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Evocation of functional and volumetric gestural knowledge by objects and words

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Abstract

We distinguish between grasping gestures associated with using an object for its intended purpose (functional) and those used to pick up an object (volumetric) and we develop a novel experimental framework to show that both kinds of knowledge are automatically evoked by objects and by words denoting those objects. Cued gestures were carried out in the context of depicted objects or visual words. On incongruent trials, the cued gesture was not compatible with gestures typically associated with the contextual item. On congruent trials, the gesture was compatible with the item's functional or volumetric gesture. For both gesture types, response latency was longer for incongruent trials indicating that objects and words elicited both functional and volumetric manipulation knowledge. Additional evidence, however, clearly supports a distinction between these two kinds of gestural knowledge. Under certain task conditions, functional gestures can be evoked without the associated activation of volumetric gestures. We discuss the implication of these results for theories of action evoked by objects and words, and for interpretation of functional imaging results.

Keywords: Embodied cognition; Gestural knowledge; Object identification; Word identification

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1. Introduction

Hand gestures produced when manipulating objects may constitute an important kind of knowledge that also plays a role in conceptual tasks such as object identification and language comprehension. The idea that motor processes may be important not only for physical action but also for conceptual operations is emphasized in theories of embodied knowledge (Barsalou, Simmons, Barbey, & Wilson, 2003; Gallese & Lakoff, 2005; Glenberg & Kaschak, 2002). For example, Bailey (1997; cited in Feldman & Narayanan, 2004) developed a computational model for the acquisition of verbs referring to hand actions that included explicit representations, called execution schemas, for the control of movement. These schemas were used to constrain the meaning of words like yank, poke, shake, and pry.

A considerable number of functional imaging studies provide indirect support for the claim that motor representations play a role in conceptual tasks involving manipulable objects. Tettamanti et al. (2005) recently demonstrated that listening to action-related sentences activates cortical motor areas. Similarly, viewing or naming objects that afford hand actions, such as tools, activate premotor cortex to a greater degree than other kinds of objects, such as animals (Chao, Haxby, & Martin, 1999; Chao & Martin, 2000). Additional evidence, however, is less consistent and suggests that visual objects do not invariably evoke motoric activation. Such activation may be task dependent. For example, Gerlach, Law, and Paulson (2002) showed premotor cortex involvement in a categorization task (natural vs. manmade), but not in object decisions (real vs. non-real). Devlin et al. (2002) reported a meta-analysis of seven studies that used positron emission tomography to examine specific activation patterns for man-made objects, especially tools, in relation to other object classes (e.g., fruits and vegetables). They found evidence for activation in left posterior temporal regions that was specific to tools, but only when subjects engaged in naming or semantic classification tasks, not during passive viewing. This result conflicts with other studies (e.g., Chao & Martin, 2000; Creem-Regehr & Lee, 2005) that have indicated that passive viewing of tools is sufficient to evoke a range of specific cortical responses associated with motor processes. Therefore, the relationship between subjects' task orientation to objects and the kind of premotor representations evoked remains an issue.

Behavioral studies with normal subjects are an additional source of evidence regarding this question. For example, Tucker and Ellis (1998) argued for automaticity of recruitment of motor representations in object identification. Subjects classified objects as appearing upright or upside down and responded with either a right-hand or left-hand key press. All objects were items with handles (e.g., teapot, frying pan) and were presented in such a way that the handle was aligned with the response hand on half of the trials and on other trials it was aligned with the other hand. Response latency was reliably shorter when the handle coincided with the side of the response hand. This result implies that the objects elicited some form of motor activity directed toward the handles even though manual interaction with the objects was not part of the classification task requirements. Glover, Rosenbaum, Graham, and Dixon (2004) primed subjects with names of objects (e.g., apple or grape) whose size was consistent or inconsistent with the size of a target (wide or narrow) that subjects had to reach and grasp between thumb and forefinger. The aperture size of the grasp was influenced by the prime (wider for apple than for grape) early in the reaching movement, but changed to conform to the target's size during later stages. This priming effect suggests that words automatically can activate motor representations that interact with the parameters of a grasping movement.

The evidence from behavioral studies goes some way toward establishing that certain aspects of hand movement are automatically recruited by objects or their names. There are limitations, however, to what we have learned so far. In particular, the central question of whether hand posture is evoked has not been addressed by the studies we described above. Tucker and Ellis (1998) demonstrated only that an object's handle influences selection of which hand to use when responding, but provided no evidence regarding whether hand shape can be influenced. Glover et al. (2004) established an interaction between the size of an object denoted by a word and finger aperture at early stages of movement, but we do not know whether more crucial aspects of hand–object interaction can be evoked automatically. Specifically, hand shape (e.g., positioning of fingers relative to palm, finger flexion, etc.) is crucially linked to how we use an object, whereas aperture size simply conveys sensitivity to the difference between large and small.

Klatzky, Pellegrino, McCloskey, and Doherty (1989) found that words denoting hand postures such as pinch or clench facilitated sensibility judgments about phrases describing actions (e.g., insert a key, draw with a zipper). They interpreted these results as indicating that subjects evaluate sentences by cognitively testing the action performed on the object such that the simulation of successful performance leads to a positive decision. Priming occurs because activating a hand shape facilitates construction of the simulation needed to represent the action–object pairing conveyed by the test phrase. A large number of the action–object pairs, however, tested knowledge of hand posture associated with the shape of an object (e.g., pick up a pencil or hold an apple). Other kinds of interactions depend on additional sources of knowledge (e.g., use a thimble to sew, use a hammer to pound a nail), and there was no distinction between these cases and shape-based interactions.

Neuropsychological evidence provides strong support for two different ways of interacting with objects. One way involves manipulating an object in accordance with its conventional use, for example, using a forefinger to depress the keys of a pocket calculator. The other way concerns the hand posture used to grasp an object to lift or move it, rather than to use it for its defined purpose. The latter gesture type would be sensitive to the shape and weight distribution of the target object. For example, picking up a stapler prototypically involves an open grasp with the hand positioned above the object. Neurological cases are consistent with this distinction between grasping an object according to shape or function. Patients with ideomotor apraxia can position and shape their hands correctly when picking up novel objects, but show impairment when asked to carry out the correct movements to use familiar objects, such as poking the buttons on a calculator (Buxbaum, Sirigu, Schwartz, & Klatzky, 2003). By contrast, Jeannerod, Decety, and Michel (1994) reported a case of optic ataxia in which hand configurations for grasping novel objects was severely impaired but manual interaction with familiar objects was preserved. We refer to gestures associated with the overall volumetric properties of objects as *volumetric gestures*. Gestures associated with the conventional uses of objects are called *functional gestures*. For some objects, typical volumetric and functional gestures are virtually equivalent; for example, picking up vs. drinking from a glass. For other objects, these two types of gesture are very different (e.g., spray bottle: open grasp to pick up and trigger to use).

The distinction between volumetric and functional gestures is similar to that made by Johnson-Frey between "acting on" and "acting with" an object (Johnson-Frey & Grafton, 2003) or between systems for prehension and utilization (Johnson-Frey, 2003). Our notion of functional and volumetric gestures, however, includes the distinction between the gestures automatically evoked by an object through memory representations and the ability to form explicit intentions to act on or with an object. In special circumstances, it is possible that functional gestures are elicited by an object even though the actor is no longer capable of forming the associated intention. This phenomenon can be seen, for example, in a patient described by Sirigu, Duhamel, and Poncet (1991) who produced correct functional gestures to objects without being able to identify them or explain what the objects are used for. It is also possible that volumetric gestures are evoked by familiar objects even when the ability to program grasp actions to novel objects is impaired (Jeannerod et al., 1994). To the extent that Johnson-Frey's distinction between acting on or with an object refers to the user's intentions, our definition differs from his. On our view, functional and volumetric gestures may be evoked because of prior experience, even though the actor may no longer be capable of forming the correct associated intention.

1.1. Logic of gesture–object opposition

In the experiments reported here, we examine whether functional and volumetric gestures are evoked by familiar visual objects while carrying out an action not directed to the object itself. To accomplish this goal, we introduce a novel approach. This approach not only provides us with a means to address the question of whether viewing objects elicits manual gestures associated with their function and/or shape, but also has considerable potential to contribute to an understanding of other unresolved issues on the nature of gestural knowledge and its causal role in processing objects and object concepts. The logic of our approach in the studies described below is based on the principle of opposition, whereby the intended action on the part of a subject is susceptible to interference from another gesture evoked by an object (Bub, Masson, & Bukach, 2003). For example, suppose that a subject is cued to produce a poke gesture while viewing an object, such as a beer mug, that affords an entirely different set of gestures associated with its use or volumetric properties. If the object evokes any of these gestures, then they will be in conflict with the intended gesture and production of that gesture should be slowed.

Subjects were cued to generate specific gestures by presenting them with objects in color. To distinguish between functional and volumetric gestures, we defined a set of gestures of each type, then selected objects to match each gesture within a type. Each color was associated with a specific gesture (e.g., red = poke). For some object–color pairs, the intended gesture and the gesture automatically evoked by the object were in conflict. For example, a stapler colored in red may cue the observer to make a poke gesture which is inconsistent with the gestures typically associated with that object (e.g., palm gesture to staple pages, open grasp to pick up). Although a variety of arbitrary gestures could be applied to any object, depending on the intention of an actor, there is good reason to define as inconsistent those gestures that depart from the manual interactions prototypically used to interact with an object under conventional circumstances. Normal subjects show very good agreement on the kind of gesture that is habitually used to manipulate a particular object (Klatzky, McCloskey, Doherty, Pellegrino, & Smith, 1987).

In addition to incongruent color–object pairings, congruent pairings were also used. In the congruent case, the gesture cued by the color was either the conventional functional gesture associated with the object (e.g., a palm gesture for a stapler) or the prototypical volumetric gesture used to pick up the object (e.g., open grasp for a stapler). Evidence that a particular functional or volumetric gesture is evoked by an object would be revealed by a difference in the time taken to carry out a gesture to the color in the incongruent vs. congruent conditions. Of course, this outcome will obtain only if our definition of congruency is valid. If open grasp for a stapler is not a primary or typical volumetric gesture that is represented as part of the action repertoire for this object, then this gesture made in response to the color of a stapler would effectively be incongruent. We would then have no possibility of observing a difference between congruent and incongruent color–object pairings as we have defined them.

The logic of this opposition approach is directly analogous to the color–word Stroop interference paradigm (Stroop, 1935), but applied to the question of gestural representations rather than color names. Consider, for example, a pocket calculator. If this object activates a poke gesture (associated with the calculator's function), then on congruent trials the gesture to the color will conform to the calculator's functional gesture. On incongruent trials, the color-cued gesture will be incompatible with the gestures normally used to interact with the object. If responding to color is faster on congruent trials relative to incongruent trials, then one can conclude that the congruent functional gesture has been evoked. The same logic applies to congruency defined by the volumetric gesture typically associated with an object. If a calculator evokes the gesture normally used to pick it up (an inverted grasp), then cuing this action by color should lead to faster responding than cuing some other action typically unrelated to interactions with the object. By comparing performance on congruent relative to incongruent trials and by using different sets of gestures, it is possible to assess separately the question of whether functional and/or volumetric gestures are evoked by objects. A similar approach based on congruency was used by Naor-Raz, Tarr, and Kersten (2003) in their investigation of color as an intrinsic part of visual object representations. In this study, subjects named the color in which an object was presented, and that color was either congruent or incongruent with the object's typical color. Incongruent colors took longer to name, implying that knowledge of object color is evoked even when doing so is not directly relevant to the assigned task.

1.2. Measurement of gestures

In our initial study using this variant of the Stroop interference paradigm (Bub et al., 2003), we relied on pantomimed responses to colors as a means of measuring subjects' generation of gestures. This measure has a number of limitations including insufficient constraints on the details or consistency of the hand postures produced and the positioning of the hand in space. We therefore constructed a response apparatus (which we call the *Graspasaurus* because of its size and antediluvian appearance) consisting of a set of three-dimensional, aluminum forms mounted on a curved base and placed in front of the subject (see Fig. 1). Each form was abstract in nature, but designed to afford a specific manual gesture. For example, the element corresponding to the poke gesture consisted of a flat base with an indentation large enough to fit the tip of a finger (left panel of Fig. 1). To respond to a color cue, the subject mentally prepared the target gesture, then lifted the dominant hand from a depressed key and immediately applied the gesture to the appropriate element of the apparatus. Although none of the Graspasaurus elements conformed to the exact shape of our target objects, there is a clear correspondence between the shape of the grasp subjects were trained to apply to a particular element and the grasp typically used when interacting with the relevant object in our set. For example, the functional gesture for a pocket calculator is a poke, and this gesture generally fits the parameters of the gesture carried out on the Graspasaurus. Single-cell recording data from monkeys reveal cells that respond to a range of similar hand postures evoked by different objects, such as a precision grasp made to a small cylinder or to a narrow plate

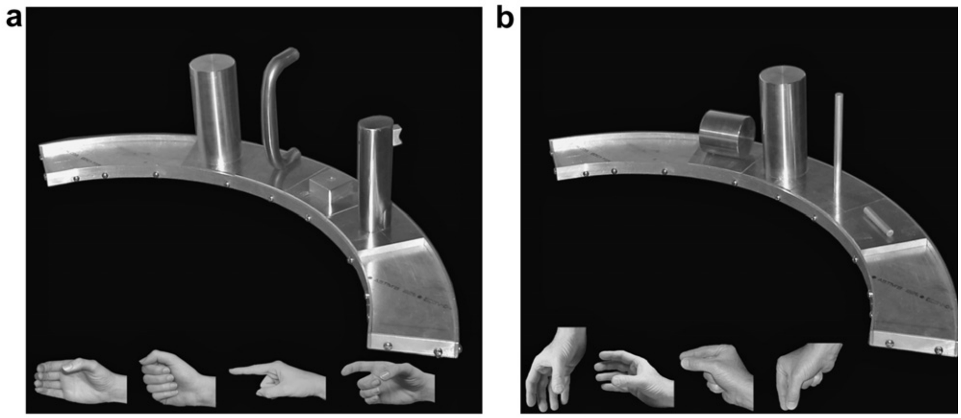

Fig. 1. The Graspasaurus is pictured with two different configurations of four elements and the gesture associated with each element. (a) Elements used for functional gestures, affording from left to right the following four gestures: open grasp, closed grasp, poke, and trigger. (b) Elements used for volumetric gestures, affording from left to right the following four gestures: horizontal grasp, vertical grasp, vertical pinch, and horizontal pinch. Subjects responded by making a target gesture to the corresponding Graspasaurus element.

(for a discussion of this evidence, see Fagg & Arbib, 1998). If the parameters of a motoric representation evoked by an object are similar to the parameters required to interact properly with an element of the Graspasaurus, then we assume that for the purpose of defining congruency there is an equivalence between the action made to that element and the corresponding action evoked by the object.

In summary, subjects were trained to make a specified response on the Graspasaurus to each of four different colors. Objects were then presented in color and the task was to respond to the color and ignore the object. On congruent trials, the required gesture matched a gesture typically evoked by the object, whereas on incongruent trials, the color gesture did not conform to an action typically associated with the object. We measured the time to initiate a gestural response on the Graspasaurus element from the onset of the colored object. An effect of congruency would establish that viewing an object evokes gestural representations independently of the gesture retrieved in response to the color.

1.3. Outline of experiments

Functional and volumetric gestures were examined in Experiment 1 by comparing congruent color–object pairs (the color cues a gestural response that matches the typical functional or volumetric gesture associated with the object) to incongruent pairs (the color cues a non-matching gestural response). In addition, a set of filler objects that do not afford manipulation gestures was included to reduce the overall proportion of trials on which the color-cued gesture was congruent with the object, thereby minimizing the likelihood of strategic recruitment of gestures based on object identity instead of color. In Experiment 2, we establish that congruency effects found in Experiment 1 are specifically the result of carrying out manual actions to elements of the Graspasaurus. In particular, we show that these effects do not obtain when subjects simply touch the base of each element rather than produce a relevant grasping action.

An advantage of the method we have developed is that it can be applied to the investigation of whether words evoke gestural representations as well as to the study of objects. In Experiments 3 and 4, we use congruent and incongruent word–color pairings where the words refer to the names of objects used in Experiments 1 and 2. In Experiment 3, we examine the question of whether congruency effects can be elicited simply by passive viewing of words and whether any such effects vary between functional and volumetric gestures. In Experiment 4, we wished to determine whether a conceptual task such as lexical decision influences the evocation of specific gestural knowledge to words. In Experiment 5, we shift to a priming paradigm in which objects are presented as primes in advance of cues to make particular gestures. A cue consisted of a photograph of a hand denoting a specific gesture. This paradigm provides better control over the time course of knowledge activation and allows us to examine a relatively early point in processing. The results of this experiment demonstrate a dissociation between functional and volumetric gestural knowledge with respect to evocation by words.

2. Experiment 1

2.1. Method

2.1.1. Subjects

Thirty-two introductory psychology students at the University of Victoria took part in Experiment 1 and received extra credit in their course in return for their participation. Half of the subjects were tested with functional gestures and the other half with volumetric gestures.

2.1.2. Materials

A set of 16 manipulable objects were selected such that two of the objects were deemed appropriate for each of the eight gestures used in Experiment 1. Four functional gestures (closed grasp, open grasp, poke, and trigger) and four volumetric gestures (horizontal grasp, horizontal pinch, vertical grasp, and vertical pinch) were defined in conjunction with their corresponding objects. For example, door bell and pocket calculator were the objects associated with the functional gesture consisting of a poke (i.e., a poke gesture is made when using these objects for their intended purpose), and lotion bottle and spray bottle were the objects associated with the volumetric gesture of vertical grasp (a grasp with the wrist vertically oriented and a large aperture between thumb and fingers typically would be used to pick up these objects). A complete list of gestures and objects is provided in Appendix A.

Digital photographs were made of each of the 16 objects and of a human hand posed in each of the eight gestures (the gestures are shown in Fig. 1). These images were modified so that background details were replaced by a black background. Five images of each of the objects were created, one in gray scale and the others in one of four colors: blue, green, red, and yellow. Each hand was used to create a set of four images, with the hand appearing in gray scale on a black background above a rectangular block of color; one image was created for each of the four possible colors. Two different versions of the images of hands and objects were created, one with the images oriented for right-handed interaction and another for left-handed interaction. These different versions allowed us to accommodate both right- and left-handed subjects. The four functional gestures and their eight objects were used for half of the subjects and the four volumetric gestures and their eight objects were used for the other half of the subjects. An additional set of eight objects that are not typically associated with one-handed manipulation (e.g., bed, truck, and ship) were selected for use as filler items in both experiments. Five images of each of these objects were prepared in the same manner as the manipulable objects.

2.1.3. Procedure

Subjects were tested individually under the supervision of an experimenter. Materials were presented using a G3 Macintosh computer equipped with two color monitors. The subject viewed one monitor while the experimenter viewed the other monitor, which presented information indicating the correct response expected on each trial. This arrangement allowed the experimenter to record the correctness of the subject's response by a key press after each trial. An error was recorded if the subject executed an incorrect gesture. The subject was seated in front of the monitor, with a response box and the Graspasaurus placed on the table between the subject and the monitor. The Graspasaurus was configured with four elements corresponding either to the four functional or to the four volumetric gestures to be tested with a particular subject. The relative positions of the four elements on the base of the Graspasaurus were counterbalanced across subjects so that each element was tested equally often in each position.

In the first phase of the procedure, subjects were trained to associate one of four colors with each of four gestures. Assignment of color to gesture was counterbalanced across subjects. In the first part of the training phase, subjects were instructed how to make each of the four target gestures using the appropriate element of the Graspasaurus. Next, subjects were presented 32 trials in which a gesture–color pair appeared on the monitor. Subjects placed the forefinger of the preferred hand on a button on the response box to begin a trial. An image consisting of a hand gesture and a colored rectangle appeared and the task was to make the pictured gesture by lifting the preferred hand from the response box and grasping the correct element of the Graspasaurus. Each of the four gestures was presented eight times. During these trials, subjects were instructed to learn the color–gesture associations. In the next part of the training phase, consisting of 80 trials, a colored rectangle was presented and the task was to generate the correct gesture from memory. If the subject demonstrated adequate accuracy, then the test phase was initiated, otherwise another round of 16 trials with color–gesture stimuli and 40 trials of color-only stimuli was run.

At the beginning of the test phase, subjects were shown each of the eight critical and eight filler objects twice in gray scale to ensure they could identify each object. On the first pass, the experimenter named each object, and on the second pass, the subject named each one. Next, a series of 18 practice trials was presented, followed by a randomly ordered set of 96 critical and 48 filler trials. On each of these trials, an object appeared in one of the four colors against a black square. When viewed from 40 cm, the square was 20.5° wide and high. Each of the objects was scaled to be no more than 16.4° wide or 19.9° high and appeared in the center of the black square. The task was to make the gesture associated with the color as rapidly and as accurately as possible, without regard to the nature of the object carrying the color.

Over the 96 critical and 48 filler trials, each critical object appeared 12 times and each filler object appeared six times. For half of the critical object presentations (*congruent* trials), the object appeared in the color whose associated gesture was appropriate for the object (e.g., poke for pocket calculator), and for the other half (*incongruent* trials), the color was associated with an incongruent gesture (e.g., trigger gesture for pocket calculator). For incongruent trials, each object appeared equally often in each of the three possible incongruent colors.

The dependent measures of interest were response latency, measured from the onset of the colored object to the moment the subject lifted the preferred hand from the response box to initiate the target gesture, and accuracy of gesture selection. We did not use the preferred measure of total time from object onset to completion of the gesture (Meegan & Tipper, 1998) because the Graspasaurus was not yet equipped with touch-sensitive detectors. Subjects were, however, carefully instructed not to begin responding until they were sure of the target gesture they intended to produce. In addition, the experimenter ensured adherence to this requirement throughout the test session. If our measure of lift-off time is seriously compromised by premature responses, then it would not be possible to obtain the clear effects we report below (see Craighero, Fadiga, Rizzolatti, & Umilta, 1998, 1999; for results using a similar measure of response latency.) Moreover, there is evidence that cognitive effects on manual action are particularly evident in initiation or early stages of the gesture (Glover, 2004; Glover & Dixon, 2002; Glover et al., 2004; Lindemann, Stenneken, van Schie, & Bekkering, 2006). Our expectation is that it is early stages of gesture planning that will be particularly affected by the congruency manipulation used here.

2.2. Results and discussion

Response latencies below 250 ms were not included in the analyses reported here. These events were considered to be instances in which subjects responded prior to having selected the appropriate target gesture and most probably involved hesitation following lift-off prior to reaching out for the correct Graspasaurus element. One subject tested with volumetric gestures was excluded from analyses because of an excessive number of response latencies below 250 ms. Another subject from that group was excluded because of unusually long response latencies, suggesting inadequate learning of color–gesture associations. For the remaining subjects, 1.5% of correct responses were made with a latency less than 250 ms and these were omitted from analyses. In addition, latencies longer than 1800 ms were excluded as outliers (0.3% of the observations). This cutoff was established so that no more than 0.5% of correct latencies were removed (Ulrich & Miller, 1994).

Mean correct response latencies for functional and volumetric gestures are shown in Fig. 2. These data were submitted to an analysis of variance (ANOVA) with gesture type (functional, volumetric) as a between-subjects factor and congruency between the target gesture and the gesture implied by the object (congruent, incongruent) as a repeated-measures factor. The significance level for tests reported in this article was set at .05. The ANOVA revealed a main effect of congruency, $F(1,28) = 18.75$, $MSE = 723$, with longer response latencies in the incongruent than in the congruent condition (634 vs. 604 ms). There was no main effect of gesture type, $F(1,28) = 1.79$, $MSE = 53{,}426$, nor an interaction between gesture type and congruency, $F < 1$. Thus, both functional and volumetric gestures showed congruency effects of a similar magnitude. The rather large difference in mean latency for the two gesture types (disregarding the congruence manipulation) appears to be the result of substantial between-subject variability (note the MSE values for the two main effects) rather than a systematic difference between the two classes of gesture. The overall error rate was 1.8%, and an ANOVA found no significant effects of gesture type or congruency on errors.

These results clearly indicate that knowledge about functional gestures (corresponding to manual interactions with an object based on its conventional use) is recruited when responding to a surface property (color) of an object. In addition,

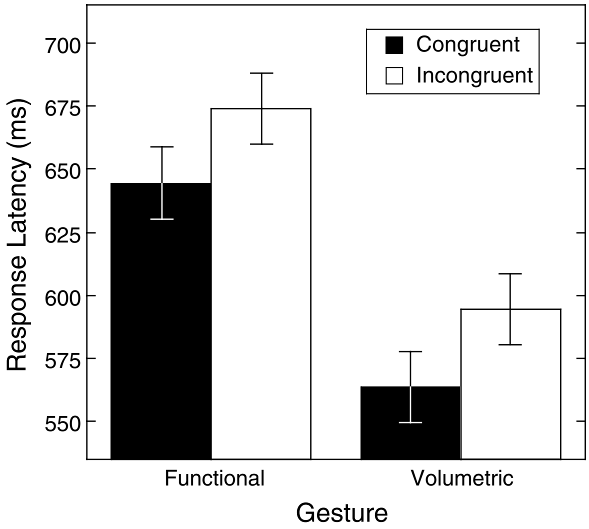

Fig. 2. Mean response latency in Experiment 1 as a function of gesture type and gesture-object congruency. Error bars represent the 95% within-subjects confidence interval and are appropriate for comparing patterns of means across congruency conditions (Loftus & Masson, 1994; Masson & Loftus, 2003).

volumetric gestures, associated with pure shape rather than function, are also activated. These forms of knowledge are not explicitly required for carrying out the assigned task in Experiment 1. Moreover, deliberate retrieval is likely to be time-consuming and, on most trials in our experiments, detrimental to task performance. Therefore, we infer that the evocation of gestural knowledge referring to form and function is obligatory under the conditions we have established.

The availability of both functional and volumetric manipulation knowledge as components of action elicited by man-made objects raises an interesting question about the interpretation of neuroimaging data that indicate premotor activity associated with viewing manipulable objects (e.g., Chao et al., 1999; Chao & Martin, 2000). We do not know at present whether this activity reflects functional or volumetric actions or some combination of the two. Indeed, Gerlach et al. (2002) showed premotor activation when subjects categorized fruits and vegetables. They concluded that manipulation knowledge is represented as part of the meaning of both natural and manmade objects that afford hand actions. Our interpretation of this result is that a substantial component of premotor activation must include gestural knowledge associated with the shape of objects (e.g., pinch to pick up a grape) in addition to their function. Consistent with this idea, Tucker and Ellis (2001) showed that small objects like a grape can be classified as natural rather than manmade more quickly if the required response is a pinch (precision) gesture than if it is a clench (power) grasp; the opposite was true for larger objects such as a banana. It would be an elementary step using our procedure to demonstrate the activation of volumetric gestures to natural objects such as these. A goal, then, for functional imaging studies would be the development of a sufficiently precise methodology to distinguish between functional and volumetric types of manipulation knowledge to support claims about specific semantic representations of manmade objects such as tools (cf., Chao et al., 1999; Chao & Martin, 2000).

3. Experiment 2

The use of the Graspasaurus as a response device requires that subjects select from among multiple elements. Before concluding that the results of Experiment 1 are specifically due to contextual effects on the preparation of hand shape, we must rule out an alternative possibility. The object on the screen may not produce effects on grasping per se, but may instead simply interfere with the selection of the correct response element of the Graspasaurus signaled by the object's color. This interference could occur because the object resembles one of the elements of the Graspasaurus, causing the subject to inadvertently orient to that element when making a response. Such interference could plausibly take place even when subjects are not engaged in making grasp responses, but simply respond by pointing. Indeed, a number of studies investigating motor priming effects of objects on action are open to this kind of limitation. For example, in the Craighero, Fadiga, Rizzolatti, and Umilta (1999) study, subjects prepared a grasp response to one of two bars that varied in orientation (diagonally oriented to the left or right). Initiation of the response was then cued by a picture of a bar oriented compatibly or incompatibly with the prepared grasp. Although there were effects of cue compatibility on response latency, these effects held even when grasp responses were replaced by other forms of responding (foot press or eye blink). Clearly, whatever stages of motor processing were influenced by response-cue compatibility, they could not have been concerned specifically with manual grasping (see also, Phillips & Ward, 2002).

Fortunately, a control experiment can be conducted that would convincingly rule out this alternative interpretation of Experiment 1. In Experiment 2, rather than requiring subjects to grasp elements of the Graspasaurus cued by color, we instructed them instead to touch the base of the cued element. All other aspects of the experimental procedure were the same as in Experiment 1, including the requirement to select the correct Graspasaurus element. The congruency between cued response and gesture associated with the viewed object was implemented as before, but if visual similarity between objects and Graspasaurus elements alone is sufficient, we should observe a congruency effect even when subjects merely reach for an element without grasping it. Our claim, however, is that congruency depends crucially on the interaction between gestural knowledge evoked by the object and the generation of a grasp response. There is considerable evidence consistent with our assumption that there should be a fundamental distinction between reaching for and grasping an element of the Graspasaurus. First, electrophysiological research with monkeys indicates that there are distinct frontal and parietal mechanisms for grasping and reaching, though these operations are integrated by additional processes (Jeannerod, 1997). In addition, a recent functional imaging study by Culham et al. (2003) demonstrated distinct activation of the parietal cortex when grasping objects as compared to reaching and touching them without making a grasp response. If the results of our Experiment 1 are specifically due to the formulation of grasp responses, then requiring subjects to reach and touch the base of the Graspasaurus elements (with no requirement to generate a manual grasp) should not yield congruency effects.

3.1. Method

3.1.1. Subjects

Thirty-two subjects were drawn from the same pool as in Experiment 1. Half were tested with functional items and half with volumetric items.

3.1.2. Materials and procedure

The same materials and procedures were used as in Experiment 1, except that in the training phase, subjects were not shown hand gestures to imitate. Rather, they were shown gray-scale images of the relevant Graspasaurus elements, each paired with one of the four colors. The task in the training phase was to touch the base of the appropriate Graspasaurus element when cued by a color. The test phase was identical to Experiment 1, except that, as in training, subjects responded by touching the base of an element of the Graspasaurus, rather than carrying out an articulated gesture.

3.2. Results and discussion

Observations were excluded according to the same criteria as applied in Experiment 1. The lower bound of 250 ms was exceeded in 0.3% of the observations and these were removed from consideration. The upper limit for correct response latencies was set at 2100 ms, which removed 0.4% of the observations. Mean correct response latencies are shown in Fig. 3. An ANOVA with congruency and gesture type as factors was computed for these data. The 8-ms congruency effect was not significant, $F(1, 30) = 1.96$, $MSE = 549$, and neither were the main effect of gesture type nor the interaction, $F\text{s} < 1$. The mean percent error across all conditions was 0.1%. An ANOVA of these error data found no significant effects.

The power of this experiment to detect a congruency effect in response latency half the size of the effect found in Experiment 1 was greater than .8. Moreover, a comparison of response latencies across the two experiments, including experiment as a factor along with congruency and gesture type revealed a main effect of congruency, $F(1, 58) = 17.91$, $MSE = 632$, and a significant interaction between experiment and congruency, $F(1, 58) = 5.87$, $MSE = 632$, indicating that the congruency effect in Experiment 1 was significantly larger than in Experiment 2. No other effects in this analysis were significant.

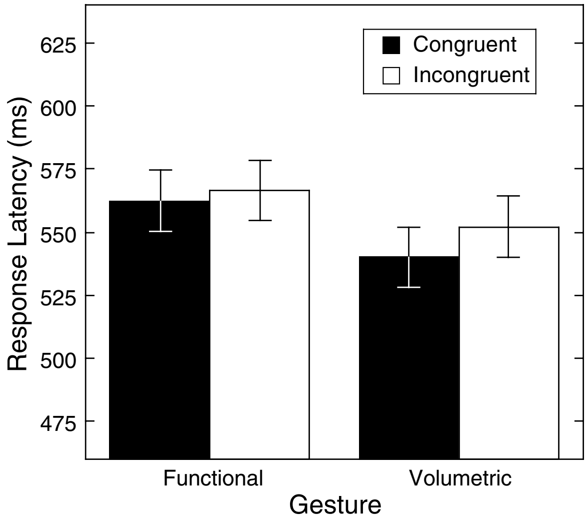

Fig. 3. Mean response latency in Experiment 2 as a function of gesture type and nominal gesture-object congruency. Error bars represent the 95% within-subjects confidence interval and are appropriate for comparing patterns of means across congruency conditions.

There was no indication, despite adequate statistical power, of congruency effects when subjects were directed to reach out and touch, rather than make a grasp response to, the Graspasaurus elements. This result clearly implies that the congruency effects found in Experiment 1 did not occur merely because of visual similarity between elements of the Graspasaurus and the objects carrying color. Nor did they arise from stages of processing that involve reaching as opposed to grasping a response element. The congruency effects observed in Experiment 1, but not in Experiment 2, represent a dissociation between reaching and grasping. The motor representation constructed for grasping an element of the Graspasaurus is affected by gestural knowledge associated with a viewed object, whereas the action of reaching for a response element without the intention of grasping it shows no such influence. In contrast to this dissociation between reaching and grasping, Pavese and Buxbaum (2002) found that both reaching for and grasping a handle showed comparable interference from the presence of a distracting alternative object. We suspect that they obtained similar results for these two types of responses because they were made by subjects in alternating blocks, which required responding with a grasp to a handle on one occasion, and responding with a reach on a later occasion. This switching between response tasks may have altered the nature of the reaching response to include representational elements of grasping. In addition, it is also possible that handles per se strongly invite a grasp even when the intended task is merely a reach. Our results are based on a larger and more diverse set of objects and hand postures, and we found evidence that manual gestures, but not reaching, are sensitive to interference from conflicting motor representations elicited by objects.

4. Experiment 3

An interesting question that we are now in a position to address is whether visually presented words are capable of eliciting motor representations of hand actions under the task conditions that we have implemented. Previous evidence is suggestive that words and sentences evoke some kind of gestural knowledge when meaning is derived, but we have little information about the nature of this motor representation. Tettamanti et al. (2005) found that listening to sentences describing hand, mouth, or leg action-related sequences caused activation of corresponding premotor areas associated with the relevant body part. Myung, Blumstein, and Sedivy (2006) used a running lexical decision task to show that priming of word identification is partly dependent on similarity of manipulation gestures between prime and target items (e.g., piano was classified faster when it followed typewriter rather than a control word). In the Myung et al. study, related word pairs referred to objects that shared a broad similarity between actions that sometimes included related arm or wrist movements but not hand posture (e.g., key and screwdriver). Other studies using words have shown that grasp aperture is influenced by words that denote objects requiring power or precision grips. For example, Glover et al. (2004) showed that words referring to large or small objects (apple vs. grape) affected grip aperture at early stages of a grasp response to a wooden block. We do not know, however, for this and other similar studies (e.g., Gentilucci, Benuzzi, Bertolani, Daprati, & Gangitano, 2000), whether the effects observed have simply to do with the size of the object referred to by the word rather than specific hand postures relevant to the object's shape or function. There is no good evidence at this point that words referring to objects can elicit hand actions related to the functions or shapes of those objects.

To examine whether functional and volumetric gestures are elicited by words just as they are by objects, we repeated Experiment 1 but this time using an object name to carry color instead of a depicted object. If words have the potential to recruit manipulation knowledge, then responding to color with no need to attend to the identity of the word carrying that color should nevertheless yield congruency effects similar to those observed in Experiment 1.

4.1. Method

4.1.1. Subjects

Forty-eight students were sampled from the same population as in the earlier experiments. Half were tested with functional gestures and half with volumetric gestures.

4.1.2. Materials and procedure

The same items and procedure were used as in Experiment 1, except that instead of using objects to carry the color cues in the test phase, words denoting those objects were used. Subjects went through the same color–gesture training procedure as in Experiment 1, but no objects were shown to the subjects at any time. In the test phase, object names were displayed in color against the same black background used in the earlier experiments. Words were printed in bold, uppercase font. Viewed from 40 cm, the letters were 1.0° high and an 8-letter word was 5.7° wide.

4.2. Results and discussion

The data from one subject in the volumetric gesture condition were excluded from analysis because this subject too frequently (74% of all trials) initiated a response earlier than 250 ms after stimulus onset, implying that the response was not fully prepared. The response latency data for the remaining subjects were filtered as in the earlier experiments. The lower bound of 250 ms led to exclusion of 1.7% of the correct responses. The upper bound on response latency was set at 1900 ms, which eliminated 0.4% of the observations. Mean correct response latency is shown in Fig. 4. An ANOVA revealed that the congruency effect of 6 ms was not significant, $F(1,45) = 1.54$, $MSE = 644$. The gesture type main effect and interaction were also not significant, $Fs < 1$. The mean error rate across all conditions was 1.2% and an ANOVA indicated that there were no significant effects of congruency or gesture type in the error data.

The power of Experiment 3 to detect an effect of color congruency on response latency equal to half the size of the effect found in Experiment 4 was greater than .97. Thus, despite substantial power to detect the evocation of gesture knowledge, Experiment 3 failed to find evidence that simply viewing words as color carriers was sufficient to recruit gestural knowledge associated with the objects denoted by those words. It is possible, then, that words generally fail to provide adequate

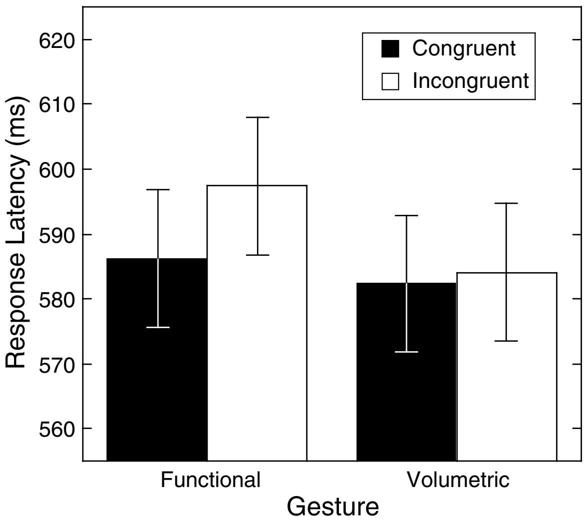

Fig. 4. Mean response latency in Experiment 3 as a function of gesture type and gesture-object congruency. Error bars represent the 95% within-subjects confidence interval and are appropriate for comparing patterns of means across congruency conditions.

context for gesture representations to be evoked and that more powerful stimuli such as objects are required to elicit these representations. Alternatively, if gesture knowledge is an important component of the conceptual representations of manipulable objects, then directing an observer's attention to the meaning of a word may succeed in recruiting object-specific gesture knowledge.

5. Experiment 4

In Experiment 4, we directed subjects to attend to word meaning by requiring a lexical decision response to be made after gesturing to color. Volumetric and functional manipulation knowledge may be affected differently by this demand. If function is more central to word meaning than object form, then congruency effects for functional gestures should be enhanced when attention is directed to the meaning of the word. By contrast, volumetric gestural knowledge may be a more peripheral part of object meaning that is not contingent on the degree to which a subject attends to a word. Thus, elevated attentional demands for volumetric gestures may not produce congruency effects. Finally, we expected that regardless of whether any congruency effect is found in Experiment 4, response latencies should be slower overall relative to Experiment 3. This slowing should arise because subjects are now required to execute an additional operation (deliberately evaluate word meaning) that was not part of stimulus processing in Experiment 3.

5.1. Method

5.1.1. Subjects

Forty subjects were sampled from the same pool as in the earlier experiments, and half were tested with each gesture set. An additional sample of 20 subjects from the pool was tested with the functional gesture set, as explained in the results section.

5.1.2. Materials and procedure

The same materials were used as in Experiment 3, except that the eight words denoting filler items were replaced by nonwords which served as foils for the lexical decision task that was performed on the letter strings that carried color. The nonwords were created to have characteristics similar to the object names used on critical trials (e.g., two-element compounds in some cases). Subjects were trained on color-gesture pairs as in Experiment 3, but were not exposed to any pictures of objects. In the test phase, subjects were instructed to gesture to color as in the earlier experiments, but after completing their gesture, they then made a button-press response using the response box to classify the letter string that carried the color as a word or a nonword. This response was based on memory for the letter string, which was erased as soon as the subject initiated a gesture response to the color. Only accuracy was stressed on the lexical decision task and response latency was not recorded.

5.2. Results and discussion

After the two initial groups of 20 subjects were tested, it was found that the congruency effect for the functional gesture group when tested separately was equivocal. We therefore decided to test a second cohort of 20 subjects using those gestures to obtain a more stable result. We report analyses based on all 40 subjects tested with functional gestures.

Mean percent correct for the classification of the colored strings as words or nonwords was 92.0% indicating that subjects accurately distinguished object names from nonwords. Responses on the gesture task were assessed as in the earlier experiments but our analyses include only those trials on which a valid object name was used to carry color. Data from nonword trials were not analyzed. Responses below 250 ms were excluded as premature initiation of gestures (0.3%) and responses longer than 3600 ms were treated as outliers (0.4%). Mean correct response latencies were computed on the basis of the remaining observations and the means computed across subjects are shown in Fig. 5. An ANOVA revealed a significant congruency effect of 44 ms, $F(1,58) = 14.66$, $MSE = 3{,}935$. The effect of gesture type and the interaction were not significant, $Fs < 1.8$.[2] The mean error rate across conditions was 0.4%. An ANOVA based on errors found no significant effects.

The difference in congruency effects obtained in Experiment 3 vs. Experiment 4 was examined in an ANOVA with experiment as a factor. This ANOVA indicated that there was a significant interaction between experiment and congruency, $F(1,103) = 8.01$, $MSE = 2{,}497$, showing that the congruency effect was reliably larger in Experiment 4. In addition to a significant main effect of congruency, $F(1,103) = 14.05$, $MSE = 2{,}497$, this analysis also showed that subjects generally took longer to respond in Experiment 4 than in Experiment 3 (938 vs. 588 ms), $F(1,103) = 67.42$, $MSE = 83{,}665$.

The magnitudes of the congruency effects for functional and volumetric gestures in Experiment 4 were very similar to one another and much larger than the nonsignificant effect seen in Experiment 3. Attending to the meaning of a word clearly increases the extent to which manipulation knowledge is activated. There is no indication, however, for a preferential status of functional over volumetric knowledge. Both appear from this evidence to be components of embodied conceptual representations for objects. In addition, the substantial increase in overall response latency in Experiment 4 relative to Experiment 3 is consistent with our assumption that subjects in Experiment 3 were not engaged in deliberate retrieval of word meaning.

The congruency effect obtained here converges with the demonstration by Myung et al. (2006) that words sharing elements of manipulation knowledge prime one another in a word identification task. Myung et al. proposed that this type of knowledge was recruited when identifying words and could serve as the basis for priming word identification. Similarly, we conclude that when identifying words or reading

[2] An ANOVA including only the first group of 20 subjects in the functional gesture condition and the 20 subjects in the volumetric gesture condition generated the same pattern of effects as that found with the full set of subjects.

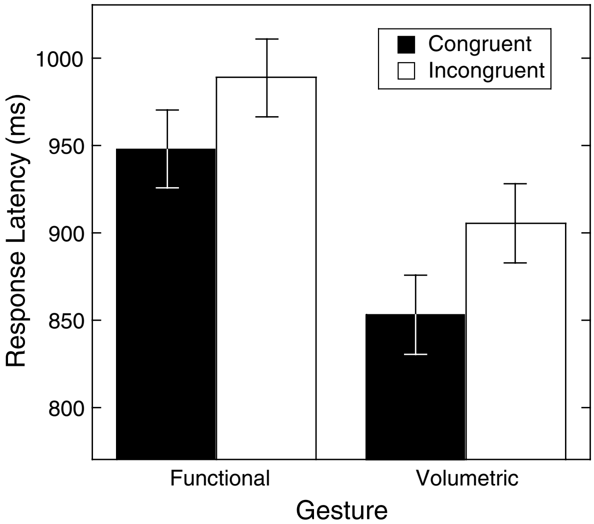

Fig. 5. Mean response latency in Experiment 4 as a function of gesture type and gesture-object congruency. Error bars represent the 95% within-subjects confidence interval based on error terms computed separately for the functional and volumetric conditions because of different sample sizes.

them for meaning, gestural knowledge associated with the objects denoted by those words is recruited. More specifically, however, our experiment shows that manipulation knowledge evoked by words includes details of specific hand movements that are integral to an object's function. Beyond this, Experiment 4 also shows that the meaning of a word denoting an object includes manipulation knowledge driven by the form of the object. This knowledge represents the shape of the hand scaled appropriately to the object's volumetric properties, in addition to the movements engaged to carry out its function. The evidence that hand actions relevant to object form as well as function can be elicited by a word has important implications for our understanding of conceptual representations and their interactions with the motor system. In Section 7, we consider ways in which these two kinds of gestural knowledge are orchestrated during object and word identification.

6. Experiment 5

Thus far we have demonstrated that words as well as objects evoke both volumetric and functional gestural representations. For words it appears necessary for subjects to attend to their meaning if these representations are to be recruited. These results are of particular interest because they indicate that stored gestural knowledge includes a fairly detailed description of the shape of the object and the grasp that is usually employed to lift or hold it. But to solidify this result, we need to establish that volumetric and functional gestural representations are not invariably activated together in word recognition tasks. After all, if the two kinds of gestures always co-occur, it may be that they reflect a common representation having to do with the way we manipulate an object when using it, rather than two different modes of interaction. Showing that we can observe one kind of gesture without the same degree of activation of the other will rule out this possibility and confirm our a priori assumption that volumetric and functional gestures are to some degree distinct.

We accomplished this goal in a final experiment by implementing the previous lexical-decision task, but with a number of important changes. First, we used photographs of hand postures instead of colors to cue specific gestures. This task was an easier one for subjects to perform and allowed us to decouple the word from the subsequent cue to perform a gesture using the Graspasaurus. By presenting the word for only a brief duration before the cue, we can create the possibility to reveal the early accrual of one type of gestural representation prior to the evocation of the other type. Unlike the color–object interference task used in the earlier experiments, this priming procedure permits us to probe a relatively early point in word processing. In addition, we present the words referring to manipulable objects (e.g., calculator) embedded in a list including abstract words (e.g., secret) as well as nonwords. Any activation of gestural representations by the words denoting objects in this context will provide further strong evidence for automaticity.

There is some indication that functional knowledge is a core element of the meaning of an object, in the sense that knowledge of function is activated very early in priming tasks (Moss, McCormick, & Tyler, 1997; Moss, Ostrin, Tyler, & Marslen-Wilson, 1995). If this assumption is correct, then knowledge of hand actions dealing with the function of an object should be recruited prior to the accrual of gestural representations corresponding to the volumetric properties of the object. Such evidence will establish that the co-occurrence of the volumetric and functional representations we observed in the previous experiments is not inevitable, and will provide support for the distinction we and others have made between these two kinds of gestural representations.

6.1. Method

6.1.1. Subjects

Twenty-two subjects were drawn from the same source as the earlier experiments.

6.1.2. Materials and design

Eight gestures, four functional, and four volumetric, were selected and photographs of a model's right hand were taken for each one. The photographs were rendered in grayscale and a left-hand version of each photograph was created by reflecting the original images along the vertical axis. The names of 18 objects were selected for use as critical items. These objects were selected so that six of them were paired with one of the functional and one of the volumetric gestures, six were paired with one of the functional gestures only, and six were paired with one of the volumetric gestures only. A list of the eight gestures and their corresponding critical object names is shown in Appendix B. Eighteen abstract words or terms (e.g., delay, heaven, and open discourse) and 18 nonword strings (e.g., banflit, gurplon, and malm jornof) were selected as filler items. These items were chosen to be similar to the object names in length and to match them with respect to the number of items that were comprised of two-part compounds. The Graspasaurus was set up with eight response elements, one for each of the eight defined gestures.

Each object name was assigned one of the abstract words and one of the nonwords approximately matched to it in length and matched to it in form (a single term vs. a two-term compound). The yoked abstract and nonword items were used to cue the same set of gestures as their matched object name. Object names that were associated in our experiment with only a functional or only a volumetric gesture were assigned one unrelated gesture from the same set as the object name's related gesture (e.g., drill: related = trigger; unrelated = palm). Object names associated with one related gesture of each type were assigned one unrelated gesture of each type (e.g., calculator: related = poke, horizontal grasp; unrelated = trigger, vertical pinch). The assignment of unrelated gestures to object names was done so that each gesture was used as the unrelated gesture for three different object names. In a test session, object names (and their yoked abstract and nonword items) associated with one related gesture were presented six times, three times each with its related gesture and unrelated gesture. Object names (and their yoked items) associated with one related gesture of each type also were presented six times each. For half of these items, four presentations were with a functional gesture (two with the related and two with the unrelated gesture) and the other two presentations were with a volumetric gesture (one related and the other unrelated). For the other half of these items, the pattern was reversed (two functional and four volumetric presentations). Assignment of such items to these two possible arrangements was counterbalanced across subjects.

6.1.3. Procedure

Stimuli were presented using the same equipment as in the earlier experiments. Words and nonwords were presented using the same font as in the earlier experiments and appeared in black letters on a white background. The hand cues appeared in grayscale on a white background and were confined to a region 20.5° horizontally and vertically when viewed from 40 cm. The order of the response elements in the Graspasaurus base was varied across subjects.

Subjects were first given 48 trials of practice at making speeded hand gestures in response to the eight hand cues. A gesture was made by lifting the forefinger of the dominant hand from a response button and grasping the correct element of the Graspasaurus as indicated by the cue. As in the earlier experiments, subjects were instructed to begin a gesture only when they were ready to lift their response hand and without hesitation grasp the correct element of the response device.

Subjects were then given the combined lexical-decision/gesture task. There were 24 practice trials followed by a randomly ordered sequence of 108 critical trials and 216 filler trials (108 each with abstract words or nonwords). On each trial, a letter string was presented for 300 ms, then it was replaced by a hand cue. After the subject responded with a gesture, he or she classified the letter string as a word or a nonword by saying YES or NO. The experimenter coded the correctness of the hand gesture and the lexical decision by key presses on a computer keyboard. Within the critical and filler trials, half cued a functional gesture and half cued a volumetric gesture. For the critical trials, half of the gestures of each type were related to the object name that was the prime on a particular trial and half were unrelated. Thus, the proportion of all critical and filler trials on which the gesture was related to the letter string was .17 (54/324).

6.2. Results and discussion

Data from two subjects were excluded, one because of unusually long response latencies when responding to the gesture cues and one because of an unusually high propensity (39% of critical trials) to initiate gesture responses less than 250 ms after onset of the hand cue. The remaining subjects averaged 96% correct responses when making lexical decisions, indicating high proficiency in that task. Aside from this assessment, data from only the critical trials were analyzed.

As in the earlier experiments, response latencies on the critical trials of the gesture task that were lower than 250 ms were excluded from analysis (1.4%). Responses longer than 2000 ms (0.3%) were classified as outliers and were excluded as well. Mean gesture response latency for correct responses is presented in Fig. 6 as a function of gesture type and relation between the object name and the gesture (related or

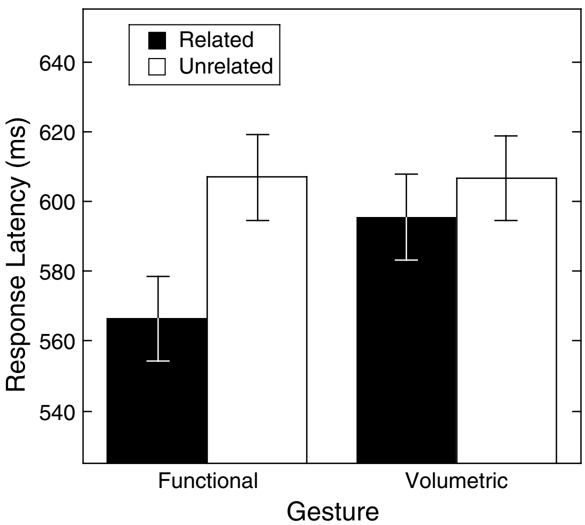

Fig. 6. Mean response latency in Experiment 5 as a function of gesture type and gesture-object congruency. Error bars represent the 95% within-subjects confidence interval and are appropriate for comparing patterns of means across priming conditions.

unrelated). These data were analyzed in a repeated measures ANOVA which revealed a significant priming effect, with lower response latencies when the target gesture was related to the object name (581 vs. 607 ms), $F(1,19) = 7.06$, $MSE = 1{,}890$. There was also a trend for responses to be faster for functional than for volumetric gestures (587 vs. 601 ms), $F(1,19) = 4.10$, $MSE = 1{,}015$, $p < .06$. More important, there was a significant interaction between gesture type and relation to the object, $F(1,19) = 6.29$, $MSE = 676$. Planned comparisons indicated that the effect of object relatedness was significant for functional gestures, $F(1,19) = 24.15$, but not for volumetric gestures, $F(1,19) = 1.87$. Thus, the same group of subjects showed a robust priming effect of 40 ms for functional gestures, while at the same time generating a small and nonsignificant effect of 11 ms for volumetric gestures.

The mean error rate for the gesture task averaged across conditions was 0.6%. An ANOVA of error rates revealed only a main effect of gesture, with more errors made with functional than with volumetric gestures (1.1% vs. 0.2%), $F(1,19) = 4.52$, $MSE = 3.78$.

The response latency data showed that functional, but not volumetric gestures, were activated relatively early (after just 300-ms of exposure) during the processing of the name of a relevant object. Moreover, this priming effect emerged against the background of a large number of filler trials on which either nonwords or the names of abstract concepts were used as primes. The rare appearance of a target gesture that was related to the object named by the prime is likely to have made subjects disinclined to use strategic processes such as expectancy when viewing the primes. Rather, we propose that the priming effect seen here is a result of the automatic recruitment of gestural knowledge related to functional aspects of the prime object. This outcome is consistent with a recent result obtained by Masson, Bub, and Newton-Taylor (in press), in which sentences with abstract verbs (e.g., *Mary constantly thought about the calculator*) were used to prime functional and volumetric gestures much like those used here. In that study, only functional gestures showed a priming effect at a relatively short delay after reading a sentence prime, but both functional and volumetric gestures tended to show priming after a longer delay. Based on these results, we suspect that had a longer cue delay been included in Experiment 5, priming would have occurred for both functional and volumetric gestures. Taken together, these results of Experiment 5 and the Masson et al. results support the conclusion that it is knowledge about functional gestures that holds a privileged place in the conceptual representations of objects.

The advantage seen here for functional gestures is consistent with findings in the developmental literature showing that preschoolers make substantial use of information about the intended use of artifacts when learning about novel objects or extending a category name to include new exemplars (Greif, Kemler Nelson, Keil, & Gutierrez, 2006; Nelson Kemler, Egan, & Holt, 2004). Indeed, when children categorize novel artifacts, they more often generalize a category label to new items on the basis of similarity of function than perceptual similarity (e.g., Kemler Nelson, Frankenfield, Morris, & Blair, 2000).

7. General discussion

Processing an object with the intention to make an arbitrary gestural response to one of its surface characteristics (i.e., color) yields concomitant activation of manipulation knowledge associated with that object. We have documented two kinds of manipulation knowledge: Hand actions corresponding to the function of an object and actions pertaining to an object's volumetric or shape-based properties. Remarkably, in Experiment 4, words referring to objects evoked both types of manipulation knowledge when subjects responded manually to their color. Attending to the meaning of the word was necessary to generate the effect of motor representations evoked by the word, but this result was equally strong for volumetric and functional gestures. It appears, then, that both classes of gestural knowledge are tied to the meaning of a word. Experiment 5, however, demonstrated that functional gestures in particular may hold a special place in conceptual representations of objects. Only those gestures showed a benefit when objects names were presented briefly as primes.

This evidence has important implications for understanding the nature of the interactions between parietal brain regions that determine the parameters of hand actions used to grasp objects and other cortical areas (e.g., frontal and temporal) that process the meaning of words and objects. Preparing to grasp an element of the Graspasaurus is modulated by the function and shape of incidentally processed objects, implying that visuomotor transformations are normally sensitive to higher-level influences. In neurological cases who have suffered severe damage to occipito-temporal regions, however, it is possible to demonstrate dissociations between grasping or using objects and their identification (e.g., Goodale, Milner, Jakobson, & Carey, 1991; Sirigu et al., 1991). These cases demonstrate the residual capabilities of motor systems divorced from contributions of conceptual domains and invite an underestimation of the interactivity of the motor system with semantic representations. We agree with Jeannerod (1997) that hand actions mediated by the parietal lobes do not operate in isolation but are "embodied in a broader system for producing action which involves other areas, including those from the ventral system" (p. 72).

Taking this position further, consider the finding that the aperture of the fingers when grasping a disc shows insensitivity to higher level contextual effects, such as the Titchener size illusion, at least when subjects are not provided visual feedback on their hand movement (Haffenden & Goodale, 1998). In the Titchener size contrast illusion, a central disc is visually perceived as smaller or larger, depending on the size of a set of discs that surround it (e.g., larger surrounding discs make the central disc appear smaller). But this illusion did not alter grip aperture under the conditions tested by Haffenden and Goodale. This evidence for independence between motor and interpretive systems concerns relatively late stages of grasp movements rather than early stages involving planning and movement initiation. Neuropsychological evidence strongly indicates that memory for the appearance of familiar objects plays a role in reaching and grasping. For example, in optic ataxia, patients have trouble grasping unfamiliar objects but are much better when grasping familiar objects (Jeannerod et al., 1994; Rossetti, Pisella, & Vighetto, 2004). Evidence from normal subjects reported by Lindemann et al. (2006) indicates that time to initiate a grasping action is influenced by a semantically related context word (e.g., mouth vs. eye as context words for grasping a cup or a magnifying glass). Our results are entirely consistent with such evidence for interactivity between conceptual knowledge and the planning and execution of motor actions.

Responding to the color carried by an object is slower when the gesture learned to the color mismatches either the functional or the volumetric gesture associated with the object. This slowing is assessed relative to a condition in which the color-cued gesture matches the functional or volumetric gesture of the object. We define the latter condition as congruent. Notice that this notion of congruency is different from the kind of congruency established in classic Stroop color–word interference. In that case, a word such as RED printed in red is congruent because the response to the color unambiguously matches the response invited by the word. Our combination of color and object on congruent trials, however, is based on the following logic. An object has both functional and volumetric gestures associated with it, and we selected the objects so that these two gestures were distinct in each case (e.g., for a calculator, the gestures were poke and horizontal grasp). On incongruent trials, the gesture cued by the color mismatched both the object's functional and volumetric gestures. On congruent trials, the target gesture matched either the functional or the volumetric gesture, but mismatched the other. Given the nature of the objects we selected, this mismatch on congruent trials was inevitable. Congruency in our experiments, then, means "not as incongruent" as the condition in which *both* functional and volumetric gestures associated with the object mismatch the target gesture.

The observed congruency effects in Experiments 1 and 4 show clearly that subjects must be recruiting some kind of gestural representations when viewing objects or making decisions about words. We infer that objects and words evoke both functional and volumetric gestures and the effects we observed occur because on congruent trials, one or the other of these gestures is compatible with the target gesture. If this inference is correct, then it follows that for objects having distinct functional and volumetric gestures, even on congruent trials subjects will be somewhat slower to respond to the color relative to a neutral condition, such as a color patch, in which it is very unlikely that any gesture is evoked. This difference would occur because on congruent trials (defined according to either the functional or volumetric gesture) there is still competition from a gesture associated with the object that conflicts with the target gesture. For example, if color cues a poke response when viewing a calculator on a congruent trial, then the volumetric grasp gesture should remain as a potential source of interference. Thus, gesturing to the color, even on a congruent trial, should be somewhat slower than on a completely neutral trial. We have preliminary evidence from a Stroop paradigm similar to that of Experiment 1 strongly favoring the hypothesis that multiple gestures are recruited at least in the case of objects. Response latency to a neutral color patch was faster than latency in the congruent condition, which in turn was faster than the incongruent condition.

This result rules out an alternative interpretation of the results presented here in which it is assumed that functional and volumetric gestures are not automatically recruited by objects or words. Instead, on congruent trials the color-cued gesture activates the matching gestural knowledge inherent in the conceptual representation of the object, whereas the complementary gesture remains dormant. For example, the poke gesture cued by the color red carried by a calculator evokes the functional gesture associated with that object and the volumetric gesture for calculator is unaffected. This interpretation would predict that in comparison to a neutral condition, congruent trials would lead to faster response latencies whereas the incongruent condition (in which no activation occurs from a color cue to any gestural knowledge associated with the object) would yield response latencies equivalent to the neutral condition. The evidence that congruent trials are slower than neutral trials suggests that multiple gestures are evoked by objects and that some of these gestures conflict with the cued response, even on congruent trials.

The fact that both functional and volumetric representations are triggered by objects and even words denoting objects is of considerable interest in regard to the interpretation of patterns of activation observed in neuroimaging experiments. Cortical areas known to mediate motor function are invoked when subjects carry out tasks with tools and other manipulable objects, including tasks that do not require explicit consideration of manual actions (Devlin et al., 2002). It is generally assumed that this activation concerns manipulation knowledge dealing with the function of the object (e.g., Chao & Martin, 2000). Our evidence that hand actions pertaining to object shape, independent of function, are a crucial part of manipulation knowledge contained in conceptual representations of objects raises an important question. Specifically, are regions of activation associated with tools indeed demonstrative of functional knowledge, or do they encapsulate both function and form? The finding that fruits and vegetables can yield activation of motor cortex (Gerlach et al., 2002) suggests that the representation of shape-based grasping is an important potential component of the observed patterns of activation.

7.1. Constraints on establishing gestural automaticity

A central question underlying the experiments we have reported concerns the extent to which viewing or identifying objects and words automatically evokes action representations. The strongest version of this claim, and one that we find implausible, is that merely glancing at an object as part of a scene is sufficient to trigger the kind of knowledge we are measuring in our experiments. A more reasonable assumption is that activation of motor representations depends on a form of attentional orienting to the object, such as identifying it or selecting and executing some kind of response. In our experiments, manual responses are necessarily required and in particular we use a response set that corresponds to the gestures associated with at least a subset of the objects, so that congruency or relatedness can be defined. These are inevitable requirements of our method. In carrying out responses to the Graspasaurus elements, it is possible that we are shaping the way in which the observer orients to the object.

Furthermore, in the experiments involving Stroop-like interference, the subject was always responding to an aspect of the object (color) that sometimes required a response that conflicts with the conventional response to the object. Typically, surface features of objects are an integral part of the description that generates action based on the object's identity. In our opposition paradigm, the presence of an object, coupled with the requirement to respond to a surface feature, may be sufficient to trigger representations of manual actions generally used to interact with the object as a whole. Given these caveats, it would be inadvisable to assume that objects invariably evoke actions regardless of the specific task under which they are viewed. For example, the Tucker and Ellis (1998) study is taken as evidence that viewing objects with handles is sufficient to evoke some kind of grasp response. Subjects, however, were required to attend and manually respond to objects by judging their orientation. Although the manual responses were not applied to the objects themselves, they were contingent on the object's identity (presumably an object must be identified if its orientation – upright vs. inverted – is to be judged). In normal experience, the explicit identification of objects is often a precursor to manually interacting with them. It is therefore not entirely unexpected that the demand to make a manual response in the context of object identification evokes an influence of manipulation knowledge associated with the object. Whether such responses are obligatory even when the requirements to identify an object and engage in motor action are relaxed, remains an open question. Passive viewing of manipulable objects has been reported to elicit activation of premotor cortex (e.g., Chao & Martin, 2000; Creem-Regehr & Lee, 2005), but Devlin et al. (2002) found that motor representations are evoked only when subjects attend to the meaning of tools. Also, Kellenbach, Brett, and Patterson (2003) note that undemanding tasks such as passive viewing would most likely encourage speculation by observers on how the object is used. There is little evidence, then, that merely viewing objects ineluctably leads to the evocation of manipulation knowledge.

Our argument, then, is that the failure of selective attention in Experiment 1 is due to the fact that subjects cannot filter out the motor representations associated with the object when responding to a surface property like color. An alternative interpretation of the congruency effect we report is that the design of the experiment created an inadvertent correlation between the irrelevant dimension of object identity and the relevant dimension of color (Dishon-Berkovits & Algom, 2000). This correlation occurred because in the incongruent condition, each object appeared equally often in each of the three possible incongruent colors. In the congruent condition, of course, each object appeared in only one color. This contingency means that given the presentation of a particular object, it is much more likely that the object will appear in its congruent color than in any one of the three possible incongruent colors. The predictive power of object identity may attract attention to that irrelevant dimension, spuriously producing a congruency effect that has nothing to do with the tendency to evoke gestural representations when responding to a surface property of the object.

There are two reasons the contingency we have identified is not a plausible cause of the congruency effects. First, when color was carried by words (Experiments 3 and 4), where the same contingency as in Experiment 1 was in place, no congruency effect was found unless subjects were instructed to attend to word meaning. Thus, the contingency alone is not sufficient to evoke gestures associated with words. Second, in an experiment similar to Experiment 1, but using pantomime gestures rather than a response apparatus, we eliminated the contingency between color and object and still obtained a congruency effect for both functional and volumetric gestures (Bub & Masson, 2006). We conclude that congruency effects occur because subjects cannot prevent the evocation of gestural knowledge when attending and responding to an object's surface properties.

The results obtained when words instead of objects carried color add to our understanding of the relationship between object identity and action. In this case, the surface features of the denoted object were not present, yet both object form and function influenced manual actions. Manipulation knowledge of objects, then, is automatically evoked by words, at least when subjects must orient to their meaning and the response set for the colors in which words appear overlaps with actions afforded by the corresponding objects.

7.2. Relation between functional and volumetric gestures

We have made the distinction between functional and volumetric gestures on logical grounds and based on neuropsychological evidence (e.g., Buxbaum et al., 2003). In addition, Experiment 5 showed that representations of functional gestures are more readily evoked by object names than is volumetric gestural knowledge. Elsewhere, we have also shown that volumetric and functional gestural knowledge can be dissociated by demonstrating that volumetric gestural knowledge is recruited later than functional gestures when subjects read sentences referring to manipulable objects (Masson et al., in press). We assume that these two different kinds of gestures may interact in interesting ways during the processing of objects. In the case of objects that have distinct functional and volumetric gestures (e.g., stapler) it is unknown how commitment to, for example, a functional gesture impacts the active representation of a volumetric gesture. One possibility is that using the object according to its function may sometimes require suppression of the potentially conflicting manual action applicable to its overall shape. In cases of apraxia, where patients show impairment in using objects, the volumetric properties may interfere with functional responses.

Finally, it is important to understand whether functional and/or volumetric motor representations have a genuine causal role in performance of conceptual tasks such as identifying objects, or whether such knowledge is evoked merely as a byproduct of carrying out particular tasks. Neuropsychological evidence in this regard has proved complex and controversial (e.g., Buxbaum & Saffran, 2002; Mahon & Caramazza, 2005). Data from functional imaging studies have little to say thus far about the potential causal role played by premotor activations in tasks such as object identification. The mere presence of activation during task execution does not necessarily imply that the activation is an essential component of task performance. Behavioral evidence based on a methodology analogous to that presented here can track the presence of functional and volumetric gestural knowledge in real time and would be of considerable relevance to this and other fundamental questions concerning objects and actions.

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Appendix A

Gestures and objects used in Experiments 1–4

Functional gestures		Volumetric gestures	
Gesture	Objects	Gesture	Objects
Closed grasp	Beer mug	Horizontal grasp	Computer mouse
	Hand saw		Service bell
Open grasp	Nutcracker	Horizontal pinch[a]	Marker
	Pliers		Paint brush
Poke	Calculator	Vertical grasp	Lotion bottle
	Doorbell		Spray bottle
Trigger	Spray bottle	Vertical pinch[a]	Pen
	Water pistol		Pencil

[a] The assignment of the four long, thin objects to these two gestures was arbitrary and was determined by the orientation of the objects as depicted in the images we showed to subjects in Experiments 1 and 2 (prone for horizontal pinch and upright for vertical pinch).

Appendix B

Gestures and critical object names used in Experiment 5

Functional gestures		Volumetric gestures	
Gesture	Objects	Gesture	Objects
Aerosol[a]	Bug spray	Horizontal grasp	Calculator
	Hair spray		Service bell
	Spray paint		Stapler

(*continued on next page*)

Appendix B. (*continued*)

Functional gestures		Volumetric gestures	
Gesture	Objects	Gesture	Objects
Palm	Bongo drum	Horizontal pinch	Eraser
	Service bell		Thimble
	Stapler		Thumbtack
Poke	Buzzer	Vertical grasp	Bug spray
	Calculator		Hair spray
	Keypad		Spray paint
Trigger	Drill	Vertical pinch	Daisy
	Spray bottle		Pencil
	Water pistol		Toothbrush

[a] In this gesture, the forefinger is curved and extended upward as when using an aerosol spray of some type.

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