Grasping Beer Mugs: On the Dynamics of Alignment Effects Induced by Handled Objects

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We examined automatic spatial alignment effects evoked by handled objects. Using color as the relevant cue carried by an irrelevant handled object aligned or misaligned with the response hand, responses to color were faster when the handle aligned with the response hand. Alignment effects were observed only when the task was to make a reach and grasp response. No alignment effects occurred if the response involved a left−right key press. Alignment effects emerged over time, becoming more apparent either when the color cue was delayed or when relatively long, rather than short, response times were analyzed. These results are consistent with neurophysiological evidence indicating that the cued goal state has a modulatory influence on sensorimotor representations, and that handled objects initially generate competition between neural populations coding for a left- or right-handed action that must be resolved before a particular hand is favored.

Keywords: action representations, object affordances, spatial alignment

Automatic spatial alignment effects induced by handled objects on a left- or right handed response are of fundamental theoretical importance given evidence from neuroimaging research that such objects evoke motor-based cortical activity in a variety of perceptual tasks (e.g., Chao & Martin, 2000; Grezes & Decety, 2002; Johnson-Frey, 2004). Our interest is further motivated by work indicating that action representations can exert a modulatory influence on perceptual processes, such that attention to parts of an object may be determined by the kind of action the observer has in mind (Hommel, 2000). Under what task conditions does the positioning of the handle of an object like a frying pan or beer mug generate spatial codes that automatically affect other intended actions requiring a left- or right-handed response? The question applies to any number of situations we might encounter every day. For example, we generally reach out and grasp an object using the arm aligned with the handle, the typical mapping between object and action. But our choice of arm may be driven by a competing intention or context. We may wish to use the left arm even though the handle is facing the other way if the right hand is occupied or injured, say, or if the final goal state we desire is best accomplished using the misaligned arm. We must then eschew the typical mapping in favor of a contextually determined response.

A number of studies are available on the nature of alignment effects evoked by manipulable objects (e.g., Phillips & Ward, 2002; Riddoch, Edwards, Humphreys, West, & Heafield, 1998; Tipper, Paul, & Hayes, 2006; Tucker & Ellis, 1998; Vainio, Ellis, & Tucker, 2007). We will argue below that these studies include a number of different compatibility effects induced by real-world exemplars of handled objects. One type involves hand action representations associated with reaching and grasping the handle of an object; if the handle is aligned with the response hand, then responses are faster than when the opposite response hand is used. Other compatibility effects induced by handled objects do not clearly reflect the evocation of reach and grasp representations, but instead involve more abstract spatial codes activated by the orientation of an object that affect any left–right response discrimination (e.g., index vs. middle finger of the same hand).

In this article, we further examine handle alignment effects evoked by images of commonplace objects like beer mugs and frying pans. Our purpose is to establish the necessary experimental conditions that automatically elicit a grasp representation that favors the hand aligned with the handle, and to determine the time course over which this preference develops. We use the evidence thus obtained to forge a link between handle alignment effects induced by familiar objects during the performance of a motor task, and the more traditional literature on spatial compatibility effects between stimulus and response (e.g., Hommel & Prinz, 1997). Before introducing the logic behind our approach, we raise some questions in regard to a number of assumptions about the nature of hand action representations automatically triggered by objects.

On the Current Status of Handle Alignment Effects

A widely cited result is that speeded key-press responses to the identity or shape of handled objects are reliably influenced by the alignment of the object's handle with the responding hand. In the original experiment (Tucker & Ellis, 1998), subjects were

required to judge whether the image of each object was upright or inverted (a task that includes the processing of object identity) by means of a left- or right-hand key press (e.g., right for upright, left for inverted). In a more recent study by Tipper et al. (2006), speeded judgments concerned the shape of a door handle (e.g., a right key press for a rounded handle, left for square), oriented so as to afford a left- or right-handed grasp. In both studies, key-press responses were faster when the handle of the object was directed toward the responding hand compared to trials in which the handle faced the opposite direction. The alignment effect reported by Tucker and Ellis (1998) was not observed when key presses were made with only one hand, and subjects used the index and middle finger to indicate their judgments of upright or inverted objects. Thus, it is the relation between object orientation and the hands that is important, and not simply the left–right status of the response keys.

Additional studies show effects of handled objects on left–right key presses that are more general because they are observed not only for a left- versus right-hand response, but also for a left–right key press using the index and middle fingers of the same hand (Vainio et al., 2007) or a left versus right foot press (Phillips & Ward, 2002). Moreover, such "alignment effects" occur even to depictions of tapered artificial cylinders that have no handles (Vainio et al., 2007). We agree with Tucker and Ellis (1998) that compatibility effects of a handled object on a one-handed response are based on "abstract coding of stimulus orientation" (p. 842) induced by the asymmetry of the object's shape, and cannot be due to the affordances for action evoked by "the relative ease with which objects could be grasped by the left or right hand" (p. 843).

We infer that very few studies have convincingly shown evidence that lateralized hand action representations are automatically evoked by a handled object and influence a left- versus right-handed key-press response (Tipper et al., 2006; Tucker & Ellis, 1998). The evidence from these latter studies has been taken as support for a number of fundamental assumptions regarding the nature of motor-based representations that are evoked during object identification. These representations would appear sufficiently general to affect responses that require only the intention to use the left or right hand, even influencing responses as elementary as pressing a key with the index finger. Furthermore, if the identity of a handled object automatically triggers the activation of sensorimotor connections potent enough to affect any motor task requiring the decision to use one or the other hand, then it follows that active suppression may frequently be needed to prevent the execution of actions unintentionally evoked during perception (Tipper, Howard, & Houghton, 1998; Tucker & Ellis, 1998). Indeed, in defense of this claim, it is often noted that patients with frontal lobe damage may engage in a form of *utilization behavior* in which familiar objects placed before them are unintentionally grasped and used without regard to task goals or instructions (Lhermitte, 1983). For these cases, it is argued, frontal inhibitory control over the motor cortex is partially lost, and the action representations automatically generated during the perception of objects lead involuntarily to overt behavior.

How secure is this claim? We suggest that without a clear consideration of the observer's intentional set, neither the behavioral evidence from neurologically intact respondents, nor the clinical evidence from frontal patients can be taken to strongly imply that the perception of handled objects automatically evokes action representations. We begin by noting an important constraint on utilization behavior in frontal cases that perhaps has been obscured in the repeated citations of the phenomenon as a straightforward example of perception leading automatically to action in the absence of frontal control. As Shallice, Burgess, Schon, and Baxter (1989) point out, a complex procedure was used by Lhermitte (1983) to induce the behavior in patients. The examiner began by stimulating the palm of the patient with some object, for example, an empty glass. Alternatively, the object was handed to the patient and then abruptly withdrawn so as to encourage or even incite the patient to reach for and grasp it. A second object, say a bottle of water was introduced in the same way. The patient may then, after handling both the bottle and the glass, pour the water into the glass and drink, without having been instructed to do so.

Shallice et al. (1989) interpret the conditions necessary to elicit utilization behavior as follows. They theorize that even in the absence of proper executive control, competition between an active motor schema and other potential schemas may be resolved through a process termed *contention scheduling*, in which task-relevant schemata block other irrelevant contenders for action that overlap in the cognitive systems they demand. Patients with frontal damage, according to this view, are most likely to engage in utilization behavior if no definite task set is operative or when the demand characteristics of the situation tacitly encourage the intention to reach for and grasp objects. These patients are less likely to do so when a task-relevant visual object is competing for action with another irrelevant object that could potentially trigger a motor schema.

If the control of action schemas to objects is partially determined by task set, how should we construe handle alignment effects occurring in neurologically intact observers performing perceptual decision tasks that demand a left- or right-handed key press (Tucker & Ellis, 1998)? Why does the orientation of the handle exert an influence on the side of responding, when no reach and grasp action is required and observers are ostensibly attending to the identity or form of the object? We suggest that spatial alignment effects occurring when subjects make left- or right-handed key-press responses to the identity or shape of handled objects do not stem automatically from the mere perception of an object. Rather, we argue that tacit consideration of an object's affordance induced by task set may generate action representations that interact with the spatial codes established for key-press responding. Indeed, Kornblum (1992, 1994; Kornblum & Lee, 1995) notes that spatial compatibility effects can occur even though stimuli have neither conceptual nor perceptual features in common with responses. Instead, the relationship between stimuli and responses depends on structural properties that arise from the task at hand. Kornblum and Lee (1995) provide a detailed discussion of the role of structural overlap and task context in generating stimulus–response compatibility effects. For example, one of the properties of a set of stimuli might be that they can be organized spatially from left to right (e.g., the integers 1 to 5), and the members of the response set could likewise have an ordinal position in space (e.g., a horizontal array of response keys). Any mapping that paired objects with their structurally corresponding responses would lead to faster performance than a mapping that deviated from this correspondence.

Given that a handled object can be used with either the left or right hand depending on its orientation, consideration of the object's affordance may generate a preference to respond with the aligned hand that interacts with the selection of the hand required for a key-press response. In support of this argument, we note that Tipper et al. (2006) presented short video clips of a hand reaching toward, grasping, and pushing down a door handle, so as to enhance the very minimal effects of alignment obtained in pilot experiments that omitted any demonstration of the object being used. Furthermore, alignment effects were greater if the door handle was displayed slanting downward to the left or right as though in the act of being turned, and more modest (even after seeing the video clip) if subjects viewed the handle in a horizontal position. Clearly, much was done in this study to encourage observers to consider the dynamic properties of door handles. Without this background context, no alignment effects occurred when observers merely pressed a response button to signal their perceptual judgments. Tucker and Ellis (1998) similarly instructed subjects to judge the upright or inverted orientation of objects like a knife or saw by considering their use. Subjects may have applied this instruction quite generally in deciding on the orientation of handled objects, implicitly attending to objects with respect to the actions needed to use them.

Evoking Automatic Handle Alignment Effects

The points argued above are intended to cast some doubt on the view that object identification alone triggers hand action representations that influence left–right button presses. Constraints on the alignment effects discussed so far imply that observers must also be biased by intentional set to consider how they would hold or use the manipulable objects they identify. We distinguish between these effects—which appear to be induced by explicit consideration of an object's affordance—and the automatic activation of action representations evoked by a manipulable object in tasks that do not require observers to attend to the object's affordances.

We will use the term *standard mapping* to refer to automatically evoked action representations that are independent of an observer's intentions. The actions pertinent to the observer's intentions we will call *contextual mapping* (cf. Murray, Bussey, & Wise, 2000). For example, a beer mug oriented with its handle to the right would have a standard mapping to a right-handed clenched grasp. The contextual mapping will be congruent with this standard mapping if the observer has the intention that the right hand pick up the object by its handle. Of course, contextual mapping is flexible in that intended hand actions on the beer mug may conflict with the standard mapping, as when the observer decides to use the left hand to grasp a right facing handle.

We have developed a behavioral visuomotor task that pits the standard mapping of a reach and grasp action, driven by the stimulus properties of a handled object like a beer mug or frying pan, against a contextual mapping between an arbitrary cue, like color, and an action. Subjects are trained to make speeded reach and grasp actions in response to a color patch, using a single response element placed directly in front of them (see Figure 1A). One color signals that the action is to be carried out with the left hand; another color indicates the same action with the right hand.

Under what circumstances might the image of a handled object that is irrelevant to the formal requirements of the contextual
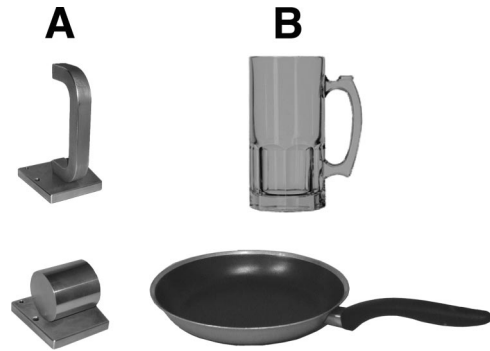

Figure 1. The response elements (A) and grayscale versions of the object photographs (B) used in Experiment 1.

mapping task yield motor representations that interact with the action determined by color? We have already emphasized the crucial, albeit tacit role played by intentional set in generating alignment effects in previous research using speeded responses to incidental properties (orientation or shape) of handled objects (e.g., Tipper et al., 2006; Tucker & Ellis, 1998). With respect to our ensemble of color and object, it is color, not the handled object, that forms the basis for decision and action. The nature of the motor response in the contextual mapping task (mapping color to action), however, may determine whether the standard object–action mapping exerts an influence.

Neuropsychological studies offer direct support for the claim that the nature of the intended motor response can play a fundamental role in modulating the influence of the standard mapping between objects and actions. Riddoch et al. (1998) have demonstrated in neurological cases that the kind of intended action applied to an object modulates interference effects caused by involuntary evocation of the standard mapping. For example, in the contextual mapping task, the required action was to pick up a cup on the left or right side of the table using the hand on the same side as the object, regardless of which way the handle of the cup was oriented (e.g., a left-hand grasp was required for a cup on the left, irrespective of whether the cup handle faced left or right). Despite being able to articulate the rule, these patients— evincing a form of utilization behavior—often produced the wrong response (e.g., grasping a cup on the left with the right hand) when the handle of the cup was aligned with the responding hand. Crucially, these inadvertent responses driven by the handle were not observed when the task was simply to point with the left or right hand depending on the location of the cup. Thus, intrusion of standard mapping on a contextual mapping task can be modulated by the intended action (see also Hommel, 2000; Humphreys & Riddoch, 2007; Linnell, Humphreys, McIntyre, Laitinen, & Wing, 2005).

We define intentional set operationally, therefore, just in terms of the hand action used by subjects to indicate their perceptual decisions about the color of an object. The shape of the response element subjects grasp in response to color can be chosen to afford a particular hand posture; for example, a horizontal cylinder requires a (wrist) inverted, closed grasp, whereas for a vertically oriented C-shaped response element (see Figure 1A), the hand posture required is (wrist) vertical, clenched grasp. In this way, it is possible to vary the parameters of the final goal state associated with the color in relation to the standard mapping afforded by the

irrelevant object. We assess the role of motor task set so defined (e.g., different reach and grasp actions, in addition to the more conventional key-press response) in evoking hand action representations from a pictured object so as to yield automatic effects of alignment on left- and right-handed responses.

A contextually determined action carried out on a response element can be congruent or incongruent with the standard mapping evoked by an object. For example, an inverted closed grasp is congruent with flashlight or frying pan and incongruent with a beer mug or a teapot. In addition, a contextually determined action with the left or right hand can be aligned or misaligned with the orientation of an object's handle. An inverted closed grasp with the left hand is congruent but misaligned with a frying pan with its handle pointing to the right. Congruency and alignment relate to different components of a reach and grasp action. The effect of congruency is determined by the relation between the hand posture evoked by the irrelevant object and the intended grasp; an evoked hand posture that is congruent with the intended target posture should yield a faster reach and grasp response than an evoked posture that is incongruent with the intended posture. The effect of alignment is due to the spatial compatibility between the hand chosen to execute the reach and grasp and the position of the object's handle. Intended responses that are aligned with the handle should be faster than misaligned responses if the standard mapping includes information about the side of the body that is most conveniently positioned to grasp the handle.

It is an open question whether the effects of congruency and alignment follow the same time course. These effects will depend on the timing of the selection of hand and hand shape in the contextually cued task. For example, the choice of which hand to use, at least under some circumstances, may be made before selecting the hand shape. Recent neurophysiological accounts of planning movement trajectory have proposed that the biomechanical details are not programmed in advance of movement initiation; rather, these parameters are established while the hand is in flight (Cisek, 2005; Ochiai, Mushiake, & Tanji, 2005; Shen & Alexander, 1997). On these accounts, the shape of the hand, as well as its movement through space could well be specified after liftoff, during the transport phase of the response. Selection of the response hand, however, must be planned and made prior to liftoff. The effect of the spatial alignment of the handle on a cued response lies in the speed with which a left- or right-handed action can be initiated. Therefore, alignment effects by definition must occur before liftoff. By contrast, congruency effects need not be confined to early preparatory stages of processing; they may be found later when the hand is moving toward a target. In the experiments we report here, we examine liftoff and movement time separately to determine in which of these response components effects of congruency and alignment are to be found.

The relative speed with which the side of the body and the type of grasp are computed for the contextual mapping task (responding to color) determines the time course of alignment and congruency effects induced by the object's standard mapping. In addition, the overall speed of contextual mapping relative to standard mapping will play a role in the emergence of alignment and congruency effects. If the requirements of the contextual mapping task can be computed before either component of the standard mapping is sufficiently active, then no influence of the standard mapping will be seen. To accommodate this possibility, we included a manipulation of stimulus onset asynchrony, whereby onset of the color cue was either immediate with the onset of the object or delayed by some interval. By delaying the onset of color (the contextual mapping cue), we allow enough time for the standard mapping to overlap with the contextual mapping task, so that any effects of alignment or congruency that are slow to accrue will have an opportunity to emerge.

In the experiments reported here, we examined the effect of handle alignment on the speed with which a congruent or incongruent reach and grasp action cued by color can be initiated and executed. If the standard mapping is evoked only when there is a correspondence between the target action and the action afforded by the object, then alignment effects should be seen only with congruent actions. Alternatively, the standard mapping may be evoked regardless of its relationship to the cued reach and grasp action. For example, the standard mapping for a beer mug may be evoked even though the cued action is an inverted closed grasp. What form of alignment effect might be produced in such a circumstance? There are two possibilities. First, if hand selection and hand shape are computed in an integrated fashion to produce the cued response (cf. Leuthold, Sommer, & Ulrich, 2004; Ulrich, Leuthold, & Sommer, 1998), then the evocation of a standard mapping should conflict with the cued response when that response is incongruent with respect to the standard mapping. This conflict should work against finding an alignment effect because of the discrepancy between the evoked action and the cued response. Second, if hand selection and parameterization of hand shape can be programmed independently, then selection of the response hand may be facilitated by an aligned handle, even when the cued hand shape is incongruent with the hand shape associated with the standard mapping. We show that both possibilities can manifest depending on the task conditions that determine the relative timing of hand selection and grasp formation. That is, alignment effects under certain conditions occur for both congruent and incongruent reach and grasp actions and under other conditions are modulated by congruency. An important caveat, however, is that alignment effects are nevertheless contingent on making some form of reach and grasp response to the color cue: conditions that show robust alignment effects with reach and grasp responses yield no such effects if the response is a left–right key press.

Experiment 1

The purpose of the first experiment was to establish that a handled object that is irrelevant to task goals can yield alignment effects when subjects produce a left- or right-handed action cued by the object's color. The cued action, applied to a response element (see Figure 1), was either congruent with the action required to grasp the object (e.g., a vertical clenched grasp for a beer mug) or incongruent (e.g., an inverted closed grasp for a beer mug). We measured two components of reach and grasp responses. The first was the time from the onset of the color cue to the moment when the hand was lifted from a response button (*liftoff* time) and the second was the time taken from liftoff to move to and make contact with a response element (*movement* time). Alignment and congruency may affect these two components differently. Hand selection must be completed prior to liftoff, so we can expect that alignment will have an effect on this response component. Hand shape is known in advance and is consistent from trial to trial because only one reach and grasp response is required of a

particular subject throughout testing. Therefore, programming this component of the reach and grasp response may be delayed until after liftoff (consistent with work by Cisek, 2005; Ochiai et al., 2005, and Shen & Alexander, 1997), leading to a congruency effect that would be observed in the movement phase.

If compatibility between the object and the cued action is crucial in generating alignment effects, then we should see a robust alignment effect on liftoff time in the congruent condition, but little or no effect in the incongruent condition. If the standard mapping continues to be evoked even for an incongruent action, then hand alignment should affect liftoff time just as it does with a congruent action. In addition to the effects of alignment, we wish to examine the influence of the irrelevant object on the formation of the hand shape that is part of the cued manual response. This congruency effect should be observed regardless of whether or not the standard mapping is evoked for an incongruent action. In either case, the standard mapping will be evoked in the congruent condition and should facilitate the formation of the hand shape cued by color. We should therefore expect shorter movement time for a congruent action relative to when the cued action is incongruent with the object (Bub & Masson, 2006; Bub, Masson, & Bukach, 2003; Bub, Masson, & Cree, 2008).

Finally, the color cue was presented simultaneously with the onset of the object (i.e., the object appeared in a color), or after a delay of 195 ms (i.e., the object was initially gray, then it changed color). If hand selection by the color cue takes place before evocation of the standard mapping, we should see no handle alignment effect. The relative timing of hand selection and evocation of the standard mapping can be modulated by delaying the onset of the color cue relative to the presentation of the object. Alignment effects that might not be observed when the color onset co-occurs with object onset (because not enough time has elapsed for the standard mapping to accrue) could be revealed if color onset is delayed.

Method

Subjects. Nintey-six undergraduate students at the University of Victoria participated for extra credit in a psychology course. All experiments reported here tested subjects recruited from this source. Data from one additional subject were discarded because of a high error rate (over 20%).

Materials. Digitized grayscale photographs of a handled beer mug and a frying pan were selected (see Figure 1B). Two colored versions of each photograph were also prepared (one green and one blue). Two versions of each photograph were generated, one with the object's handle oriented to the right side and the other with the handle oriented to the left. When displayed on the computer monitor used in the experiment and viewed from 50 cm, the image of the beer mug was 8.2° vertically and 6.1° horizontally, and the image of the frying pan was 5.3° vertically and 19.3° horizontally.

Procedure. Stimuli were presented on a Macintosh G3 computer. Subjects were assigned to one of four groups, defined by a factorial combination of the object used to carry color (beer mug or frying pan) and the type of hand action used to make responses (vertical clenched grasp or inverted closed grasp). In the first phase of the testing session, the subject was trained to make a left- or right-hand response cued by color. Assignment of color to re-

sponse hand was counterbalanced across subjects. On each of 80 training trials, a grayscale photograph of a hand forming the target hand shape (either a vertical clenched grasp or an inverted closed grasp) was shown together with a rectangle colored green or blue. Green indicated a left-hand response and blue indicated a right-hand response, or vice versa. Each trial began with the subject resting his or her index fingers on two response buttons arranged horizontally on a button box. Responses were made by lifting the index finger of the response hand then making contact with a metal response element designed to accommodate a the target grasp. The elements for the two grasps are shown in Figure 1A. The response element was located at the subject's midline between the computer monitor and the response box. A weak electrical current passing through the metal response element was broken by hand contact and signaled to the computer that a response had been completed. This arrangement allowed us to measure liftoff time (i.e., the time between onset of color and initial hand movement) and movement time (i.e., the time from liftoff to contact with the response element). An experimenter monitored the responses and recorded any errors. Automated feedback was given if a response was initiated more than 700 ms after color onset or was incorrect.

The training phase was followed by a series of 20 practice trials on which a beer mug with the handle oriented to the left or right was presented in grayscale. After a brief interval, the mug changed to a green or blue color. The interval preceding color onset systematically decreased across the first five practice trials and on the remaining trials the interval was either 0 or 195 ms, determined randomly. Practice trials were followed by 320 critical trials. Eighty critical trials were presented in each combination of handle orientation (left, right) and cue delay (0 ms, 195 ms). On practice and critical trials, the colored object was erased from the monitor as soon as the response hand was lifted from the response button so that the monitor was blank while the hand moved toward the response element. Trials were presented in an independently determined random order for each subject.

Results and Discussion

Liftoff time was measured from the onset of color in the object to the moment one of the subject's hands was lifted from the response button. Movement time was measured from liftoff to the moment the subject's hand contacted the response element to complete the response. Correct response latencies lower than 200 ms or longer than 1,000 ms for liftoff time or longer than 800 ms for reach time were excluded as outliers. The lower bound was fixed as the threshold for false starts on liftoff time (no lower bound for movement time was used) and the upper bound for each measure was set so that no more than 0.5% of correct responses were excluded either due to being classified as a false start or as an unusually long response (Ulrich & Miller, 1994). This method of trimming outliers generally eliminates fewer observations than using a criterion based on two or three standard deviations from the mean. This trimming procedure was applied in all the experiments reported here, using the same lower bound but varying the upper bound. In addition to examining response times, we also examined response time distributions to determine whether effects appeared only on trials with long response times or across the entire response time distribution. The analysis provides another way of assessing the time course of the influence of the standard

mapping on the production of a reach and grasp response. A very early influence would be reflected in effects appearing across the entire response time distribution, whereas a late influence would lead to effects being found only among longer latency trials.

Liftoff time. Mean correct liftoff times are shown in the top part of Figure 2 as a function of handle alignment, congruency between object and grasp response, and cue delay. These data were submitted to an analysis of variance (ANOVA) with alignment and cue delay as repeated-measures factors and congruency as a between-subjects factor. Type I error rate was set at .05 for this and all analyses reported here. The ANOVA revealed significant effects of handle alignment, $F(1, 94) = 19.78$, mean square error (MSE) = 214, $\eta_p^2 = .17$, and cue delay, $F(1, 94) = 86.62$, $MSE = 343$, $\eta_p^2 = .48$. The interaction between alignment and cue delay was also significant, $F(1, 94) = 11.19$, $MSE = 87$, $\eta_p^2 = .11$. In addition, however, the three-way interaction was significant, $F(1, 94) = 6.76$, $MSE = 87$, $\eta_p^2 = .07$. The pattern of means in Figure 2 indicates that the three-way interaction emerged because the handle alignment effect was present for congruent grasps (12 ms) only when the color cue was delayed (immediate onset: $F < 1$; delayed onset: $F(1, 47) = 16.57$, $MSE = 207$, $\eta_p^2 = .26$), whereas a small alignment effect (7 ms) was present for incongruent grasps both with immediate color onset and with delayed onset (immediate onset: $F(1, 47) = 9.04$, $MSE = 104$, $\eta_p^2 = .16$; delayed onset: $F(1, 47) = 9.73$, $MSE = 145$, $\eta_p^2 = .17$).

We further examined the handle alignment effect by plotting the cumulative response time distribution for each congruency by cue-delay condition, as shown in Figure 2. These distributions are based on the mean liftoff time for equal-sized quintiles (i.e., liftoff times for each subject were rank ordered and the first quintile consisted of the first [shortest] 20% of the observations; the second quintile consisted of the next 20%, and so on). ANOVAs were conducted to determine whether alignment effects varied across quintiles. The main effect of quintile was, of course, always significant so we do not discuss that point further. For the congruent grasp condition with immediate color onset, the interaction between alignment and quintile only approached significance once the Greenhouse-Geisser correction for violation of sphericity was applied, $F(4, 188) = 3.29$, $MSE = 170$, $p < .06$, $\eta_p^2 = .07$. As Figure 2 indicates, there was a small alignment effect (9 ms) emerging in the longest quintile. For incongruent grasps with immediate color onset, the interaction between alignment and quintile was significant, $F(4, 188) = 24.27$, $MSE = 140$, $\eta_p^2 = .34$, with alignment effects apparent only in the two longest quintiles (8 ms and 26 ms). With delayed color onset, both grasp types produced alignment effects that did not significantly vary across quintiles, $F < 1$ for congruent grasps, $F(4, 188) = 2.21$, $MSE = 101$, $p > .10$, for incongruent grasps.

Clear alignment effects in the congruent condition emerged only when the standard mapping evoked by the handled object was given a head start by delaying the onset of the color cue. In the incongruent condition, alignment effects were observed in the 0-delay condition, but only in the two longest response-time quintiles. This pattern of results suggests that the evocation of the standard mapping is slightly delayed for congruent actions. We propose that in the congruent condition, presentation of the object initially evokes a representation of hand shape congruent with the object. We assume that this representation is evoked for both hands, creating a competition that must eventually be resolved in favor of one or the other hand. This view is consistent with neurophysiological evidence indicating that patterns of activity in premotor cortex, especially during preparatory stages of processing, can be relatively independent of the choice of response hand (Cisek, Crammond, & Kalaska, 2003). Bilateral preparation gives way to an effector-dependent representation as the movement unfolds. Consequently, it will take some time for the ensuing competition between the two hands to be tipped in favor of the side aligned with the handle, leading to a delay in the alignment effect.

For the incongruent condition, the action cued by the color conflicts with (rather than supports) the action evoked by the object. This conflict will weaken the degree to which the hand shape associated with the object is evoked during the preparatory stage of the movement. As a result, the competition between the two hands is reduced and the influence of the handle's position can have an earlier impact on hand selection.

Movement time. Mean time required to move the response hand after liftoff to make contact with the response element is shown in Figure 3. These data and the analyses we report are based only on 43 subjects in the congruent condition because movement time data for the remaining five subjects were lost due to an
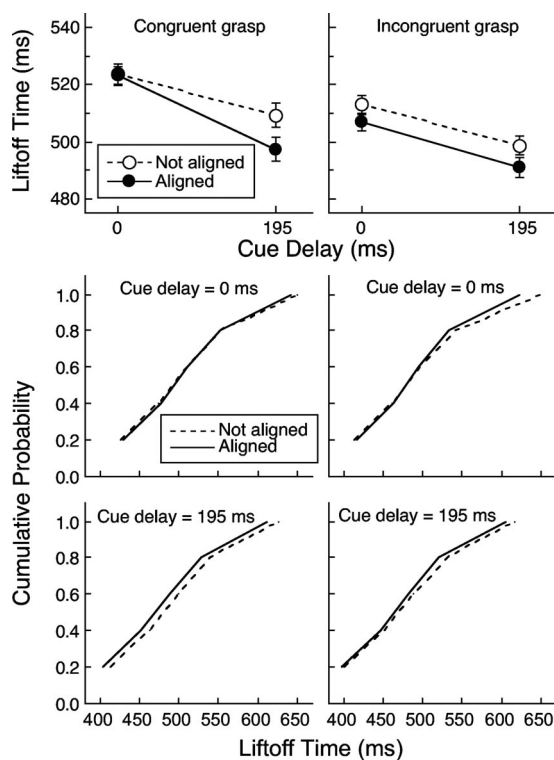

Figure 2. Mean liftoff time (upper panels) and associated cumulative response time distributions (middle and lower panels) in Experiment 1. Error bars indicate the within-subjects 95% confidence interval based on the MSE for the comparison between aligned and not-aligned conditions at each cue delay (Loftus & Masson, 1994; Masson & Loftus, 2003). The cumulative response time distributions show the effect of handle alignment separately for congruent (left panels) and incongruent (right panels) grasps in each cue delay condition. A response-time advantage is indicated in the cumulative distributions when a function reaches a given probability at an earlier response time value (i.e., is displaced to the left).
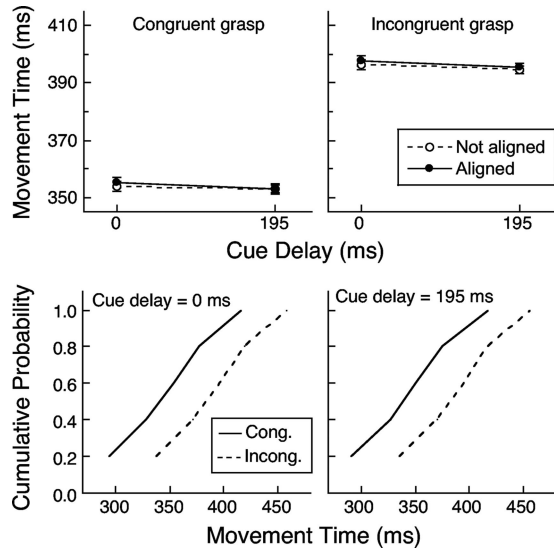
Figure 3. Mean movement time (upper panels) and associated cumulative response time distributions (lower panels) in Experiment 1. Error bars indicate the within-subjects 95% confidence interval based on the *MSE* for the comparison between aligned and not-aligned conditions at each cue delay. The cumulative response time distributions are averaged across the alignment manipulation.

equipment malfunction. An ANOVA with response congruency as a between-subjects factor and handle alignment and cue delay as repeated-measures factors revealed only main effects of congruency, $F(1, 89) = 9.97$, $MSE = 16,293$, $\eta_p^2 = .10$, and cue delay, $F(1, 89) = 6.91$, $MSE = 43$, $\eta_p^2 = .07$. There was no effect of handle alignment, $F(1, 89) = 1.90$, $MSE = 30$, and no interactions ($Fs < 1$). Because response congruency but not handle alignment had a reliable effect on movement time, we plot cumulative response time distributions as a function of congruency in Figure 3. A strong effect of congruency (approximately 40 ms) is present throughout the response time distribution, regardless of the length of cue delay ($Fs < 1.3$ for interaction between congruency and quintile).

The analyses of movement time revealed a robust effect of congruency. The time from liftoff to make contact with the response element was considerably faster when the target hand shape was congruent with the irrelevant object. Importantly, this effect was independent of both cue delay and handle alignment. The fact that an effect of congruency was seen even with no cue delay and even with a misaligned handle is consistent with our assumption that bilateral representations of hand shapes are evoked rapidly by the object.

It is also important to note that although congruency effects were found primarily on the movement time measure, alignment effects were seen only in liftoff time. This result is sensible because there is no reason to assume that factors influencing the choice of hand have a persistent effect after hand selection has been made. Furthermore, the persistence of congruency effects during the movement stage supports the idea that parameters of action such as hand shape continue to be established well after movement has been initiated (Cisek, 2005).

Percent error. Mean percent error is shown in Figure 4. An ANOVA indicated that fewer errors were made when the response

hand was aligned with the object's handle, $F(1, 94) = 6.06$, $MSE = 4.8$, $\eta_p^2 = .06$. In addition, error rates were higher when the color onset was delayed, $F(1, 94) = 5.77$, $MSE = 4.3$, $\eta_p^2 = .06$. No other effects were significant. The alignment effect on error rate is generally consistent with the alignment effect seen in liftoff time, although the more subtle interaction effects did not appear in errors. The main effect of cue delay suggests that the shorter liftoff times seen when the cue was delayed may have been a result of a speed–accuracy trade-off. But nothing in the error data suggests that any of the effects involving alignment or congruency resulted from such a trade-off.

Experiment 2

We have argued that key-press responses are not sufficient to evoke alignment effects without prior contextual prompts that encourage observers to consider the function of handled objects. Previous results using color to cue the response hand found no alignment effect with key pressing (Tipper et al., 2006), but these null effects occurred when there was no delay between color and object onsets. It is possible that some modest effect of alignment would be observed when a delay is introduced between object and color onset as in Experiment 1. The purpose of Experiment 2 was to establish that no such effects are seen, even when color onset is delayed over a substantial time course. We replaced the reach and grasp responses used in Experiment 1 with a key-press response
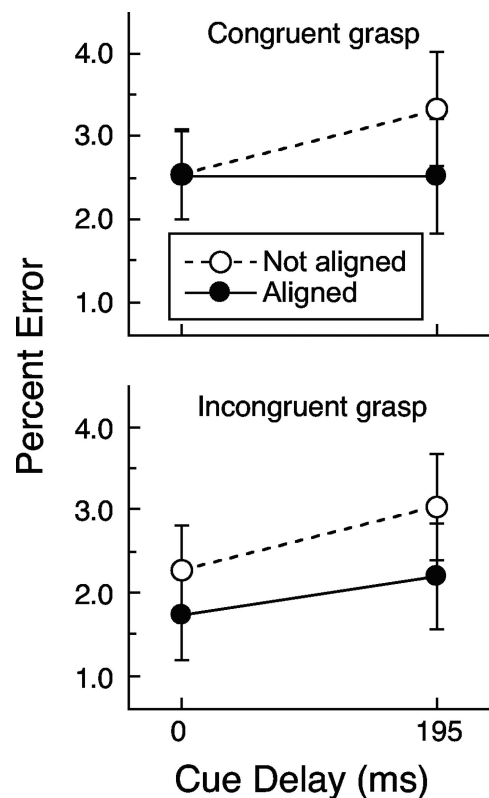

Figure 4. Mean percent error in Experiment 1. Error bars indicate the within-subjects 95% confidence interval based on the *MSE* for the comparison between aligned and not-aligned conditions at each cue delay.

and we dispensed with the 0-ms cue-delay condition, given that more robust alignment effects were seen with a delayed cue. We instead used cue delays of 195 ms and 630 ms.

Method

Subjects. Fifty-four subjects were tested in the experiment.

Materials and procedure. The materials and procedure were similar to the earlier experiments with the following exceptions. Two subgroups of subject were tested: 24 subjects were tested with a beer mug as the object carrying the color, as in Experiment 1, and 30 subjects were tested with a teapot rather than a beer mug. The teapot was 9.9° horizontally and 6.9° vertically when viewed from 50 cm. It had a spout on one side and a handle on the other. The teapot was considered to be aligned with the response hand when its handle was on the same side as the response hand. Like the beer mug, the teapot was presented either with its handle on the left or on the right. Subjects responded to the object's color by pressing one of the buttons on which their index fingers rested (left or right), rather than making a reach and grasp response. In the training phase, subjects were verbally instructed to respond to the green color with one hand and the blue color with the other. Eighty practice trials using a blue or green dot as the color cue were presented, followed by 20 practice and 320 critical trials using a beer mug (for 24 subjects) or a teapot (for 30 subjects) as the colored object as in Experiment 1. The color-cue delays used in this experiment were 195 ms and 630 ms, rather than 0 ms and 195 ms.

Results

Response time. Response times less than 200 or more than 900 were classified as outliers. The upper limit on response times was defined so that fewer than 0.5% of correct responses were excluded. Mean response time as a function of handle alignment and cue delay is shown in Figure 5. Data shown in this figure are collapsed across the two subgroups of subjects (beer mug versus teapot) because an ANOVA that included subgroup as a factor found no effects involving that variable ($Fs < 1$) and the pattern of means for the two object types was very similar (see Table 1). The only significant effect in this analysis was cue delay, $F(1, 52) = 129.60$, $MSE = 200$, $\eta_p^2 = .71$. All other effects were nonsignificant ($Fs < 1$). The power of this experiment to detect a main effect of handle alignment of 10 ms was greater than .99 and the power to detect an interaction between alignment and cue delay of the same size found in Experiment 1 for subjects in the congruent action condition was also over .99 (based on the G*Power 3 program; Faul, Erdfelder, Lang, & Buchner, 2007). An additional ANOVA compared the alignment effect at the 195-ms cue delay across Experiments 1 and 2, using alignment and experiment as factors. This ANOVA indicated that the 10-ms effect in Experiment 1 was significantly larger than the effect of –1 ms in Experiment 2, $F(1, 148) = 14.10$, $MSE = 150$, $\eta_p^2 = .09$.

The cumulative response time distributions are shown in Figure 5. These distributions reveal no indication of an alignment effect at any of the response time quintiles for either cue-delay condition. Separate ANOVAs for each cue delay failed to find either a main effect of alignment ($Fs < 1$; with power greater than .99 to detect a 10-ms effect in each case) or an interaction between
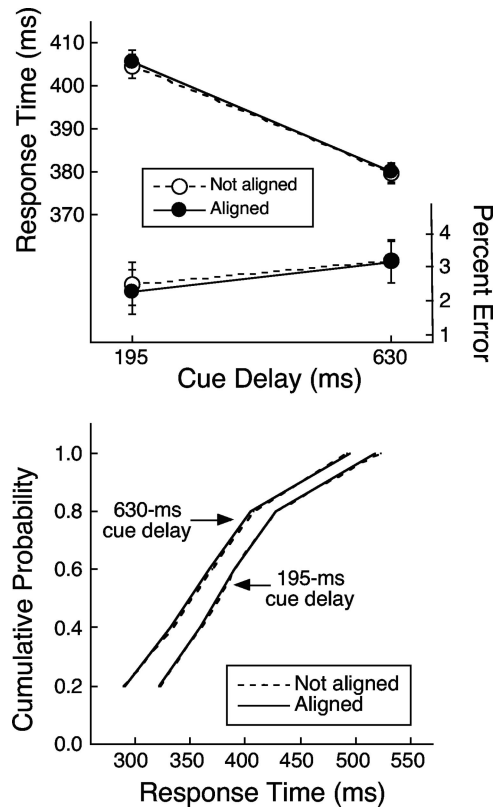

Figure 5. Mean response time and percent error (upper panel) and cumulative response time distributions (lower panel) in Experiment 2. Error bars indicate the within-subjects 95% confidence interval based on the *MSE* for the comparison between aligned and not-aligned conditions at each cue delay.

quintile and alignment ($Fs < 1.7$). A comparison of these distributions to the cumulative distributions for liftoff times in Experiment 1 shows that when a range of response times common to both types of distribution is considered (i.e., 400 ms to 550 ms), no alignment effect is seen in Experiment 2, but a clear alignment effect is seen in liftoff time in the 195-ms cue-delay condition of Experiment 1. Thus, it is not the case that the lack of an alignment effect observed for key pressing occurs because responses are too fast to detect such effects.

Percent error. Mean percent error for key-press responses is shown in Figure 5. An ANOVA analogous to the one computed for response time revealed that only the main effect of cue delay was significant, $F(1, 52) = 7.43$, $MSE = 4.0$, $\eta_p^2 = .13$, with fewer errors in the 195-ms delay condition than in the 630-ms delay condition. No other effects approached significance, $Fs < 1.8$. As with the measure of liftoff time in Experiment 1, the response-time advantage associated with the longer cue delay in Experiment 2 appears to be due at least in part to a speed–accuracy trade-off.

Discussion

The results clearly indicate that even with a relatively long cue delay no alignment effects occur for key-press responses cued by object color, consistent with arguments presented by Tipper et al.

Table 1
Mean Response Time in Experiment 2 Shown Separately for Subjects Tested With a Beer Mug or With a Teapot

	Cue delay			
	195 ms		630 ms	
Object	Aligned	Not aligned	Aligned	Not aligned
Beer mug	407	406	380	378
Teapot	405	403	379	380

(2006). It is not the case, however, that alignment effects cannot occur in general when color is the relevant attribute and the object is irrelevant to the task. Rather, the goal state (the set of left- and right-handed responses required for the contextual mapping task) plays a crucial role in determining whether an object automatically will evoke left- or right-sided hand actions. Apparently, a key press is too far removed from any action compatible with the irrelevant object to evoke motor representations that favor one hand over another. Moreover, depressing a finger already resting on a response key does not involve the process of transporting the hand to a target location in space and forming the hand shape to fit that target. We propose that it is the act of reaching for and grasping a object in space that is responsible for the automatic alignment effects that we see in Experiment 1.

In other unpublished experiments in our laboratory similar to Experiment 1, we have found that making a vertical clenched grasp response in the presence of a teapot produced clear alignment effects on liftoff time at cue delays close to those used in Experiment 2. Similarly, we have found that using a beer mug as the object also produces an alignment effect at a cue delay of 500 ms when a clenched grasp response is used. Finally, in Experiment 4 reported below, both a beer mug and a teapot yield alignment effects when a clenched grasp is used. The overall pattern provides very strong support for the claim that the nature of the response (i.e., reach and grasp versus key press) plays a crucial role in determining whether handled objects evoke action representations that produce alignment effects of the form we have documented.

We conclude that previous demonstrations showing alignment effects with key-press responses (e.g., Tipper et al., 2006; Tucker & Ellis, 1998) cannot be based on the explanation we have advanced here. These results are induced by contextual activity such as prior viewing of a video depicting functional interaction with an object or by instruction to consider the function of an object (see also Loach, Frischen, Bruce, & Tsotsos, 2008, for an example based on texture cues that were argued to be an action-relevant dimension). An important aspect of these demonstrations of alignment effects on key-press responses is that attention to color as a surface property fails to show any effect of alignment (Loach et al., 2008; Tipper et al., 2006), despite the fact that consideration of object affordances is encouraged by task set or by context. We suggest that alignment effects on key-press responses require attention to object form or identity and reflect motor representations arising from mental simulation of actions afforded by handled objects. If the shape or identity of an object is irrelevant to the task, then no alignment effects occur. By contrast, we show

robust effects of alignment on a reach and grasp response using color cues under conditions in which the object is irrelevant. We infer that a reach and grasp response, but not a key press, automatically evokes action representations from a handled object.

Experiment 3

The procedure we have introduced relies on a two-choice response task that reflects the build up of competition between two response channels (left and right hand). In the aligned condition, the flow of activation from the handled object would favor the response side cued by color. In the not-aligned condition, this activation potentially competes with the correct response. This proposed combination of facilitation and interference is analogous to stimulus–response compatibility effects obtained in other two-choice response tasks, such as the Eriksen flanker task (Eriksen & Eriksen, 1979). In this task, subjects respond with a different hand to two different critical letters. On each trial, one of these letters is presented as a target with flanking letters that are either the same as the target (i.e., compatible with the correct response) or identical to the other critical letter (i.e., incompatible with the response). A great deal of work supports the suggestion that competition in the flanker task is due to the continuous parallel flow of information along processing channels from stimulus analysis to response selection (Coles & Gratton, 1986; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988).

Our method differs from the Eriksen flanker task in an interesting way. In the flanker task, compatibility effects depend on both target and flanker stimuli belonging to the response set: across trials, critical letters serve both as targets and flankers. By contrast, in our procedure, the irrelevant object never requires a response and it is the prior history of the object, based on a standard mapping between the orientation of its handle and the preferred hand, that generates competition. It is this mapping that determines the compatibility between the object and the cued hand, whereas the compatibility effect in the Eriksen flanker task is due to the arbitrary mapping between stimulus and response defined by task instructions. Despite this difference in task arrangements, we propose that the alignment effects we have found, like the Eriksen flanker effect, are due to the passive build up of information over time in two response channels serving the left and right hand. According to this principle of continuous flow of information, the handled object acts in concert with or against the response activation accumulating to color, leading to benefits or costs relative to some neutral condition. Establishing a neutral condition in our case is relatively straightforward: we introduce a beer mug with no handle to carry the color. Such a symmetrical object evokes neither left- nor right-handed preference. Thus, comparing performance on these neutral trials to trials that depict beer mugs with handles aligned or misaligned with the response hand, should yield an ordering of conditions in which the neutral condition is intermediate between the aligned and not-aligned conditions (see Phillips & Ward, 2002, for a similar result involving spatial coding induced by a handled object).

Thus, in Experiment 3, we examined alignment effects relative to a neutral condition to establish the presence of both costs and benefits. In addition, we wish to determine the durability of the spatial information evoked by the irrelevant handled object. Irrelevant spatial codes tend to decay over time. For example, the left

or right location of an object produces compatibility effects with a left- or right-sided response (Simon, 1969), but this effect is typically short-lived and decays with slower responses (Buhlmann, Umilta, & Wascher, 2007). Under certain conditions, however, spatial compatibility effects are sustained; the Simon effect is prolonged when spatial codes are defined by goal states that depend on a more complex pairing than a left- or right-sided response button and a corresponding simple left- or right-sided response (e.g., key press). For example, Buhlmann et al. obtained a sustained Simon effect by requiring subjects to make actions that were crossed so that the left hand was used to produce a right-sided effect, and vice versa. Under this more complicated arrangement, a prolonged Simon effect was found.

Therefore, we expect that responding to a single, centrally located element using a reach and grasp action consistent with the object that carries the color, now with one hand, now with the other, should be associated with goal states that produce sustained spatial compatibility effects induced by handled objects. In Experiment 3, then, we used a relatively long cue delay (495 ms) between the onset of a handled object and the presentation of the color cue.

Method

Subjects. Twenty-one subjects participated in the experiment.

Materials and procedure. The same equipment and beer mug images as in the earlier experiments were used. In addition to the images of the beer mug with the handle on the left or right side, a third version was created in which the beer mug appeared without a handle. This image was used in the neutral condition. The task was once again to make a vertical clenched grasp response to object color. Subjects were first given 20 training trials in which a picture of a hand making a clenched grasp posture was paired with either a blue or green color patch. The task was to learn to make a clenched grasp response as rapidly as possible using the left or the right hand, depending on the color of the patch. Next, a set of 20 training trials presented a blue or green disk as the response cue. Twenty practice trials were then presented on which a beer mug with its handle facing left or right or without a handle was presented in grayscale. After a cue delay of 495 ms, the beer mug changed to either a blue or green color, cuing the subject to make a left- or right-hand response. After the practice trials, a series of 330 critical trials was presented using the same procedure as in the practice trials. Fifty-five critical trials were assigned to each of the six combinations of beer mug orientation (left, right, neutral) and color (blue, green). The 330 critical trials were presented in an independently determined random order for each subject. Throughout the training, practice, and critical trials, subjects were given automated feedback if the time taken to initiate their response (i.e., lifting the response hand from the button box) exceeded 700 ms. Subjects returned to the laboratory the day after the first session and participated in a second session that followed exactly the same training, practice, and critical trial procedure as in the first session.

Results and Discussion

Data are reported as an aggregate over the two testing sessions. Response times less than 200 ms or greater than 900 ms for liftoff

time or 600 ms for movement time were excluded as outliers (fewer than 0.5% of correct responses).

Liftoff time. Mean liftoff time is shown in Figure 6. The difference between the aligned and not-aligned conditions was 15 ms, which is very similar to the 12-ms effect seen in Experiment 1 with a congruent action and a 195-ms cue delay. An ANOVA with handle alignment (aligned, neutral, not aligned) as the only factor indicated that there was a reliable alignment effect, $F(2, 40) = 16.67$, $MSE = 70$, $\eta_p^2 = .45$. Planned comparisons indicated that mean response time was reliably shorter in the aligned than in the neutral condition, $F(1, 20) = 11.66$, $MSE = 52$, $\eta_p^2 = .15$, and reliably longer in the not-aligned than in the neutral condition, $F(1, 20) = 10.66$, $MSE = 72$, $\eta_p^2 = .19$. The cumulative response time distributions for liftoff time are also shown in Figure 6. There was no interaction between alignment condition and quintile, $F < 1$.

Consistent with Experiment 1, alignment effects were clearly revealed in liftoff time. Handled objects produce both costs when the handle is not aligned and benefits when the handle is aligned, relative to a neutral condition. Moreover, the analysis of response time distributions indicated that both facilitation and interference effects followed the same time course, emerging in the shortest quintile and continuing throughout the distribution. We infer that the handle of an object aligned with a particular arm automatically triggers action representations governing that side of the body. These representations will conflict with an action made by the contralateral arm or facilitate an action from the ipsilateral side.

Movement time. The results for movement time are shown in Figure 6. No influence of alignment was seen on the means for this measure, $F < 1$, nor did the cumulative response time distribution reveal any effect of alignment. As in Experiment 1, no effects of handle alignment were seen in movement time, indicating that the effect is not sustained after hand selection.

Percent error. Mean percent error was 3.0%, 2.0%, and 1.9% for the not aligned, neutral, and aligned conditions, respectively. An ANOVA indicated that the alignment effect was significant,
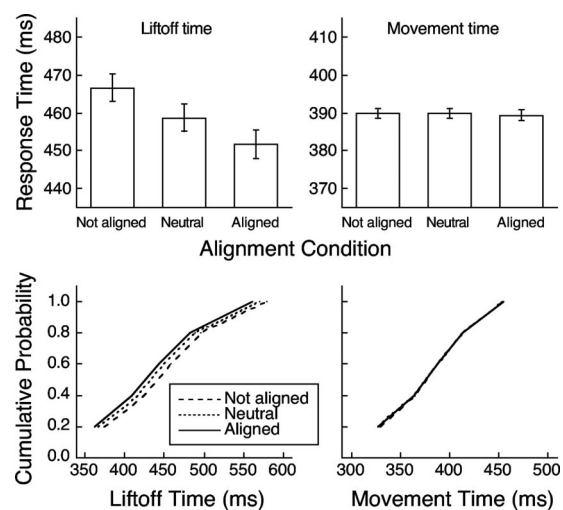

Figure 6. Mean liftoff and movement time (upper panels) and cumulative response time distributions (lower panels) in Experiment 3. Error bars indicate the within-subjects 95% confidence interval based on the *MSE* for the comparison between alignment conditions.

$F(2, 40) = 4.82$, $MSE = 1.5$, $\eta_p^2 = .19$. Planned comparisons found that the not-aligned condition produced more errors than the neutral condition, $F(1, 20) = 6.36$, $MSE = 1.5$, $\eta_p^2 = .14$, but there was no reliable difference between the aligned and neutral conditions, $F < 1$. No speed–accuracy trade-offs in the response time data are implied by these results.

Experiment 4

In Experiment 1, we showed that alignment and congruency effects influenced different components of a reach and grasp response. The handle alignment of an irrelevant object affects the selection of the hand during preparation to lift off. The shape of the target response in relation to the object primarily affects the movement time after liftoff. We noted earlier that this separation of influences may not reflect a fixed sequential relationship between hand selection and hand shape. In other words, under certain task conditions, it may not be possible to delay setting the hand shape parameters until after hand selection. We consider such a circumstance in Experiment 4.

Subjects were required to determine on a trial by trial basis both hand shape and hand selection. Color cues were presented to indicate which of two hand shapes and which of the two hands were to be used on a given trial. The cued hand shape could be congruent or incongruent with the object and the object's handle could be aligned or not aligned with the response hand. This arrangement differed from Experiment 1 in which the hand shape was identical from trial to trial and therefore was always known in advance. In that case, the demands of time pressure before liftoff were applied to selection of the correct hand, not to formation of hand shape which could be delayed until the movement phase. In Experiment 4, we induced subjects to choose between two possible hand shapes as well as between a left- and right-handed response prior to liftoff. The formulation of hand shape parameters is unlikely to be postponed until the movement phase under these circumstances, especially since we removed the color cue immediately after the subject initiated a hand movement (as in the earlier experiments).

There are a number of possibilities given the demands of this task arrangement. One possibility is that hand selection as well as selection and programming of hand shape are processed independently. This form of processing would entail that cued responses that overlap completely with the standard mapping (i.e., congruent actions that are aligned with the handle) would be faster than cued responses that overlap partially (congruent action that is misaligned, or an aligned incongruent action), which in turn would be faster than a cued response that has no overlap with the standard mapping (incongruent or misaligned). Alternatively, hand shape and hand selection may be specified in such a way that the complete action is formulated by integrating the two components. This is the view favored by Leuthold et al. (2004; Ulrich et al., 1998) using amplitude of the lateralized readiness potential (LRP) as an electrophysiological measure of motor preparation. The LRP amplitude is greater over motor cortex contralateral to the responding hand given a precue that signals which hand to use before an imperative cue is presented. Ulrich et al. found that additional information provided either for finger movement (extension vs. flexion) or force (strong vs. weak) yielded no increase in LRP over

cuing the hand alone. The LRP was increased, however, if both finger movement and force were cued in combination.

This pattern implies that hand information, response force, and finger movement are integrated into a compound code during preparation. All three parameter sets must be combined for the movement to be prepared; omission of either force or finger movement in the precue prevents development of the integrated motor program and no cuing effect from the retained component is seen. If the formulation of the parameters of the reach and grasp response in Experiment 4 is integrated in this way, then the standard mapping evoked by the object may affect responding only when it matches the goal response on both dimensions. That is, a standard mapping that differs from the cued response either with respect to alignment or hand shape should not influence performance. If this suggestion is correct then we expect alignment effects to occur only when a congruent hand shape is cued. Similarly, an effect of congruency should be found only when the object's handle is aligned with the cued response hand.

Method

Subjects. Thirty subjects were tested.

Materials. We used the digital photographs of a beer mug and a frying pan from Experiment 1, a larger photograph of the teapot from Experiment 2 (12.2° wide and 8.4° high), and a photograph of a flashlight (10.8° wide and 4.4° high). Each object was depicted in two versions, with its handle facing left or facing right. Each version was rendered in grayscale, in red with high or low saturation, and in blue with high or low saturation.

Procedure. Subjects were tested using the same equipment and general procedure as in earlier experiments, except that the response apparatus now included two response elements, one used for a vertical clenched grasp and one for an inverted closed grasp (Figure 1A). Both elements were situated side by side directly in front of the subject. Left and right position of these two elements was counterbalanced across subjects. Subjects were first trained to respond to color cues which indicated the response hand and grasp that was to be made on a given trial. The first block of training trials displayed a color patch and photograph of a left or right hand depicting the target action. The patch was red or blue and the color was of high or low saturation. Color indicated which grasp to make and saturation indicated which hand to use. Assignments of colors to actions and saturation levels to hands were counterbalanced across subjects. The second block of training trials presented a color patch without a hand cue. After a total of 88 training trials, subjects were given blocks of 16 criterion trials with color-patch cues. These blocks were continued until the subject completed an entire block without error and with mean total response time (liftoff plus movement time) less than 1,200 ms. Throughout training, a feedback message was displayed if the time between response initiation and contact with the response element exceeded 500 ms.

After the training criterion had been met, subjects were shown displays of each of the four objects in each color-saturation combination to familiarize them with the stimuli. Subjects were then given 16 practice trials in which each object appeared once in each color-saturation combination. The cue delay for color onset was either 0 ms or 495 ms and the object's handle faced either left or right. These two features were randomly determined for each trial.

The practice trials were followed by 384 critical trials with breaks provided after every 64 trials. Across the critical trials, each combination of object, handle orientation, color, saturation, and cue delay (0 ms or 495 ms) was presented six times. This arrangement resulted in 24 trials for each cell of the design defined by a factorial combination of object–action congruency (congruent, incongruent), handle alignment (aligned, not aligned), and cue delay. These trials were presented in an independently determined random order for each subject. Randomization was constrained so that no action (grasp-hand combination) and no object was repeated on consecutive trials.

Results and Discussion

The liftoff and movement time data were filtered as in earlier experiments, with a lower bound set at 200 ms and the upper cutoffs set at 3,400 ms for liftoff times and 1,400 ms for movement times. These boundaries eliminated fewer than 0.5% of correct response times.

Liftoff time.   Mean correct liftoff times are shown in Figure 7. Liftoff times in Experiment 4 were longer than in Experiments
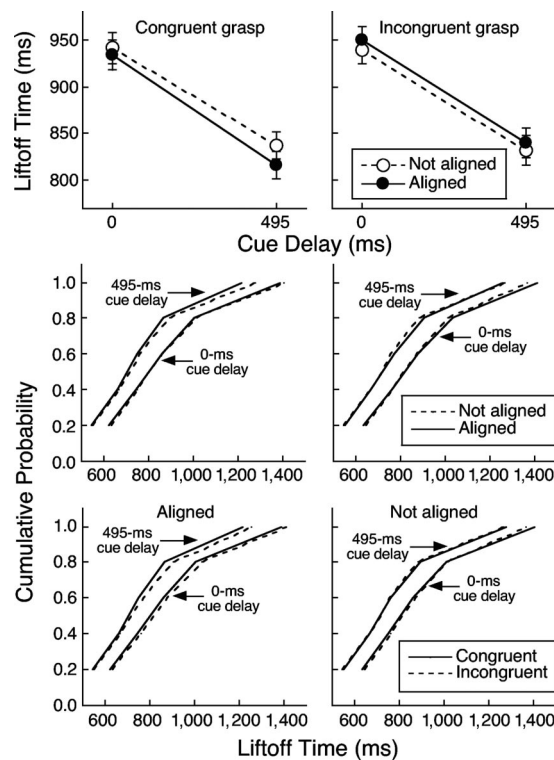

Figure 7.   Mean liftoff time (upper panels) and associated cumulative response time distributions (middle and lower panels) in Experiment 4. Error bars indicate the within-subjects 95% confidence interval based on the *MSE* for the comparison between aligned and not-aligned conditions at each cue delay. The cumulative response time distributions in the middle panels show the effect of handle alignment separately for congruent (left panel) and incongruent (right panel) grasps in each cue delay condition. The cumulative response time distributions in the bottom panels show the effect of grasp congruency separately for aligned and not aligned response hand in each cue delay condition.

1 and 3 because subjects had to learn to discriminate four different color values rather than just two. An ANOVA with object–action congruency, handle alignment, and cue delay as factors revealed a reliable effect of cue delay, $F(1, 29) = 122.51$, $MSE = 5,860$, $\eta_p^2 = .81$, and an interaction between congruency and alignment, $F(1, 29) = 6.83$, $MSE = 1,144$, $\eta_p^2 = .19$. No other effects were significant ($Fs < 1.9$). Although cue delay did not significantly interact with either alignment or congruency, it is apparent from Figure 7 that the alignment effect was observed only when a congruent hand action was made and when the cue delay was 495 ms, $F(1, 29) = 4.69$, $MSE = 1,429$, $\eta_p^2 = .14$. This significant 21-ms effect contrasts with the lack of alignment effects in any other condition, $Fs < 1$. Similarly, the 23-ms congruency effect in the aligned condition with a 495-ms cue delay was significant, $F(1, 29) = 4.19$, $MSE = 1,983$, $\eta_p^2 = .13$, but there was no significant congruency effect in any other condition, $Fs < 1.8$.

The cumulative response time functions for alignment and congruency effects are shown in Figure 7. ANOVAs applied to these data indicated that there were no significant interactions between alignment or congruency and response time quintile, $Fs < 1.9$.

The liftoff time results yielded two important outcomes. First, as expected, a congruency effect was clearly apparent in the liftoff measure, whereas in Experiment 1 this effect was confined to the movement phase of the reach and grasp response. Congruency has an early influence here because the demands of the task required a selection of both hand shape and response hand. This requirement could be met during the preparatory phase prior to liftoff or postponed until the movement phase. The fact that liftoff time in Experiment 4 was nearly twice as long as in Experiment 1 indicates that selection of hand shape as well as response hand was initiated prior to liftoff. The additional time required to process the cue implies that even with immediate onset of the color cue there is sufficient time for the standard mapping to begin to have an influence on performance. Consequently, the robust interaction between cue delay and alignment effects seen in Experiment 1 was not apparent here.

A second important outcome is that alignment effects were observed only when the cued action was congruent with the object and, conversely, congruency of hand shape was contingent on the handle being aligned with the response hand. This remarkable codependency supports our proposal that the processes of establishing parameters for hand selection and hand shape are integrated under the demands of the task used in Experiment 4. We note that if determination of hand selection and hand shape merely overlapped in time, but were processed independently rather than being integrated, then a partial mismatch between the standard mapping and the cued response should have resulted in a shorter liftoff time than a complete mismatch. For example, suppose the cued action was a left-handed vertical clenched grasp whereas the standard mapping afforded a right-handed vertical clenched grasp. This combination should produce better performance than the same cued action combined with a standard mapping that afforded a right-handed inverted closed grasp. We found no such ordering. Instead, performance was affected only if both components of the reach and grasp were shared with the standard mapping of the object.

Movement time

The results for movement time are shown in Figure 8. An ANOVA applied to this measure yielded only one significant effect: a 4-ms advantage for congruent over incongruent actions, $F(1, 29) = 6.84$, $MSE = 123$, $\eta_p^2 = .19$. There were nonsignificant trends for congruency and alignment to interact with cue delay, $ps < .08$, but no other effects approached significance, $Fs < 1$. Pairwise comparisons indicated that in none of the congruency by cue delay conditions was the effect of alignment significant, $Fs < 1.7$. Cumulative response time distributions for the congruency effect are shown in Figure 8. ANOVAs indicated that, once the Greenhouse-Geisser correction for violation of sphericity was taken into account, in the interaction between congruency and quintile approached significance in the 0-ms delay condition, $F(4, 116) = 3.44$, $MSE = 273$, $\eta_p^2 = .11$, $p < .06$, and was reliable in the 495-ms delay condition, $F(4, 116) = 9.98$, $MSE = 323$, $\eta_p^2 = .26$. These interactions indicated that the congruency effect emerged only when movement times were relatively long.

In contrast to the large congruency effect seen in movement time in Experiment 1, only a small effect was found in Experiment 4. We note that an interesting aspect of this effect is that we observed no contingency between congruency and alignment in movement time despite the fact that such a contingency was clearly apparent in liftoff time. We interpret this result to imply that some aspects of hand shape continued to be programmed after hand selection, although much of this work was accomplished in the earlier phases of the response.

Percent error

Mean percent error is shown in Figure 9. An ANOVA with congruency, alignment, and cue delay as factors revealed significant effects of congruency, with lower error rates for the congruent
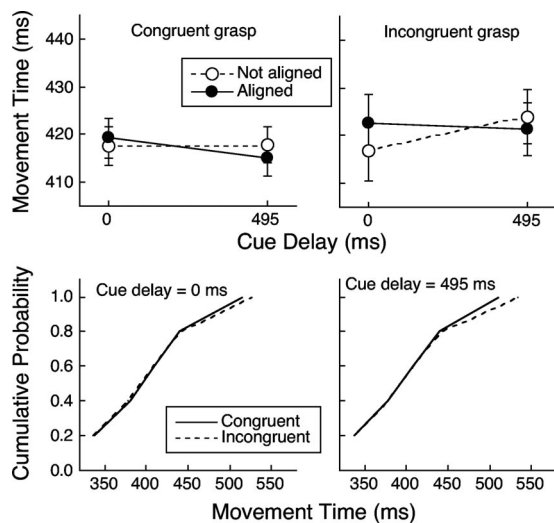

Figure 9. Mean percent error in Experiment 4. Error bars indicate the within-subjects 95% confidence interval based on the *MSE* for the comparison between aligned and not-aligned.

condition (4.6% vs. 5.8%), $F(1, 29) = 6.64$, $MSE = 13.1$, $\eta_p^2 = .19$, and alignment, with fewer errors in the aligned condition (4.7% vs. 5.7%), $F(1, 29) = 4.29$, $MSE = 14.2$, $\eta_p^2 = .13$. No other effects approached significance, $Fs < 1.6$. These results suggest that the benefits of congruency and alignment seen in response times were not due to a speed–accuracy trade-off.

General Discussion

Our experimental procedure pits automatic hand action representations evoked by handled objects against a contextually driven task, in which a left- or right-handed action is arbitrarily associated with the color carried by the object. Thus, the object can be deemed irrelevant with respect to the task goal of simply responding with one or the other hand to the relevant stimulus, the color cue. Actions to color were carried out on grasp elements that afforded different hand postures varying in relation to the posture afforded by the visual object. In the light of previous research showing that action may prime perception of object attributes (Humphreys & Riddoch, 2007; Hommel, 2000) we evaluated the possibility that handle alignment effects depend on the nature of the motor goal dictated by task demands. Specifically, we demonstrate that motor goals involving a reach and grasp response evoke reliable handle alignment effects, whereas a simple key-press response yields no such effects. We infer from this finding that

Figure 8. Mean movement time (upper panels) and associated cumulative response time distributions (lower panels) in Experiment 4. Error bars indicate the within-subjects 95% confidence interval based on the *MSE* for the comparison between aligned and not-aligned conditions at each cue delay. The cumulative response time distributions are averaged across the alignment manipulation.
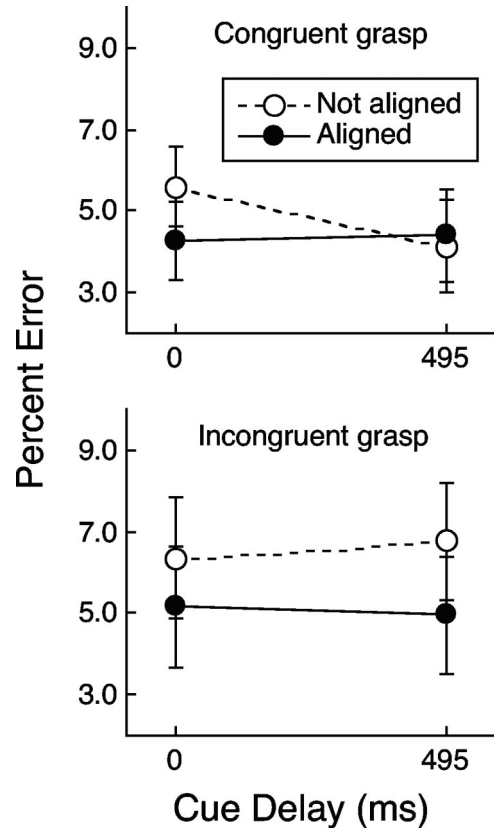
merely looking at a handled object in the absence of a goal to make a reach and grasp response fails to evoke automatic hand action representations. Thus, the activation of motor affordances, at least to handled objects, depends not only on the intention to act, but also on the type of intended action.

In Experiment 1, we used pictures of a beer mug with its handle facing left or right. The orientation of the handle was not predictive of the left- or right-handed action cued by the color. Subjects responded to the color cue with a reach and grasp action on a response element located directly in front of them. The shape of the grasp element required a reach and grasp response that was either very similar (congruent) to the action afforded by the object carrying the color or unrelated to it (incongruent). We examined two components of the reach and grasp response: the time to initiate a response (liftoff time) and the time to complete the response (movement time). Handle alignment effects on liftoff time were observed for both congruent and incongruent actions. No alignment effects were observed during the movement phase, a sensible outcome given that the alignment of the handled object should have its primary effect on hand selection rather than the movement of the hand through space. In addition to the alignment of the handle, a powerful relationship was observed between the handle's shape and the shape of the response hand, but only during the movement phase. Cued actions that were congruent with the shape of the handle were executed faster than incongruent actions. The fact that this congruency effect was situated in movement, but not liftoff, time is consistent with neurophysiological evidence indicating that some components of planning continue during the execution phase of a response (Cisek, 2005).

In Experiment 2, we showed that a key-press response to color yielded no alignment effect, consistent with previous demonstrations by Loach et al. (2008) and Tipper et al. (2006). It is not the case, however, as these authors suggested, that responding to color can evoke no handle alignment effect. Rather, as we have demonstrated, the influence of handle alignment is crucially dependent on the relationship between the goal state associated with the target response and the form of the hand action associated with the irrelevant object. A key press is sufficiently far removed from a reach and grasp that no hand actions are evoked by the goal state defined by pressing a key in response to color. Indeed, consistent with this view, Pavese and Buxbaum (2002) found that key-press responding to a target object (a cup) selected on the basis of color was insensitive to the presence or absence of a handle on a distracting object. Distractor effects were determined instead by perceptual factors like the proximity of the irrelevant object to fixation. By contrast, if a hand action, including a reach and grasp, was made to the target object, distracting objects with handles produced greater interference than distractors without handles (see Riddoch et al., 1998, for similar evidence).

In Experiment 3, we used the image of a beer mug with its handle removed as a neutral condition to show that alignment effects evoked by a handled beer mug are the result of both cost, when the handle is misaligned with the response hand, and benefit, occurring when there is alignment between the handle and the responding hand. Thus, the handled object yields spatial representations that facilitate, as well as compete with, reach and grasp responses driven by color cues. In addition, the alignment effect was observed with a delay of 495 ms between the object and the onset of the color cue. Previous research on involuntary spatial alignment effects induced by the location of an object (e.g., the Simon effect) has shown that such effects dissipate quite rapidly (Hommel, 1994). More recent work, however, indicates that the Simon effect can be sustained, particularly when a response involves a more complex mapping between spatial representations and action than a simple left- or right-sided key press (Buhlmann et al., 2007). The handle alignment effects that we observed depended on a decision to reach and grasp a single element with one or the other hand. It is reasonable, then, to expect sustained effects of an irrelevant object under these circumstances.

In Experiments 1 and 3, reliable effects of alignment were clearly obtained, despite the fact that only one object was used throughout a testing session for any particular subject. In this respect, handled objects generate automatic alignment effects that appear to be as obligatory as the spatial effects generated by the widely used arrowhead in previous experiments on involuntary attention–the object's influence persists despite repeated exposure to a single object (e.g., Hommel, Pratt, Colzato, & Godijn, 2001; Ristic, Friesen, & Kingstone, 2002). The crucial difference between a handled object and an arrow, however, is that motor representations evoked by the former yield alignment effects only under the intention to make a reach and grasp response, whereas arrows and other symbolic directional cues elicit compatibility effects over a much wider range of response modes.

The final experiment examined the contingency between congruency and alignment effects. Recall that the congruency of an action refers to its compatibility with the hand shape invoked by the standard mapping. A beer mug invites a clenched grasp action to lift it by the handle; a congruent action cued by color would involve the same action applied to a response element, whereas an incongruent action would consist of a different hand shape applied to a different response element. In Experiment 1, subjects knew in advance which hand shape to make and the only selection requirement was choice of response hand. Under these conditions, it makes sense that programming the parameters of hand shape occurred after hand selection. In Experiment 4, both choice of hand and hand shape depended on the color cue. The evidence indicated that the processing of hand and hand shape now entailed an integrated compound code; the standard mapping affected the liftoff component of the cued response only if both hand and hand shape were the same for the cued response and the grasp afforded by the irrelevant object. This constraint yielded a contingency between congruency and alignment effects. No congruency effect occurred when the response hand was not aligned with the handle, and no alignment effect occurred when the cued response was incongruent with the afforded action. Thus, the effect of hand action representations evoked by an object is restricted to the side of the body aligned with the object's handle.

Remarkably, although in Experiment 4 congruency depended on alignment in liftoff time, an additional small effect of congruency was also seen in the movement component of the response that was independent of alignment. The integration of hand shape and hand therefore appears to concern a preparatory phase of movement that is distinct from subsequent phases in which parameters of hand shape are established. We propose that preparation leading up to liftoff includes the specification of hand and hand shape as the goal of the movement, whereas additional effects of congruency after liftoff concern the real-time shaping of the hand in flight. The fact that the irrelevant object continued to influence the movement

phase following removal of the object from view has implications for accounts that claim that the on-line control of the hand is primarily based on bottom-up information from the retina rather than high level perceptual representations of an object (Milner & Goodale, 2008). Clearly, however, Experiment 4 shows that movement time to a fixed response element cued by color reflects the influence of an irrelevant object on hand shape even well after the movement has been prepared. The perceived form of an irrelevant object (processed by the ventral stream) continues to exert an effect on the execution of the color-cued movement controlled by the dorsal stream.

It is of considerable interest that we have obtained evidence for the integration of hand alignment and hand shape in the liftoff time data. This evidence converges with measurements from LRP studies (Leuthold et al., 2004) but not with response time data from these very same experiments. For example, although the LRP indicated that advance information about direction of movement, movement force, and hand is combined in a compound code to prepare a response, the response time data showed evidence for independence between force and direction. That is, response time was fastest when both of these dimensions were specified in advance, intermediate when only one of them was specified, and slowest when neither was cued. The explanation given for the discrepancy between effects seen in response time and LRP is that the former provides a measure of a central process that makes use of advance information by treating each dimension of the movement independently, whereas the latter reflects the actual representation computed for the movement (Rosenbaum, 1985; Ulrich et al., 1998). The implementation of the motor program relies on a compound code in which parameters of hand movement are integrated.

We argue that the difference in response time patterns between our experiments and those reporting independent effects of cuing movement dimensions is due to the nature of the advance information provided. Cuing experiments have largely relied on abstract symbols to denote values on movement dimensions (e.g., a large square on the upper left of a display indicates strong finger flexion with the left hand). Processing these cues would indeed rely on central mechanisms prior to formulation of a motor program. In our case, however, the standard mapping of the irrelevant object acting as the source of advance information would provide a more direct entry to motor representations. The motor affordance evoked by an irrelevant object lies closer to an implemented motor program than does an abstract cue.

Goal States and Modulation of Attention to Perceptual–Motor Features

The data we have presented pose a challenge for the widely held view that perceived objects automatically evoke affordances, regardless of the intentions of the observer (e.g., Derbyshire, Ellis, & Tucker, 2006; Sumner & Husain, 2008). Rather, the standard mapping of an irrelevant object is evoked only when the task requires a reach and grasp response, whereas more conventional response modes, such as key pressing, are insufficient to yield this kind of affordance. Our evidence is more consistent with recent theoretical arguments that planning a particular action will modulate attention to action-relevant features of an object, such as its handle (e.g., Hommel, 1997).

The idea that the goal state plays a role in the evocation of motor affordances fits well with a recent theoretical analysis of neural networks by Brozovic, Gail, and Andersen (2007). These authors attempted to clarify the functional architecture by which sensory events (e.g., a colored light) are integrated with abstract behavioral rules or context (e.g., a red light means reach to that location) in posterior parietal cortex (PPC) of the primate brain. The parietal reach region (PRR) must take visual information, specified by the location of the target in the periphery (the visual stimulus), and map this information to a new location, specified by the color or context (the motor goal). They compared two quite different architectures in analyzing the function of cells in PRR, shown in Figure 10. Architecture A has the rule component (denoted by C) acting directly on the hidden layer of processing units that are positioned between the visual stimulus processing module and the motor goal module. The network is predominantly feed-forward, with the responses of the hidden units depending on the previous activity of units in that layer via recurrent connections.

This type of architecture has in fact been widely used in the literature on computational modeling of stimulus–response compatibility effects, including influential work on Stroop color–word interference by Cohen, Dunbar, and McClelland (1990). The task goal acts directly on hidden units to modulate their activity to emphasize the relevant perceptual dimensions for the task. Architecture B, in contrast, is based on the assumption that the mapping rule becomes available to sensorimotor areas (i.e., the hidden units) only after the contextual information (e.g., color) has been interpreted by higher cognitive regions and a motor goal defined at the level of the motor cortex. Thus, component C acts on the motor goal, whereas the hidden units in Architecture B receive information about the remapping rule only indirectly, via top-down feedback from the units that represent the motor goal.

Both architectures were trained on the remapping task and both learned successfully. But examination of the units in the hidden layer in each network revealed that they functioned very differently in the two cases, and only one of the architectures accurately captured the dynamic activation pattern of neurons recorded in
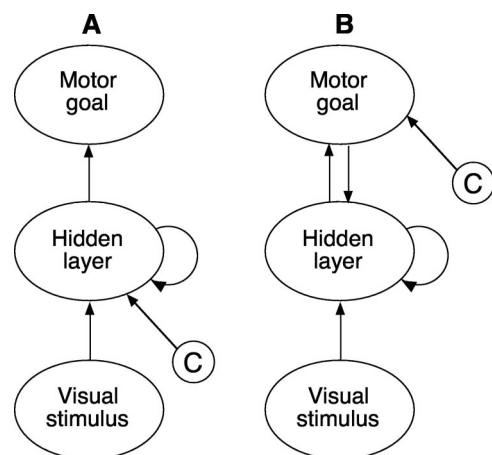

Figure 10. Schematic representation of two alternative architectures describing the interaction between a standard mapping from a visual stimulus to a motor goal and a contextual mapping between a cue and a motor goal (adapted from Brozovic et al., 2007).

PRR. The majority of units in the hidden layer of Architecture A exhibited a unimodal tuning function with respect to the position of the visual stimulus, where the peak of the tuning function consistently was independent of the remapping rule. Brozovic et al. (2007) described the functional properties of the hidden layer units in Architecture A as "context modulated visual memory tuning." By contrast, the peaks of the tuning functions of the hidden units in Architecture B strongly depended on the particular mapping rule invoked on that trial. These hidden units, in other words, represented the contextually determined motor goal, and their dynamic activation pattern resembled the neural dynamics of context-specific transformations observed in primate PPC.

Neurophysiological and neuroanatomical constraints, therefore, provide support for the idea that the motor goal in a contextual mapping task indirectly affects visuomotor transformations via top-down feedback. Contrasting theoretical views that assume automatic release of affordances during perception, regardless of the goal state, would require different assumptions to explain the fact that key-press responses show no alignment effects with color cues. The lack of alignment effects with a key press is due, on these accounts, to the lack of similarity between dimensions of the response and those of the affordance. In other words, an object like a beer mug with its handle pointing to the right evokes a right-handed clenched grasp, and the dimensions of this action are too far removed from a key-press action to influence the response. This type of explanation assumes a feed-forward model (Architecture A in Figure 10), with the amount of competition being dependent on the degree of dimensional overlap between the response automatically evoked by the irrelevant object and the cued response (Kornblum, Hasbroucq, & Osman, 1990).

We have good evidence that the presence of an alignment effect is not simply contingent on the similarity between the cued action and the standard mapping, provided the action requires a reach and grasp response. Under certain task conditions, as in Experiment 1, hand selection cued by color occurs before programming of hand shape. Alignment effects on liftoff time occur when the handle of the irrelevant object influences selection of the hand, regardless of the degree of overlap between the subsequently programmed movement and the grasp afforded by the irrelevant object. An additional, unpublished experiment from our laboratory offers further support for the claim that it is not similarity between the reach and grasp response and the standard mapping that determines alignment effects. In this experiment, the response consisted of reaching out and placing the palm of the right or left hand on a flat plate. Liftoff time in this experiment showed an alignment effect of 11 ms when the cue delay was 195 ms. The irrelevant object was a beer mug for some subjects and a frying pan for others. Arguably, the incongruent action in Experiment 1 (a vertical clenched grasp to a frying pan or a horizontal closed grasp to a beer mug) was more similar to the standard mapping than is a palm action. Nevertheless, the effect size obtained with a palm response was slightly larger than the 8-ms effect seen with the incongruent action in Experiment 1. We infer that the absence of alignment effects with a key press is not due to the lack of similarity between cued response and the standard mapping, but rests instead on the fact that no reach and grasp (or reach and touch) is required by key pressing. This claim makes an interesting prediction: a reach response that ends with the same posture as is used for a key press (a poke) should yield a clear alignment effect, whereas a response that simply requires lifting the right or left hand from a response key, without any requirement to move the hand through space to contact or grasp a response element, should show no such effect.

Time-Course of Handle Alignment Effects

The particular time course over which handle alignment effects develop is of considerable interest. It is well-established that compatibility effects of an irrelevant stimulus on responding are dynamic, in the sense that they accrue and diminish over time. For example, the effect of a word on naming a color in the Stroop task depends on the relative timing of the word and color components of the compound stimulus. Correspondence effects are large when the word and color are presented simultaneously. This is the conventional Stroop effect–naming the color is considerably slowed when there is a mismatch between word and color (e.g., *green* printed in red) compared to naming the color of a matched color–word (*green*/green) pair (Dyer, 1971; Glaser & Glaser, 1982). On the other hand, word reading as the relevant task is typically quite unaffected by an irrelevant color, but a small effect of color on word reading can be observed if the color is presented 200 ms before the word (Glaser & Glaser, 1982; Lu & Proctor, 2001; Sugg & McDonald, 1994). Apparently, certain stimulus–response pairings (such as naming colors carried by color words) yield robust correspondence effects when relevant and irrelevant stimuli occur roughly at the same time. Other stimulus–response ensembles (e.g., reading a color word printed in color) show no apparent correspondence effects, yet measurable effects can be observed if the irrelevant stimulus is introduced at some point in time before the onset of the relevant stimulus. We present an argument motivating the assumption that a handle alignment effect is most strongly apparent after a short delay between the onset of the object and the color, allowing information about the object's handle alignment to accrue.

A recent view of the motor cortex includes the notion of neural populations that do not initially encode a single action representation. Rather, sensory information pertaining to the shape of the object can be used to define the parameters of several possible actions simultaneously if the object has been associated with multiple responses in the past (Fagg & Arbib, 1998). These action representations appear as separate peaks of activity in a neural population (Cisek, 2006, 2007; Cisek & Kalaska, 2005; Platt, 2002). Multiple peaks compete against each other through mutual inhibition. As activity associated with a particular choice gains in strength, suppression of competitors will yield a dominant response. There is considerable support for this interpretation of how a representation specific to one or the other type of action may evolve through competition within a neural population initially coding for both actions. For example, Cisek and Kalaska (2005) analyzed cells in the dorsal premotor and primary motor cortex of the monkey when two possible targets (each associated with a particular action) were presented during a cuing period, but only one of these possibilities was ultimately designated as the actual target. Cells tuned to both targets initially were active during the delay, but one group of cells associated with the eventual target action became more strongly activated while the other group was suppressed.

We argue that under certain circumstances an object like a beer mug initially generates neural activity corresponding to potential grasp actions for each limb simultaneously, independent of the direction in which its handle points. This initial, short-lived evocation of hand shape sets up competing representations between hands in a manner analogous to the ambiguous cues used by Cisek (2006). Over time, the standard mapping fully evolves; the alignment of the handle with one or the other side of the body increases activation of the motor response on that side. If subjects are able to select the correct response hand very quickly after color onset, then it follows that the influence of the handled object on the final response should be found only after a delay is introduced between the onset of the object and the color. With a cue delay of 0 ms, the activation generated by the beer mug has not yet had enough time to strongly favor the side aligned with the handle, so no effect of alignment on the response to color will be observed.

Linking Alignment Effects and Activation Strength

Alignment effects are absent or only weakly present when the color and the object appear at the same time, but consistently emerge more gradually after a delay of about 200 ms is introduced between the handled object and the contextual cue. We have discussed this result as due to the slow emergence of a lateralized hand action representation evoked by a handled object. Furthermore, we note that this time course conforms to one identified by Lu and Proctor (2001; Lu, 1997) as reflecting weak spatial compatibility effects induced by an irrelevant object (in our case, the object) on the relevant stimulus–response mapping (the color–response pair). These authors assume that S_i–R and S_r–R associations (where S_i = irrelevant stimulus, S_r = relevant stimulus, and R = response) in a particular task context can be characterized by different activation-decay functions. Compatibility effects depend on the temporal overlap between S_i–R and S_r–R associations (c.f., Hommel, 1994). A further assumption is that the stronger an S–R association, the faster is the activation of the response code from the onset of the stimulus. Thus, correspondence effects will be modulated by the relative strengths of S_i–R and S_r–R associations. If the association between S_i and R is strong in relation to S_r–R associations, then S_i will rapidly generate a response code, so that correspondence effects can be easily observed when S_i is presented at the same time as S_r.

A different pattern of stimulus onset asynchrony effects will be found should the activation between S_i and R be relatively weak. Correspondence effects will not occur if S_i is presented simultaneously with S_r because the irrelevant S_i–R association is too slow to compete with the relevant S_r–R pairing. But if the onset of S_i is arranged sufficiently early, before the onset of S_r, then the irrelevant object could influence performance because the temporal overlap between activations now becomes optimal. Clearly, our results consistently demonstrate that the S_i–R association embodied in a handled object is weak in relation to the activation generated by the color cue. The account of alignment effects we have developed provides a neurophysiological basis for the concept of a weak S_i–R association in the context of the motor representation automatically evoked by a handled object. A neural population coding for both hand shape and side of body is weakly activated inasmuch as there is competition present from a rival population coding for the same hand shape but the opposite

side. The object initially generates equal activation in both hands and the competition between hands must be resolved over time under the combined influence of the handle's position and the color–response mapping rule.

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