Time Course of Motor Affordances Evoked by Pictured Objects and Words

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Correspondence effects based on the relationship between the left/right position of a pictured object's handle and the hand used to make a response, or on the size of the object and the nature of a grip response (power/precision), have been attributed to motor affordances evoked by the object. Effects of this nature, however, are readily explained by the similarity in the abstract spatial coding of the features that define the stimulus and response, without recourse to object-based affordances. We propose that in the task context of making reach-and-grasp actions, pictured objects may evoke genuine, limb-specific action constituents. We demonstrate that when subjects make reach-and-grasp responses, there is a qualitative difference in the time course of correspondence effects induced by pictures of objects versus the names of those objects. For word primes, this time course was consistent with the abstract spatial coding account, in which effects should emerge slowly and become apparent only among longer response times. In contrast, correspondence effects due to object primes were apparent even among the shortest response times and were invariant across the entire response-time distribution. Using rotated versions of object primes provided evidence for a short-lived competition between canonical and depicted orientations of an object with respect to eliciting components of associated actions. These results suggest that under task conditions requiring reach-and-grasp responses, pictured objects rapidly trigger constituents of real-world actions.

Keywords: motor affordances, object primes, reach-and-grasp actions, spatial codes

The term affordance generally refers to a possible action offered (i.e., afforded) by an object in relation to an observer's physical capabilities. The word is now widely used alongside the claim that pictures and even stylized drawings of manipulable objects automatically give rise to constituents of action (e.g., Caligiore, Borghi, Parisi & Baldassarre, 2010; Tucker & Ellis, 1998). Despite widespread endorsement of the idea (e.g., Sumner & Husain, 2008; Vankov & Kokinov, 2013), the assumption that depicted objects, no less than the objects themselves, give rise to affordances is debatable on both theoretical and empirical grounds. For Gibson (1979), affordances were linked to the direct perception of three-dimensional objects. The fact that the term now refers to potential actions induced by photographs as well as solid objects obscures the distinction between what Gibson referred to as air theories (dealing with flat shapes like drawings or pictures) and ground theories of vision (dealing with real, textured surfaces).

Perhaps this blurring of terminology is harmless enough, or even beneficial, imbuing the notion of an affordance with "... a new relevance" (Caligiore et al., 2010, p. 1188). Unfortunately, affordances in their present context remain vexed on other grounds. Much of the research taken as support for the claim that affordances are evoked by two-dimensional images is open to dispute. Indeed, Proctor and Miles (2014), after an informative and critical review, stated: "... there is little evidence to justify application of the concept of affordance to laboratory studies of stimulus–response compatibility effects, either in its ecological form or when it is divorced from direct perception and instead paired with a representational/computational approach" (pp. 227-228).

We agree with many of the criticisms leveled by Proctor and Miles (2014). Nevertheless, we will continue to argue that depicted objects, under the right task conditions, trigger features of action that can reasonably be viewed as motor affordances. A key assumption on which we rely is that the task set of engaging in reach-and-grasp grasp actions itself plays a crucial role in triggering motor constituents from depicted objects. Indeed, we are not the first to make this claim. Girardi, Lindemann, and Bekkering (2010) have argued that, "... object affordance effects strongly depend on the action context ... suggesting that object-related actions are not automatically activated in the observer." (p. 338). These authors documented correspondence effects of pictured objects on the kinematics of reach-and-grasp actions. No such effects occurred when subjects engaged in pointing movements. Lindemann, Stemme, van Schie, and Bekkering (2006) found that when subjects prepared to grasp objects, correspondence effects were induced by words referring to the goal of the intended movement, but not when subjects prepared finger-lifting movements to object location. Lindemann et al. inferred

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that "... functional semantic information about the use of objects may require activation of motor representations to enable the semantic information to be addressed" (p. 641).

The methodology we have developed is likewise motivated by the assumption that constituents of real-world actions are evoked by pictures of objects (such as a beer mug or frying pan) when subjects attend to them while concurrently planning a reach-and-grasp action. For example, an upright beer mug oriented with the handle on the left should induce a left-handed, vertical power grasp. The same object rotated ninety degrees clockwise will trigger a horizontal power grasp. If the outcome of an action is taken into account, this particular view of a beer mug will favour a left-handed grasp. Selection of the right hand would incur an awkward counterclockwise rotation of the arm to restore the object to its upright position, producing an uncomfortable end-state (Rosenbaum, Chapman, Weigelt, Weiss, & van der Wel (2012). Needless to say, we conjecture that the depicted view of an object yields motor constituents that are not directly afforded by words. Furthermore, our assumption that motor intentions play a crucial role in evoking features of grasp actions conflicts with the notion that objects automatically trigger actions regardless of an observer’s intentions (e.g. Ellis & Tucker, 2000).

The structure of the present article is as follows. A brief overview is presented of the evidence widely considered to support the notion that limb-specific affordances are responsible for compatibility effects induced by depicted objects, and we recapitulate the numerous deficiencies already noted by Proctor and Miles (2014). We are persuaded that many results are likely due to perceptual or semantic influences on responding that occur prior to the programming and execution of real-world actions. We nonetheless argue that certain effects – in particular, those obtained when subjects actually engage in speeded reach-and-grasp actions – do support the idea that pictures of objects can trigger motor affordances.

A methodology is next introduced, allowing us to effectively track the influence of pictures of everyday objects like beer mugs and frying pans on speeded grasp responses varying with respect to left/right hand and vertical/horizontal wrist orientation. Proctor and Miles (2014) contended that such effects are invariably based on the spatial coding of complex semantic information and therefore would be expected to accrue slowly, given previous evidence on the time course of spatial effects induced by abstract objects like words and arrows (e.g., Proctor, Miles, & Baroni, 2011). The temporal dynamics of correspondence effects that we document, however, do not support this conjecture. We argue that under the right task conditions, depicted objects can rapidly generate features of actions that may reasonably be considered as affordances.

Effects of Handle Alignment on Keypress Responses

Photographs of graspable objects like beer mugs and frying pans, with their handles oriented to the left or right, can induce spatial compatibility effects on speeded keypress responses. Tucker and Ellis (1998) required observers to indicate with a keypress using their left/right hand whether the depicted object was in an upright or inverted orientation. Performance was faster when the position of the handle on the left or right matched rather than mismatched the left/right hand making the keypress response. A second experiment involving responses with the index and middle fingers of one hand assigned to a left- versus right-sided keypress yielded no such correspondence effects.

The specificity of the alignment effect led Tucker and Ellis (1998) to argue that keypress responses were influenced by the "... relative ease with which the objects could be grasped by the left or right hand" (p. 843). Their claim rests on evidence that the spatial correspondence effects they observed emerged only when keypresses involved a left- versus right-handed response, but not when the fingers of just one hand were used. This outcome is noteworthy because for most other stimulus-response compatibility effects, what matters is the left-right correspondence in extra-personal space between position of the key and the location of a stimulus, not the choice of effector. For example, in the well-known Simon (1990) effect, the task might be to respond with a left-sided keypress to one object (say, a circle) and a right-sided keypress to another (say, a square). Response times are shorter and more accurate when the position of the object, although irrelevant to the task, matches the side of the response. Whether the left or right hand is assigned to a particular keypress is generally of little or no import; compatibility effects depend primarily on the mapping between the locations of the stimulus and the response key (see Proctor & Vu, 2006, for a review).

How secure, then, is the claim that pictures of manipulable objects automatically induce grasp affordances that influence the selection of a limb-specific response (a left- versus right-handed keypress)? Pappas (2014) has reported an outcome consistent with the original result by Tucker and Ellis (1998). Subjects were asked to make upright/inverted decisions to a depicted object (images of a frying pan, either in the form of high-quality photographs or as silhouettes) using between- or within-hand keypress responses to indicate their speeded judgments. Alignment effects occurred for between- and not within-hand keypresses, but only when viewers responded to high-quality photographs. Pappas argued that detailed images of an object rather than silhouettes or stylized drawings, are needed to induce affordances.
Unfortunately, numerous other studies have either found no handle alignment effects, despite the use of high-quality photographs (Yu, Abrams, & Zacks, 2014), or when effects do occur, they are not limited to between-hand responses (Cho & Proctor, 2010; Phillips & Ward, 2002). A recent attempt on our part to replicate the outcome reported by Pappas (2014), using the same task, experimental design and object depicted as high-quality images, proved unsuccessful (Bub, Masson, & Marshall, 2016; unpublished data). We obtained a reverse alignment effect (faster performance on misaligned trials; see Yu et al. for a similar outcome), regardless of whether keypress responses occurred within- or between-hands.

Substantial evidence indicates that depicted objects typically do not trigger left/right correspondence effects if the entire object including the handle is centered (Cho & Proctor, 2010). Alignment effects are found only when the body of the object is centered and the handle appears in a clearly distinct physical location on the left or right (Cho & Proctor, 2013). Contrary to the widely cited result obtained by Tucker and Ellis (1998), the presence or absence of these effects does not in fact depend on responses produced with the left versus right hands. Any choice between a left- or right-sided keypress suffices, whether carried out with two fingers of a single hand (Cho & Proctor, 210), two hands, two feet (Phillips & Ward, 2002), or with the hands crossed such that the left key is pressed with the right index finger and the right key with the left index finger (Phillips & Ward, 2002).

We agree with Proctor and Miles (2014) that studies relying on keypress responses offer little support for the idea that motor affordances are responsible for handle alignment effects. Instead, the results widely confirm that when the handle is prominently displayed on the left or right, asymmetrical visual features draw attention to one or the other side of space, triggering a Simon-like effect on response selection.

**Effects of Object Size on Grip Responses**

Other attempts to show that pictures of graspable objects automatically evoke affordances have relied on a speeded choice between static grip postures rather than left/right keypress responses. In these experiments, subjects were required to hold a small response element between their forefinger and thumb, while concurrently the middle, ring, and little fingers of the same (dominant) hand gripped a larger cylinder. The positioning of the thumb and forefinger on the smaller element was taken to mimic a precision grip whereas that of the remaining three fingers on the larger cylinder resembled a power grip. Response times were recorded by means of pressure switches attached to each response element (Derbyshire, Ellis, & Tucker, 2006; Tucker & Ellis, 2001).

In general, experiments using this type of device have yielded the following correspondence effects when subjects carry out speeded forced-choice responses (e.g., classifying objects as natural versus manufactured) to pictures of objects. Small objects resulted in faster responses when assigned to a precision rather than a power grip, whereas the reverse was true for large objects. The notion of motor affordances, however, is surely not needed to account for an influence of object size on response options that also vary along the same dimension. As Proctor and Miles (2014) pointed out, according to standard principles of dimensional overlap "… a correspondence effect between large/small objects and large/small grips is to be expected" (p. 254). Indeed, two facts are especially hard to reconcile with the claim that motor affordances are responsible for the influence of object size on power/precision responses. First, the names of objects yield the same correspondence effects as do pictures (Tucker & Ellis, 2004), an outcome which fails to capture an important distinction between the motor representations induced by the conceptual description of an object and its depicted view. Second, the effects are long-lasting (Derbyshire et al., 2006), whereas motor priming is generally short-lived (Jax & Rosenbaum, 2009). The expectation that motor features should remain active for only a brief duration is motivated by the temporal dynamics of their role in the programming and execution of sequential movement; the shorter the delay between successively planned actions, the more likely they will have features in common. Longer lasting effects of a word or picture on grip responses do not appear consistent with the view that features of grasp actions are responsible for such correspondence effects.

**Effects of Handle Alignment and Orientation on Reach-and-Grasp Actions**

We turn now to correspondence effects observed when performance is based on the programming and execution of reach-and-grasp actions, rather than keypresses. Here, the evidence is more favourable to the idea that depicted objects can evoke affordances. Ferri, Riggio, Gallesse, and Costantini (2011) presented visual images of objects inviting a power or precision grip under stereoscopic viewing conditions that created an impression of depth. Subjects made power or precision reach-and-grasp actions to classify depicted objects as naturally occurring or manmade. Correspondence effects occurred for objects within but not outside of reachable space. This outcome is consistent with the idea that action-relevant properties are triggered only when the depicted object appears near enough to be grasped. Two further considerations lend weight to the view that the impact of the object is indeed due to its motor properties. First, the authors
pointed out that their results stand in contrast to those of Tucker and Ellis (2001), who observed no impact of reachability on correspondence effects when subjects relied on static power/precision grips to visual objects (see the previous section for further comments on this mode of responding). Ferri et al. argued that the intention to engage in a reaching task played a crucial role in evoking action constituents. In addition, the effect of reachability on speeded grasp actions appeared specific to visual objects. The requirement to match a word to a pictured object evoked correspondence effects on reach-and-grasp actions that were not modulated by the object's location in reachable space. For analogous effects of action-relevant object features that specifically manifest when subjects intend to engage in power/precision reach-and-grasp actions see Girardi et al. (2010).

Pictures of handled objects affect cued grasp actions in ways that provide further support for the claim that constituents of real-world actions are responsible for observed compatibility effects. The handles of such objects are either vertically (e.g., an upright beer mug or teapot) or horizontally oriented (e.g., an upright frying pan or saucepan). In addition, objects may be displayed with the handle situated on the left or right. Both of these spatial properties, the vertical/horizontal orientation of the handle and its left- or right-sided position, yield correspondence effects on cued reach-and-grasp actions (Bub & Masson, 2010).

An alignment effect occurs when objects are depicted with their handles aligned or misaligned in relation to the hand producing a cued grasp response, and performance is faster when the choice of left/right hand matches rather mismatches the position of the handle on the left or right. For example, an alignment effect can be observed when subjects are cued to make speeded reach-and-grasp actions with their left versus right hand based on the color of a depicted object (Bub & Masson, 2010). No alignment effect was observed when the color cue required a left- versus right-handed keypress. Thus, a depicted object can exert an influence on left/right-handed grasp actions despite the absence of Simon-like effects on left- versus right-sided keypress responses.

An effect on grasp actions is also produced by the vertical/horizontal orientation of the handle. A depicted object with a vertical handle (e.g., the picture of an upright beer mug) induces slower production of a cued reach-and-grasp response demanding a horizontal rather than a vertical wrist posture (Masson, Bub, & Breuer, 2011). The reverse is true for a picture of an object with the handle oriented horizontally (e.g., an upright saucepan). We will refer to this effect of handle orientation as a congruency effect reflecting an impact of the vertical/horizontal orientation of the handle on the speed of a cued action that itself requires a vertical or horizontal grasp posture.

Furthermore, congruency effects are sensitive to the depicted view of an object, and so can be distinguished from effects induced by words. The image of a beer mug rotated from its upright orientation by ninety degrees will prime a cued horizontal grasp rather than a vertical grasp (Masson et al., 2011). Interestingly, motor features evoked by the object also represent information about the outcome of the action in relation to the object’s typical orientation. This result is consistent with considerable evidence indicating that action outcomes are automatically evaluated, even when they are irrelevant to task performance (e.g., Creem & Proffitt, 2001; Hommel, 1993; Kiesel & Hoffmann, 2004). A beer mug rotated 90 degrees clockwise from an upright orientation affords a horizontal grasp with the right hand rather than the left hand if the opening is facing left. The right hand, after grasping the object, can easily rotate to restore the object to its typical upright orientation. The image of a rotated object will not trigger a congruency effect (or will trigger measurably weaker congruency effects) if the cued action matches the orientation of the handle but does not conform to a grasp that is naturally commensurate with the object’s proper function (i.e., the opening of the mug is on the right and the right hand is cued; Masson et al., 2011).

Finally, congruency effects induced by the photograph of an object are not limited to early stages of movement. The kinematics of the cued action are altered throughout its trajectory, including the rotation and forward motion of the hand (Till, Masson, Bub, & Driessen, 2014). For example, the image of an upright beer mug, consistent with a vertically oriented grasp, yields a priming effect that delays the forward motion and counterclockwise rotation of the right hand, initially positioned in a vertical orientation, to produce a cued horizontal grasp. A depicted object affording a horizontal grasp (e.g., the photograph of frying pan) generates the reverse influence on rotation, delaying the clockwise movement of the right hand starting from a horizontal position to carry out a vertically oriented grasp. These results imply that the representations triggered by photographs of objects are coded in a form compatible with the actual execution of a motor program, competing with and affecting the entire trajectory of an intended action.

In our view, the effects we have described offer reasonable evidence that depicted objects exert their influence on cued reach-and-grasp responses via real-world features of actions rather than abstract, supramodal codes. Nevertheless, this claim remains open to dispute. The congruency and alignment effects we previously documented appear to emerge slowly over time (Bub & Masson, 2010). As Proctor and Miles (2014) noted, the leisurely time course of spatial correspondence effects is typical of more abstract stimuli such as words and arrows. Why assume that an
object’s influence on reach-and-grasp actions is anything more than the "... activation of complex semantic spatial codes that in turn activate associated response codes rather than object affordances directly activating the associated actions" (Proctor & Miles, 2014, p. 256)?

Assessing the Time Course of Action Compatibility Effects

The time course of the correspondence effects on reach-and-grasp responses that we previously observed was based on actions cued by color (Bub & Masson, 2010). Subjects learned to carry out speeded left- versus right-handed grasp responses involving either a horizontal or vertical wrist orientation, depending on the color of a depicted object. No correspondence effects were observed when the color was presented at the same time as the object, but were clearly present if the visual object was displayed in grey scale for 200 ms or longer before taking on the color cue. Apparently, the effect of the object on reach-and-grasp actions is not rapid, but builds quite slowly over time.

It is possible, however, that the method we chose to determine the time course of alignment and congruency effects may itself have contributed to this outcome. Subjects were instructed to respond only to the color cue, while the passively viewed object was irrelevant to their task. Selective attention to the color may well have prevented any influence of shape on performance when the cue to respond was presented at the same time as the irrelevant object (see also Bub, Masson, & Bukach, 2003). When the object was displayed for a brief duration before the onset of the color cue, attention would initially be drawn to visual features, thereby inducing correspondence effects. In other words, task conditions that demand attention to color are probably not ideal for revealing an early impact of shape on speeded grasp responses.

In the experiments reported here, we rely on the photograph of a left or right hand as the cue to respond, indicating a vertical or horizontal grasp posture (see also Masson et al., 2011). The hand is shown from an egocentric viewpoint and depicts the end state of a speeded reach-and-grasp action applied to one of a pair of response elements placed before the subject. Each element is shaped to afford either a horizontal or a vertical power grasp. The hand cue is presented in conjunction with the photograph of a graspable object, displayed either at the same time as the hand cue, or asynchronously, so that a brief delay occurs between the onset of the image and the onset of the cue. Subjects must attend to the object so as to enable later report of the object's identity, but their speeded reach-and-grasp responses are determined only by the hand cue. Our interest lies in the nature of any correspondence effects induced by the object on cued grasp actions.

The use of a photographed hand posture as the cue for a motor response has a number of important advantages. First, the task of responding to a grasp posture is much easier to learn, and yields faster and less variable performance than responses cued by arbitrary color-action pairings. Second, the task includes a tacit laterality judgment; subjects must produce a left- or right-handed action based on the viewer-centric image of a hand depicting a vertical or horizontal grasp posture. Compelling evidence indicates that this kind of decision is based on limb-specific representations (Grafton & Viswanathan, 2014; Parsons, 1987; Sekiyama, 1982). Clearly, to engage in grasp actions cued by a depicted hand posture, subjects must discriminate between features of real-world actions, including the choice between left/right hand and vertical/horizontal wrist orientation.

The crucial issue is whether the compatibility effects of a depicted object on grasp actions occurs at the level of these motor constituents or alternatively, at a more abstract level where semantically-mediated spatial codes exert their influence on response selection. As we have already noted, a hallmark of correspondence effects attributed to the latter kind of influence is their slow development over time. For example, Philips and Ward (2002) found no alignment effects on left/right keypress responses when the cue to respond occurred at the same time as the depicted object (the silhouette of a frying pan), whereas longer delays between cue and object produced substantial effects. In addition, Cho and Proctor (2010) found that alignment effects increased across the response-time distribution, with slower responses consistently yielding larger correspondence effects than faster responses. Our methodology allows us to track the time course of both alignment and congruency effects on reach-and-grasp actions. We will establish that their temporal dynamics are clearly distinct from the correspondence effects induced by abstract spatial codes.

Canonical Versus Depicted Orientation

An object like a beer mug is typically encountered in a definite upright orientation, and grasping the object generally occurs with the palm of the hand in a vertical position. We will refer to the grasp posture associated with the prototypical representation of an object as a canonically oriented grasp, leaving aside the question of whether this representation also incorporates the laterality of a particular (dominant) hand. A canonically oriented grasp is determined by the stored description of an object, and is therefore associated with the form of a beer mug regardless of the particular orientation of the image currently in view. In addition, however, the visual image of a beer mug induces the representation of a grasp posture contingent on its actual depicted orientation; the pictured object generates what we will
term a *de pictively* oriented grasp.

For example, consider the motor representations triggered by the image of a beer mug depicted as rotated 90 degrees from its typical upright orientation, with its handle now running along the dorsal surface of the mug. The depicted form of the object invites a horizontally rather than a vertically oriented wrist posture. The same visual image of a horizontal beer mug is associated with a canonical grasp posture featuring the wrist in a vertical position.

We assume, building on previous evidence for a dual-route model of action (e.g. Chainay & Humphreys, 2002), that the photograph of an object gives rise to separate representations of depictively and canonically oriented grasps under certain task conditions. In particular, two functionally separate mechanisms determine action selection. A visual route generates motor representations based on an object’s shape and an analysis of its structural parts (such as graspable handles). A conceptually-driven route incorporates knowledge of actions previously associated with the object. An implemented version of the dual-route model (Yoon, Heinke, & Humphreys, 2002) has not dealt explicitly with the issue of how changes in the orientation of an object affect the nature of motor representations, but we invoke the uncontentious assumption that actions determined by the conceptual route must be based on an object’s typical (i.e. canonical) orientation. In contrast, the visual route generates actions driven by the perceived form of an object.

Much evidence (e.g., Buxbaum, Sirigu, Schwartz, & Klatzky, 2003; Chainay & Humphreys, 2002; Gentilucci, 2002; Herbert & Butz, 2011; Randerath, Li, Goldenberg & Hermsdörfer, 2009) indicates that conceptual knowledge and directly perceived structural properties of an object contribute jointly to the programming of reach-and-grasp actions. If these dual routes generate competing motor representations, perceptually-driven motor features must ultimately control the selection of action (e.g., Chainay & Humphreys, 2002). In other words, the depictively oriented grasp (determined by perceptual information) should play a dominant role over the canonically oriented grasp (driven by stored knowledge of actions previously associated with the object).

We will establish that pictured objects trigger motor features of both canonically and depictively oriented actions that together exert an early (i.e., rapidly occurring) influence on cued reach-and-grasp responses. However, the effect of the canonical posture (associated with the object as an abstract conceptual type rather than a specific token form) quickly dissipates over time, leaving a representation of the depictively oriented grasp as the major determinant of correspondence effects. Our results lend support to the claim that pictured objects, under the right task conditions, trigger motor constituents of real-world actions.

**Experiment 1**

In Experiment 1, we investigated the time course of priming action representations by presenting a picture of a manipulable object at various time points relative to a hand cue which directed the subject to make a specific reach-and-grasp response. In Experiment 1A, three stimulus onset asynchronies (SOA) were used: -250 ms, 0 ms, and 250 ms. Experiment 1B was a replication that used improved stimulus materials and included only the latter two SOA values because the SOA of -250 produced no reliable priming effects. In both versions of the experiment, the prime object was presented either in its upright, canonical view, or in a view rotated 90 degrees from upright so that a canonically oriented vertical handle was now horizontally oriented, or vice versa. Subjects were cued to make either a right- or left-handed horizontally or vertically oriented reach-and-grasp action. This cued action could correspond with the prime object on either, both, or neither of these two dimensions.

For upright primes, we expected that if pictured objects evoke grasp affordances, then executing an action that matches the handle’s left/right positioning and vertical/horizontal orientation should be more efficient, producing correspondence effects for hand alignment and wrist posture. Further, if these are genuine motor affordances, they should emerge quite rapidly rather than building up rather slowly over time.

The rotated primes presented an opportunity to examine the influence of two different kinds of motor affordance. Assume that motor representations are induced by the canonical description of an object as well as its depicted form. For an upright object, these different representations converge on the same grasp posture at any point in time. For a rotated object, however, the grasp postures evoked by the canonical description and depicted form are in opposition if simultaneously active. For example, the depicted form of a beer mug rotated 90 degrees would afford a horizontal grasp, whereas the canonical representation is associated with a vertical grasp. Should both affordances be simultaneously co-active and compete equally at an early point in time, no clear congruency effect will be observed. Alternatively, one motor representation may be more active than another, yielding a small congruency effect that will indicate whether the competition is ultimately resolved in favor of the canonically or depictively oriented posture. We anticipated, however, that with a longer SOA, the depicted orientation would clearly dominate, evoking a grasp posture that corresponds to the visible form of the object. Note that the possibility of competing
affordances implies different predictions regarding the
time course of congruency effects for upright and
rotated objects. Upright objects should yield
congruency effects that do not change appreciably over
time because there is no competition between
depictively and canonically oriented grasp postures.
Rotated objects should induce weak congruency effects
(indicative of competition between canonically and
depictively oriented grasp postures) at an early time
point and a stronger congruency effect favoring the
depictively oriented grasp at a later point in time.

One additional aspect of priming with a rotated
object needs to be considered. Namely, when an object
is rotated away from its canonical, upright orientation,
which hand, if either, would be preferred for grasping
it? Masson et al. (2011) found that in such cases, an
advantage was conferred to the hand that could, with
a simple wrist rotation, return the object to its upright,
functionally useful position. For example, a rotated beer
mug with the opening facing to the right should be
graped with the left hand, which would permit a
comfortable wrist rotation to bring the mug back to the
upright. Finding an alignment effect of this nature in
conjunction with priming of the grasp that is congruent
with the depicted orientation of the object prime would
indicate a lingering influence of the object's canonical
representation, even when processing is dominated by
the depicted view.

Method

Subjects. Seventy-two students at the University of
Victoria participated in exchange for extra credit in an
undergraduate psychology course. There were 31
subjects in Experiment 1A and 41 subjects in
Experiment 1B. In these experiments we aimed for
approximately 40 subjects in each, but terminated
Experiment 1A somewhat early because of the
unusually long response times that were observed. The
target of 40 subjects was consistent with a power
analysis based on standard null hypothesis significance
testing methods, assuming a within-subjects
comparison between two conditions with a small effect
size ($d = .2$), a correlation between conditions of .90,
and power of .8. Two additional subjects were tested in
Experiment 1A, but their data were excluded before
analyses were computed because of inattentiveness or
inaccuracy in reporting the prime object.

Materials. Object primes consisted of grayscale
photographs of eight handled objects, four with
canonically vertical handles (beer mug, coffee pot, saw,
teapot) and four with canonically horizontal handles
(frying pan, knife, sauce pan, strainer). Four versions of
each object's photograph were digitally generated: two
with a upright orientation, with the handle oriented to
either the right or left, and two with a rotated
orientation with the handle positioned to favor either a
right- or left-handed grasp. In the case of the rotated
views, the original view was rotated 90 degrees so that
in the case of canonically vertical handles, the handle
was now in a horizontal orientation on the upper
surface of the object. For canonically horizontal
handles, the object was rotated so that the handle
pointed downward. Our definition of the left/right
orientation of rotated primes was based on which hand
should be used to grasp the object so that a comfortable
rotation would bring it back to upright. For example, a
rotated beer mug with its opening on the left, ought to
be grasped with the right hand, and a rotated sauce pan
with the opening of its bowl facing left should be
graped with the left hand. In Experiment 1A these
objects subtended a maximum of 11.0 degrees of visual
angle horizontally or vertically when viewed from 50
cm. For Experiment 1B, the images were expanded to
21.5 degrees. When these primes were presented on the
computer monitor, they were placed so that the
horizontal and vertical midpoint of the image was
centered on the monitor. This placement was intended
to avoid having handles protrude in a way that would
invite an object-based Simon effect (Cho & Proctor,
2011).

Photographs of a male hand were used to cue the
subject to make a specific grasp action (either a
horizontally or vertically oriented power grasp). The
original versions of these photographs were taken of the
model's right hand, and a left-hand version of each was
digitally created by a mirror reversal. This resulted in
four digital renderings of hand cues: right-hand vertical
grasp, right-hand horizontal grasp, left-hand vertical
grasp, and left-hand horizontal grasp, representing the
four actions that subjects were cued to make. In
Experiment 1A, the hands were in grayscale and
positioned on a white rectangular background trimmed
to the maximum horizontal and vertical extent of the
hand. These images subtended a maximum of 2.7
degrees of visual angle horizontally or vertically. In
Experiment 2B, all of the white space was trimmed
away so that when superimposed on an object, no part
was obscured by this white background (see Figure 1).
Also, the hands were depicted in flesh color and
subtended a maximum of 5.7 degrees of visual angle.
The increased size of the prime and hand cue was
implemented in Experiment 1B after the results of
Experiment 1A indicated that average response times
were longer than in our earlier experiments using a
similar task. This increase in response time was
attributed to suboptimal visual discrimination of the
hand cues and object primes, leading us to increase the
size of the images and to make the hand cues more
distinctive by coloring them.

Procedure. Subjects were tested individually with an
experimenter present, and sat facing a computer
Figure 1. Illustration of the sequence of events on a trial and the response elements from Experiment 1. The stimulus onset asynchrony of 250 ms is illustrated here for each condition of the experiment. After viewing the prime for 250 ms, the hand cue was superimposed on the object prime. Relative to the vertical/horizontal orientation and the right/left position of the object's handle, the cued hand action was congruent or incongruent and aligned or not aligned with the prime, as indicated here. The relevant response element for a particular cued response is shown in each example. The object primes and hand cues shown here are from Experiment 1B and the actual hand cue was flesh colored (as shown in the online version of this article) in that experiment.
monitor with a button box placed on the table in front of them. Between the button box and the monitor was a response apparatus consisting of a curved base with two metal response elements mounted on it. The elements were placed, one on either side of the midline, so that either one could be reached by either hand using a reach of about 25 cm in extent. One element consisted of a vertically oriented, C-shaped bar with the ends pointing away from the subject. Subjects were instructed to use this element for vertical grasps. The other element was a horizontal bar mounted on a vertical support and was used for horizontal grasps. Positioning of the elements (one to the right of midline and one to the left) was counterbalanced across subjects. The elements are shown in Figure 1.

Subjects were given two training phases. In the first training phase, the hand cues were presented one at a time on the computer monitor and subjects practiced making reach-and-grasp responses indicated by these cues. On each trial, subjects began with the index finger of each hand resting on a button mounted on the button box. In response to a hand cue, the subject lifted the indicated hand and moved it to the relevant target element, making either a vertical or horizontal power grasp, as dictated by the hand cue. Contact with the element closed an electrical circuit that signaled a computer, allowing us to measure the response time.

In the second training phase, subjects named each of the prime objects, presented in their upright orientation, two times. Some latitude was allowed in the names generated by the subjects (e.g., glass instead of beer mug) as long as they were used consistently.

In the test phase, each trial began with a fixation cross presented at the center of the computer monitor, which signaled the subject to ensure that the index of each hand was resting on one of the response box buttons. Once their fingers were in place, the fixation cross was erased and the computer monitor was blank for 500 ms. Next, depending on the SOA, the prime object and hand cue were presented. Subjects were instructed to make the hand action indicated by the hand cue as quickly and as accurately as possible. In addition, they were informed that on a portion of the trials they would be asked to report the identity of the prime object. This requirement was intended to ensure that subjects attended to the prime objects. Subjects were cued to report the object at the end of a randomly chosen 25% of trials.

In Experiment 1A, three SOA conditions were used: −250 ms (in which the hand cue came on first, and after 250 ms it was replaced by a picture of that same hand cue superimposed on the picture of the object prime), 0 ms (in which the object and hand cue appeared simultaneously, with the hand superimposed on the object), and 250 ms (in which the object appeared first, then the hand cue was superimposed upon it after a delay of 250 ms). In Experiment 1B, only the latter two SOA conditions were used. Figure 1 shows an example of the sequence of events for the 250-ms SOA condition for each type of trial in the design. As soon as the subject lifted his or her finger from the button box, the display was erased. Response time was measured from the onset of the hand cue to contact with the correct response element, thereby including both planning and movement phases of the response. After the response was complete, the subject waited for the fixation cross to appear before returning their fingers to the button box. During that waiting period, the experimenter pressed a key on the computer keyboard to classify the response as correct or incorrect.

In Experiment 1A, the test phase began with 16 practice trials followed by a block of 384 critical trials. An additional block of 384 critical trials was completed on a later day, separated from the first session by 4 to 10 days. Testing was conducted on two separate days to avoid fatigue. Each block of 384 trials consisted of a randomly ordered presentation of all possible combinations of prime object (there were eight possibilities), SOA, left/right orientation of the prime object's handle, upright/rotated orientation of the prime object, left/right response hand, and horizontal/vertical orientation of the response hand. This arrangement ensured that the prime object was entirely non-predictive with respect to the features of the reach-and-grasp response to be performed on a given trial. In Experiment 1B, all combinations of the variables were covered by 256 trials rather than 384 trials because only two SOA values were included. Subjects were tested in a single session consisting of 16 practice and two blocks of 256 trials, making a total of 512 critical trials.

**Results and Discussion**

Time taken to complete a reach and grasp response, measured from the onset of the hand cue to contact with the response apparatus, was taken as the dependent measure. This measure was preferred over separate assessments of liftoff and reach time because we exerted no control over how early in the response planning stage subjects might raise their response hand from the button box (indicating the start of the reach portion of the response). For example, a tendency to lift the response hand before planning was complete would lead to a hesitation before moving the hand toward the relevant response element. This hesitation could cause a portion of the priming effect to be misattributed to reach time. For the present experiments, we made no theoretical claims about whether the influence of object primes would apply to response planning or to execution. Therefore, we used total response time as our primary measure.
Nevertheless, for the sake of completeness we also mention the outcome of analyses of movement time as a dependent measure. Response times longer than 2,900 ms in Experiment 1A (0.48%) and 2,000 ms in Experiment 1B (0.50%) were treated as outliers and were excluded from analyses. These cutoffs were determined so that no more than 0.5% of correct responses were excluded from either experiment (Ulrich & Miller, 1994). A response was classified as an error if the subject made contact with the wrong response element, responded with the incorrect hand, or applied an incorrect grasp to an element. Although we did not record error types, casual reports from the experimenters indicated that most errors were of the former two types. Errors were excluded from the response time analyses.

Data were analyzed by computing the Bayes factor favoring either a model that included the effect of interest or a model that excluded that effect. In addition, mean effects are plotted with 95% highest posterior density intervals, which show the 95% most plausible estimated values for effect size (Morey, Hoekstra, Rouder, Lee, & Wagenmakers, 2016). Analyses were computed using the BayesFactor package in R with default settings for parameters (see Rouder, Morey, Speckman, & Province, 2012, for the theoretical foundation of the methods used in this package, and Rouder, Morey, Verhagen, Swagman, & Wagenmakers, in press, for a practical explanation of its use). A Bayes factor greater than 3.0 is generally deemed to be at least "positive" evidence for the favored model over the less likely model (Raftery, 1995). In reporting our results, we report the Bayes factor (BF) and indicate whether it favors the presence or absence of an effect. Whenever we report that the Bayesian analysis indicates the presence of an effect, that effect would also be significant in a standard null-hypothesis significance test with $p < .05$.

Analyses of the 250-ms SOA condition in Experiment 1A revealed no evidence for priming effects for either upright or rotated primes in either response times or error rates ($BF > 2.4$ favoring the null hypothesis in all cases). Mean response time for that SOA condition was 1,727 ms and the mean percent error was 0.6%. Given that this SOA condition produced no priming effects, we combined the data from the 0-ms and 250-ms SOA conditions across Experiments 1A and 1B for the analyses that we report here.

Mean response time for upright and for rotated prime conditions are shown in Figure 2. Our primary interest was in testing the presence of congruency and alignment effects at the 0-ms and 250-ms SOA conditions, and so we also present the mean congruency and alignment effects in Figure 2. The alignment effect was defined as the difference in response time between trials where the handle was positioned on the same side of midline as the cued response hand (aligned) and trials where the handle and the response hand were on opposite sides of the midline (not aligned). The congruency effect was defined as the difference between response times when the depicted orientation of the object's handle was congruent versus incongruent with respect to the orientation of the cued hand action. Effect sizes are plotted with 95% highest posterior density intervals, representing the most plausible values for effect size.

Considering first the priming effects for upright objects, a Bayesian analysis with alignment, congruency, and SOA as factors indicated that subjects responded faster with a longer SOA and that both congruency and alignment effects were observed ($BF > 1,000$ in all cases). In addition, the alignment effect increased with SOA ($BF = 324.7$), whereas there was no clear evidence for such an increase for the congruency effect ($BF = 1.2$ favoring the null hypothesis). An analysis of error rates, however, indicated that the congruency effect was stronger with the longer rather than the shorter SOA ($BF = 5.7$). The overall error rate when upright primes were used was 1.6%, and the congruency effect went from -0.2% to
0.8% for 0-ms and 250-ms SOA, respectively. No effects were present in the analysis of movement time.

When rotated primes were used, there was no indication of an alignment effect ($BF = 7.1$ favoring the null hypothesis) and there was only weak evidence for an interaction between alignment and SOA ($BF = 2.0$ favoring the presence of an interaction). Figure 2 shows, however, that there is evidence for an alignment effect at 250-ms SOA (the 95% highest posterior density interval for plausible effect sizes excludes zero). We note that the lack of a reliable interaction between alignment and SOA indicates that we cannot claim that the alignment effect is reliably larger at 250-ms than at 0-ms SOA. Although the overall effect of congruency was not supported ($BF = 5.8$ favoring the null hypothesis), there was strong evidence for an interaction between congruency and SOA ($BF > 1,000$). As indicated in Figure 2, a modest negative effect of congruency was apparent at 0-ms SOA, consistent with an influence of the canonical orientation of the prime, but a robust positive congruency effect occurred at 250-ms SOA (in both cases, the 95% highest posterior density interval excludes zero). The overall error rate in the rotated prime condition was 1.5%, and a Bayesian analysis indicated that none of the effects in the design were supported ($BF > 2.6$ favoring the null hypothesis in all cases). This outcome indicates that the response time effects are not compromised by speed/accuracy trade-offs. The analysis of movement time found only an effect of SOA ($BF = 47.5$), with shorter movement time when the SOA was 250 ms.

To obtain a more detailed view of the speed with which alignment and congruency effects accrue in the generation of reach-and-grasp responses, we examined these effects across the full distribution of response times. Doing so allows us to ask whether these effects are apparent even among the fastest responses that subjects produce. The analysis involved assigning each subject's rank-ordered response times within a condition into successive, equal-size quintiles, with the 20% shortest response times assigned to the first quintile, the next 20% to the second quintile, and so on (see Dittrich, Kellen, & Stahl, 2014; Ridderinkhof, 2002; and Yap, Balota, & Tan, 2013, for other applications of this method). We next computed each subject's mean response time within each quintile for each condition. For the alignment effect, conditions were defined as aligned and not-aligned, collapsing across congruency. For the congruency effect, congruent and incongruent condition means were obtained by averaging across the alignment variable. We computed the relevant effect at each quintile by taking the difference between the aligned and not-aligned, or the congruent and incongruent conditions, to determine the size of the relevant effect at each quintile for each subject.

The mean alignment and congruency effects across quintiles are shown in Figure 3. These functions are referred to as delta plots, as they express the size of the difference between conditions as a function of response-time quintile (Ridderinkhof, 2002). In all cases, there is no indication that effect size increases with longer response times. If anything, there is a general tendency for effects to diminish at longer response times. The relatively flat functions indicate that the effect in question persists across the full response-time distribution, suggesting that the effect has shifted the entire distribution rather than, for example, influencing only the trials with the longest response times (Yap et al., 2013). For upright primes, there is evidence for both alignment and congruency effects in the first quintile, corresponding to the fastest group of responses, and this occurs at both the 0-ms and 250-ms SOA. For rotated primes, only at the 250-ms SOA are both alignment and congruency effects apparent in the shortest quintiles.

The results of Experiment 1 indicate that for upright primes alignment and, to some extent at least, congruency effects emerge very early during the processing of a pictured object. Although the alignment effect for upright primes increased with longer SOA, the effect was clearly present even among the fastest responses with a 0-ms SOA. Further, there was no tendency for this alignment effect to increase with longer response times, contrary to what might be expected if the source of the effect
were semantic coding of spatial position. The relatively flat delta plots for both alignment and congruency effects suggest that a relevant prime provided a headstart in preparing the related action feature of the reach-and-grasp response (see Yap et al., 2013, for a similar "headstart" interpretation of flat delta plots in the context of primed word identification).

When rotated primes were presented, there was modest evidence for a congruency effect at the 0-ms SOA, but this effect favored the canonical orientation of the primes, rather than the orientation actually in view. We take this outcome as evidence for the convergent impact of two, conflicting influences on the motor system. One influence is from the depicted view of the object prime (e.g., a horizontal grasp for a rotated beer mug), but the other, opposing influence is from the canonical orientation of the prime (a vertical grasp for a beer mug). Figure 3 indicates that the latter influence has an advantage only on trials with longer response times.

At the 250-ms SOA, rotated primes led to a clear congruency effect favoring the depicted view, and also an alignment effect. The former result indicates that with a longer SOA, the competition between the depicted view of a prime object and its canonical orientation is resolved in favor of the depicted view. The alignment effect is a replication of the commensurability effect reported by Masson et al. (2011) in which subjects appear to favor a grip that will allow a rotated object to be reoriented to its upright position with a comfortable rotation of the wrist (see also Rosenbaum et al., 1990). This finding suggests that with sufficient time available to process the prime object, the motor system is influenced by knowledge about how an object must be oriented for normal use. It is also consistent with our proposal that not only the depicted view, but also knowledge about the canonical orientation of the prime object have an impact on the motor system.

One might argue that the difference in the pattern of congruency effects for upright and rotated primes was a product of greater difficulty in the processing of rotated objects. For example, subjects might hesitate to begin their reach-and-grasp response until they have adequately identified the prime object, given the potential requirement to report its name at the end of the trial. Two points mitigate against this possibility. First, each of the prime objects appeared in rotated form dozens of times in a given test session and there were only eight unique objects. Research on training subjects to identify rotated images of objects indicates that the effect of rotation on identification time is substantially reduced with practice (Jolicoeur, 1985). Second, we can consider how efficiently subjects processed upright and rotated primes by examining response times on trials where the potential benefits of overlapping features between prime object and cued action were absent. (This is an important consideration as we claim that sources of overlapping features are different for upright and rotated primes.) These are trials where both the response hand (left/right) and the depicted orientation (horizontal/vertical) differ between the prime and the cued action. When such trials were considered, mean response time did not meaningfully vary as a function of the prime's upright versus rotated orientation (upright mean = 1,320 ms, rotated mean = 1,322 ms; BF = 6.8 favoring the null hypothesis), indicating virtually no advantage for upright primes with respect to object identification.

We infer that the failure to observe alignment and congruency effects for rotated objects at an SOA of 0 ms occurs because of competing motor representations induced by their stored and depicted forms. The idea that both canonically and depictively oriented grasps yield such rapid motor competition may appear surprising, given previous claims that actions based on conceptual knowledge are retrieved more slowly than actions triggered directly by the shape of an object (e.g., Jax & Buxbaum, 2010). Note, however, that the two kinds of motor representations entail only a distinction between the grasp retrieved from the canonical description of an object and the grasp assigned to its depicted form. Both of these representations can be activated directly by the visual form of an object, without prior recruitment of associative or contextual knowledge (Marr, 1982, Chp. 5; Warrington & Taylor, 1978). We have no reason to assume, therefore, that the canonically oriented grasp is generated more slowly than the depictively oriented grasp.

Experiment 2

Experiment 1 provided evidence for a very early emergence of both alignment and orientation congruency effects induced by photographs of objects. Moreover, these effects involved a shift of the entire response-time distribution, with delta plots remaining relatively flat over the full range of response times. These observations stand as potentially important support for our contention that priming of reach-and-grasp responses by objects reflects the evocation of motor affordances, rather than spatial coding of semantic information as proposed by Proctor and Miles (2014; Proctor et al., 2011). Experiment 2 was conducted to replicate with greater statistical power the key results obtained in Experiment 1 in the 0-ms SOA condition, which showed evidence for both alignment and orientation effects even on trials with the shortest response times. Two versions of Experiment 2 were conducted, differing only in the number of prime objects used.
Method

Subjects. A new sample of 73 subjects, 40 in Experiment 2A and 33 in Experiment 2B, were recruited from the same source as in Experiment 1. A smaller sample was tested in Experiment 2B because it was decided to combine the data from both experiments as the pattern of results was the same in both cases. Data from two additional subjects in Experiment 2A and one in Experiment 2B were excluded before analyzing the results because these subjects engaged in atypical behaviors when responding (e.g., pronounced asymmetry in performance with left vs. right hand).

Materials. The colored hand cues and grayscale object primes from Experiment 1B were used with the following exceptions. First, the image of a coffee pot was replaced with a more prototypical image (reducing the maximum size of prime objects to 15.6 degrees). Second, in Experiment 2B, we reduced the number of prime objects from eight to four (two for each hand orientation: beer mug, teapot, frying pan, saucepan). The reduction in number of prime objects was intended to further ensure efficient processing of rotated primes, but the same pattern of results was obtained for Experiments 2A and 2B, so we report analyses based on the aggregated data.

Procedure. The procedure was similar to Experiment 1B, except that only the 0-ms SOA condition was used. Also, for Experiment 2B, because there were only four prime objects, all combinations of factors were covered by 128 trials. Two blocks of 128 trials were presented for a total of 256 critical trials. Experiment 2A, like Experiment 1B, included 512 critical trials.

Results and Discussion

Response time was again measured as time taken to complete a cued reach-and-grasp response, starting from the onset of the hand cue (which was always coincident with the object prime because only the 0-ms SOA condition was tested). Response times exceeding 1,900 ms in Experiment 2A (0.23%) and 2,400 ms in Experiment 2B (0.42%) were treated as outliers and were excluded from analyses, as were erroneous responses. Mean correct response times for upright and rotated primes are shown in Figure 4. A Bayesian analysis of response times in the upright prime condition with alignment and congruency as factors indicated that both effects were present ($BF > 150$ in both cases), but there was no interaction ($BF = 3.3$ favoring the null hypothesis). The effect sizes are shown in Figure 4. The mean error rate was 1.7% and there were no effects of alignment or congruency on errors ($BF > 3.1$ favoring the null hypothesis in all cases). No effects were found with movement time.

The mean response times for rotated primes are also shown in Figure 4. A Bayesian analysis of these data found no evidence for either alignment or congruency effects or their interaction ($BF > 4.6$ favoring the null hypothesis in all cases). The mean error rate was 2.1% and a Bayesian analysis indicated that there was an alignment by congruency interaction ($BF = 74.0$), such that more errors were made on congruent than on incongruent trials when the handle was aligned with the response hand (congruency effect $= -1.1$%), but the reverse was true on non-aligned trials (congruency effect $= 0.5$%). Only the former effect was reliable by a Bayesian analysis ($BF = 5.1$). This effect on error rates, although confined to cases where the prime's handle was aligned with the response hand, is consistent with the weak response-time evidence from Experiment 1 regarding the apparent influence of a rotated prime's canonical orientation on the production of reach-and-grasp responses. In this case, subjects were less prone to error when the grasp was consistent with the prime's canonical orientation. Moreover, the analysis of movement time found evidence for a small but reliable reverse congruency effect, in which movement time was shorter when the action was consistent with the prime's canonical orientation rather than its depicted view (427 ms vs. 431 ms; $BF = 6.2$).
We also examined delta plots for the alignment and congruency effects on response time. These plots are shown in Figure 5. For upright primes, as in Experiment 1, alignment and congruency effects showed no indication that the effect size increased with longer response time. If anything, the alignment effect diminished with longer response times. Moreover, both effects were present even at the shortest response time quintile. No effects on response time were apparent at any quintile for rotated primes.

Consistent with what we observed in Experiment 1, alignment and congruency effects clearly emerged with a 0-ms SOA between an upright prime object and an action cue, and were present even among the fastest responses that subjects produced. These findings are not consistent with the suggestion (e.g., Proctor & Miles, 2014) that priming of reach-and-grasp responses by pictures of handled objects is a product of abstract spatial coding of object features. Rather, they are compatible with the proposition that object primes directly evoke their associated action representations, which in turn allow for more efficient programming and/or execution of compatible reach-and-grasp movements. In addition, we found two sources of evidence for the presence of competing effects of the canonical orientation of the object prime in the rotated condition. First, error rates were lower when the grasp action was compatible with the rotated object's canonical orientation (contingent on the object's handle being aligned with the response hand), and movement time was shorter when the grasp was compatible with the object's canonical orientation.

**Experiment 3**

As a test of the validity of our interpretation of the results of Experiments 1 and 2, we conducted a final experiment in which cued reach-and-grasp actions were primed not with pictures of objects, but with object names. Word primes necessarily rely on a conceptual route to influence manual actions, and we expected that such primes would produce qualitatively different effects than object primes. Although there is no natural way to generate an alignment effect using object names as primes, one might expect to observe faster responding with the dominant hand. More important, however, an object's canonical orientation could lead to a congruency effect with respect to the horizontal/vertical orientation of the action being made, even with word primes. For example, a beer mug most typically has its handle oriented vertically and this knowledge, primed only by the object's name, could support a vertically oriented reach-and-grasp action. But doing so would require following a semantic route from the visual input of the prime word to action representations (Yoon et al., 2002). Consequently, we expected to observe that the congruency effect with word primes would increase with longer response times (a positively sloped delta plot). In Experiment 3, then, we used the names of objects rather than photographs of objects as primes. A single SOA of 300 ms was used to increase the probability of the word primes being able to generate a measurable congruency effect. Our previous work using auditory presentation of object names as primes indicated that priming effects for reach-and-grasp actions were stronger with longer SOAs (Bub & Masson, 2012). Moreover, that work showed that priming effects generally increased with longer response times, yielding delta plots with positive slopes, in contrast to the delta plots seen in Experiments 1 and 2 here. We anticipated finding results in Experiment 3 that would be consistent with the effects observed using auditory word primes.

**Method**

**Subjects.** Thirty-two new subjects recruited from the same source as in Experiments 1 and 2 were tested. A smaller sample size was warranted because examination of the data from Experiment 1 indicated that the correlation between conditions was over .95 and a revised power analysis based on that new information indicated that a sample size of 32 would be sufficient to achieve power of .8.

**Materials.** The names of the same four objects used as primes in Experiment 2B were used as word primes and grayscale versions of the hand cues used in the earlier experiments were used to cue responses. Word primes were printed in lowercase letters, and extended a maximum of 2.3 degrees of visual angle horizontally, and 0.7 degrees in height. The hand cues were edited to fit within a maximum of 7.4 degrees horizontally and 6.3 degrees vertically.

**Procedure.** Subjects were tested as in the earlier experiments except that printed words served as the
primes. Also, a 300-ms SOA was used and to avoid overlap of the hand cue and the word, which would have led to the word being obscured, the word prime was erased from the monitor when the hand cue appeared. Subjects first practiced making the four possible responses (horizontal or vertical power grasp with left or right hand) for 16 trials, then received 16 practice trials consisting of a word prime and a hand cue. A fixation cross signaled subjects to place the index finger of each hand on the buttons of the response box and after doing so the monitor was blank for 500 ms. The word prime then appeared for 300 ms, followed by the hand cue. The practice trials were followed by 256 critical trials consisting of a randomly ordered presentation of 16 repetitions of each of the 16 possible combinations of word prime and hand cue. Subjects were instructed to make the cued hand action as quickly and as accurately as possible and were told that they would sometimes be required to report the word prime at the end of the trial. This report was made on a randomly chosen 25% of the trials.

Results and Discussion

We excluded response times exceeding 2,000 ms (0.41%) and errors from the analysis of response times. The mean response times are shown in Figure 6 as a function of response hand (dominant/nondominant) and congruency of object/hand orientation. A Bayesian analysis with response hand and congruency as factors indicated that both effects were reliable ($BF > 5.5$ in both cases), but the interaction was not ($BF = 3.9$ favoring the null hypothesis). The effect sizes are shown in Figure 6. To assess the consistency of the advantage for the dominant hand in making reach-and-grasp-responses, we tested the effect of that factor in Experiments 1 and 2. In both experiments, for both upright and rotated primes, responses made with the dominant hand took less time than the nondominant hand. The advantage ranged from 25 ms to 33 ms ($BFs > 1,000$). The overall error rate in Experiment 3 was 1.2% and there were no reliable effects ($BFs > 2.6$ favoring the null hypothesis).

We also addressed the question of whether the congruency effect would appear among the shortest response times, as was seen when object primes were used in Experiments 1 and 2. Figure 6 shows the delta plot for the congruency effect and it is clear that the effect increased with longer response times and that it was not present in the shortest response time quintile. The linear trend for the congruency effect across quintiles was tested by multiplying each subject's congruency effect in a given quintile by a coefficient defined by a standard set of linear trend weights ($-2$, $-1$, $0$, $1$, $2$). A weighted effect for each subject was then computed by summing across quintiles the

Figure 6. Mean response time, mean congruency and hand-dominance effect, and mean congruency effect at each response time quintile in Experiment 3. Means for response time quintiles are positioned horizontally according to the mean response time within a given quintile, averaged across congruent and incongruent conditions. Error bars for mean response times are 95% within-subject confidence intervals suitable for comparing all four means, and error bars for plots of effects indicate the 95% highest density intervals.
product of the coefficient and the effect. If no linear trend were present, the mean of these weighted effect scores would be expected to equal zero. Contrary to this expectation, the mean weighted effect score was 76.9 ms with a 95% highest posterior density interval of [4.0, 138.5], indicating a positive linear trend.

We next compared the size of this linear trend with the delta plot of the congruency effect obtained in Experiment 1 for upright primes in the 250-ms SOA condition (this was the SOA value from Experiments 1 and 2 that was closest to the value used in Experiment 3). The mean weighted effect for subjects in Experiment 1 was -17.8 ms. A comparison between the weighted congruency effect in Experiments 1 and 3 using a Bayesian comparison between two independent groups indicated that the means were reliably different ($BF = 7.6$).

The results of the comparison of the linear trend in the delta plots of the congruency effect between Experiments 1 and 3 supports the conclusion that the congruency effect is qualitatively different across these two experiments. By using object names as primes instead of pictures of those objects, we sought to confine congruency effects to a semantic route between vision and action as articulated by Yoon et al. (2002). In so doing, the congruency effect would necessarily depend on semantically based spatial coding rather than a directly elicited motor representation. According to Proctor and Miles (2014), semantically induced correspondence effects should accrue slowly. That is what we observed in Experiment 3, with the congruency effect growing as a function of response time. This outcome is consistent with similar effects using word primes reported by Proctor et al. (2011). But this pattern stands in sharp contrast to the alignment and congruency effects with upright primes reported in Experiments 1 and 2, whereby the effects emerged with a 0-ms SOA, were apparent even among the shortest response times, and did not increase with longer response times. The temporal dynamics of priming by pictures of objects strongly indicates a different, affordance-based source for correspondence effects.

**General Discussion**

Pictures of graspable objects yield correspondence effects on cued reach-and-grasp actions that occur rapidly and show no change in magnitude between fast and slower responses. For upright objects, both alignment and congruency effects are clearly present even in the fastest 20% of responses, without any change in effect size across the response-time distribution. If anything, alignment effects tended to diminish at longer response times. This pattern occurs at an SOA of both 0 ms and 250 ms between the prime and the cue to respond, even though alignment effects were larger at the longer SOA. Analogous "head-start" effects that nonetheless grow with increasing exposure to a priming event have been reported in other domains (e.g., Balota, Yap, Cortese, & Watson, 2008). In our experiments, the depicted object has pre-activated the left or right hand by a constant amount, yielding the same impact on fast and slow grasp actions.

We confirmed the fact that correspondence effects remained constant across the response-time distribution in a second experiment with greater statistical power, using an SOA of 0 ms. Alignment and congruency effects were again clearly observed for upright objects, and they did not increase with longer response times. Consider now the results for pictures of objects rotated ninety degrees from their upright position. Alignment effects can be defined for such objects by considering the outcome of grasping the handle with the left or right hand. For example, a rotated beer mug with the opening on the left and the handle positioned above the body affords a horizontal (palm down) grasp with the right hand because the object can be easily rotated into its upright form. The same grasp posture, by contrast, applied with the left hand would require an awkward clockwise rotation of the wrist to produce the same outcome. In a previous publication (Masson et al., 2011), we established that this form of commensurability effect has an impact on speeded grasp actions; rotated objects pictured in a commensurate (i.e., aligned) orientation yielded faster responses than objects depicted in an incommensurate (i.e., misaligned) orientation.

We found clear alignment and congruency effects for pictures of rotated objects at an SOA of 250 ms. As is the case for objects depicted in an upright orientation, these effects remained invariant across the response-time distribution. However, unlike the compatibility effects observed for pictures of upright objects, rotated objects showed no alignment or congruency effects at the 0-ms SOA. In what follows, we discuss this outcome, based on the assumption that action selection can be determined by retrieving the grasp posture associated either with (a) the stored description of an object in its prototypical, upright orientation, or (b) the depicted form of the object.

Recall that subjects are cued to produce either a vertical or a horizontal grasp with the left or right hand while concurrently attending to the pictured object. The depicted form of a rotated object will rapidly activate one grasp posture (say, a horizontal grasp to the image of a rotated beer mug) while access to knowledge about the object’s typical orientation will concurrently generate the alternate posture (in this case, a vertical grasp to the same image). Given these assumptions, the net result would be that no robust congruency or alignment effects occur at an SOA of 0 ms. The conflict between action representations is...
short-lived, however. It is the depicted form of an object that must be bound to spatio-temporal codes for overt report (Chun, 1997). Attending to a visual object ensures that its perceived orientation (e.g., the picture of a horizontally rotated beer mug) rapidly dominates the grasp posture associated with the object’s typical orientation (an upright beer mug). Thus, the depictively oriented grasp overrides the canonically oriented motor representation, and we observe correspondence effects determined by the object’s depicted form (i.e. the rotated beer mug triggers the representation of a horizontal grasp).

A number of additional considerations support our proposal that finding weak or no correspondence effects for rotated objects is the outcome of competing motor representations at a short SOA. We have ruled out the possibility that correspondence effects are delayed for rotated objects merely because subjects take longer to process their identity (recall that subjects must report the object after the cued grasp action on 25% of trials). Note that each object appeared many times during an experiment. It is well known that practice greatly reduces the effect of object orientation on the speed of identification. Moreover, there is clear evidence that rotated objects were indeed processed as efficiently as upright objects. Their impact was equivalent on cued grasp actions sharing neither the left/right hand nor the vertical/horizontal wrist posture with the motor constituents of the object.

In other words, when performance could not potentially benefit from motor features shared between the depicted object and cued action, attending to rotated objects did not result in slower grasp responses than upright objects.

A second indication that canonically oriented grasp representations exert an influence on performance at a short SOA can be found in the nature of early-onset congruency effects. The image of a rotated object yielded faster responses for the grasp posture associated with its upright rather than depicted form (Exp. 1). For example, a rotated beer mug, affording a horizontal grasp, triggered a small congruency effect in favor of a vertical grasp, while the reverse was true for the image of a rotated frying pan (the object produced a small advantage in response time for a cued horizontal rather than a vertical grasp). This result points to the subtle and early influence of a canonically oriented grasp, also observed in Experiment 2. For rotated objects, error rates were reliably greater on congruent relative to incongruent trials when the handle was aligned (i.e., commensurate) with the response hand. To state this outcome another way, fewer errors occurred when the cued grasp action matched the upright rather than the depicted form of the rotated object. At a longer SOA, however, the motor constituents triggered by the depicted view clearly had a dominant influence on performance.

The alignment and congruency effects we have documented are relevant to the question of whether pictures of graspable objects trigger constituents of real world actions. The rival possibility is that correspondence effects reflect the influence of higher-level spatial codes, analogous to those generated by abstract objects like words or arrows. Such objects yield correspondence effects that increase across the response-time distribution (Cho & Proctor, 2010), an outcome that also invariably applies to evidence taken as support for the claim that pictured objects and words automatically give rise to motor affordances. For example, in a recent article, Saccone, Churches, and Nicholls (2016) reported effects of handle alignment even when subjects engaged in vertically arranged keypress responses to pictured objects with their left and right hands (that is, a left-handed keypress was faster than a right-handed keypress when the handle was aligned with the response hand). Because there was no obvious spatial correspondence between the up/down location of the response buttons and the left versus right hand, the authors concluded that this outcome must reflect the influence of motor affordances rather than abstract spatial codes. Alignment effects, however, increased across the response-time distribution, consistent with previous evidence (Cho & Proctor, 2010; Riggio et al., 2008). Along with the fact that the positioning of hands in a vertical arrangement can induce left/right spatial codes in relation to the fingertip-to-wrist axis (Proctor & Vu, 2006; Lippa, 1996), the slow development of the alignment effect, to echo Proctor and Miles (2014), "... is not consistent with a functionally automatic process such as an affordance, which brings about rapid interaction with the environment" (p. 256).

The present results are the first to clearly establish a qualitative difference between the time course of correspondence effects induced by pictures of graspable objects on cued reach-and-grasp actions and the effects more typically associated with the influence of abstract spatial codes on speeded responses. Furthermore, words have a different impact on performance than depicted objects, yielding congruency effects that increase across the response-time distribution (Exp. 3). In this respect, our results again diverge from previous evidence; the notion of affordances is often tied to correspondence effects that are no different for words than pictured objects. For example, Tucker and Ellis (2004) found that precision and power grip responses to words referring to graspable objects produced a correspondence effect that was indistinguishable from the effect observed when subjects responded to the depicted objects themselves. We agree with Proctor and Miles (2014) that this outcome, which is readily explained in terms of conceptual overlap between stimulus and response,
is hard to reconcile with the notion of a perceptual affordance. In addition, given our results, it makes little sense to apply the term affordance indiscriminately to correspondence effects induced by words as well as by objects (e.g., Flumini, Barca, Borghi, & Pezzulo, 2015; Zhang, Sun, & Humphreys, 2016).

Our methodology has produced evidence more consistent with the assumption that pictured objects, under the right task conditions, do indeed rapidly trigger constituents of real-world actions. Words, by contrast, generate a correspondence effect that grows with increasing response times and so resembles the effects typically observed when abstract spatial codes exert their influence on response selection. It remains to be determined, of course, whether the congruency effect for words is indeed governed by supra-modal representations. After all, retrieving grasp actions via conceptual knowledge occurs for words as well as visual objects (Yoon et al., 2002). Perhaps the congruency effect induced by words, although exhibiting a more protracted time-course than the effect associated with depicted objects, is in fact determined by limb-specific motor constituents. Future work may shed light on this issue.

We conclude by taking note of what remains uncertain. The idea that constituents of real-world actions might play a role in compatibility effects has been broached long before its present incarnation, and has repeatedly succumbed to rigorous scrutiny. Against this extended background of false starts, very strong evidence is needed before we might claim with any conviction that an important subset of correspondence effects, triggered by pictures of graspable objects, is indeed produced by limb-specific motor representations instead of abstract spatial codes. The present results go some way towards establishing this claim. We have demonstrated that under certain task conditions, pictured objects trigger correspondence effects that are rapid, and remain invariant across the RT distribution. Furthermore, motor features evoked by the depicted view of an object quickly dominate the features associated with its stored canonical form. Words by contrast, yield correspondence effects that are clearly larger for slower response times. These results are certainly provocative, and increase the plausibility of the claim that motor affordances have an explanatory role to play in spatial correspondence effects.

References


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