Playing on the typewriter, typing on the piano: Manipulation knowledge of objects. *Cognition*, *98*, 223–243.

Perenin, M. T., & Vighetto, A. (1988). Optic ataxia: A specific disruption in visuomotor mechanisms: I. Different aspects of the deficit in reaching for objects. *Brain*, *111*, 643–674.

Phillips, J. A., Humphreys, G. W., Noppeney, U., & Price, C. J. (2002). The neural substrates of action retrieval: An examination of semantic and visual routes to action. *Visual Cognition*, *9*, 662–685.

Phillips, J. C., & Ward, R. (2002). S–R correspondence effects of irrelevant visual affordance: Time course and specificity of response activation. *Visual Cognition*, *9*, 540–558.

Pulvermüller, F., Shtyrov, Y., & Ilmoniemi, R. (2005). Brain signatures of meaning access in action word recognition. *Journal of Cognitive Neuroscience*, *17*, 884–892.

Sirigu, A., Cohen, L., Duhamel, J. R., Pillon, B., Dubois, B., & Agid, Y. (1995). Congruent unilateral impairments for real and imagined hand movements. *NeuroReport*, *6*, 997–1001.

Sirigu, A., Duhamel, J. R., & Poncet, M. (1991). The role of sensorimotor experience in object recognition. *Brain*, *114*, 2555–2573.

Tettamanti, M., Buccino, G., Saccuman, M. C., Gallese, V., Danna, M., Scifo, P., et al. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience*, *17*, 273–281.

Truxaw, D., Krasnow, M. M., Woods, C., & German, T. P. (2006). Conditions under which function information attenuates name extension via shape. *Psychological Science*, *17*, 367–371.

Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica*, *116*, 185–203.

Ulrich, R., & Miller, J. (1994). Effects of truncation on reaction time analysis. *Journal of Experimental Psychology: General*, *123*, 34–80.

Vandenberghe, R., Price, C., Wise, R., Josephs, O., & Frackowiak, R. S. J. (1996). Functional anatomy of a common semantic system for words and pictures, *Nature*, *383*, 254–256.

Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General*, *135*, 1–11.