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Limits on Action Priming by Pictures of Objects

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When does looking at an object prime actions associated with using it, and what aspects of those actions are primed? We examined whether viewing manmade objects with handles would selectively facilitate responses for the hand closest to the handle, attempting to replicate a study reported by Tucker and Ellis (1998). We also examined whether the hypothesized action priming effects depended upon the response hand's proximity to an object. In 7 experiments, participants made judgments about whether pictured objects were manmade or natural or whether the objects were upright or inverted. They responded by pressing buttons located either on the same or opposite side as the objects' handles, at variable distances. Action priming was observed only when participants were explicitly instructed to imagine picking up the pictured objects while making their judgments; the data provide no evidence for task-general automatic priming of lateralized responses by object handles. These data indicate that visually encoding an object activates spatially localized action representations only under special circumstances.

Keywords: action priming, affordance, stimulus-response compatibility

Does viewing a graspable object inevitably prime the motor system for action? This intuitive proposal has received considerable recent attention—and considerable support. Viewing manipulable objects has been found to facilitate actions that are typically associated with using them (e.g., Tucker & Ellis, 1998; Bub, Masson, & Cree, 2008; Borghi, Bonfiglioli, Ricciardelli, Rubichi, & Nicoletti, 2007). In particular, reaching and grasping responses are sometimes facilitated when they are compatible with an object's afforded actions and inhibited when they are incompatible. Such *action priming* effects have been reported for a number of tasks involving left- and right-handed button presses (Tucker & Ellis, 1998; Tipper, Paul, & Hayes, 2006; Iani, Baroni, Pellicano, & Nicoletti, 2011) and grasping responses (Bub & Masson, 2006; Tucker & Ellis, 2004).

However, there are still important open questions about *when* viewing an object primes an action related to that object and *which* aspects of that action are primed. A number of researchers have argued that objects automatically prime actions (Tucker & Ellis, 1998; Grèzes & Decety, 2002; Borghi, 2005; Makris, Hadar, & Yarrow, 2011), which is consistent with some embodied theories of cognition where action plans are intrinsic to the conceptual representation of objects (e.g., Barsalou, 1999; Derbyshire, Ellis, & Tucker, 2006). According to those views, under typical circumstances, viewing an object should automatically activate some aspect of an action plan relevant to using that object. Presumably, automatic priming implies that affordances should prime actions in the absence of an explicit intention to pick up or use the objects. We examine this proposition in the present study. Our results indicate that action plans are not automatically activated upon viewing objects, although they can be activated through an effortful process involving motoric simulation.

When one reaches out to pick up an object, the action representation must specify where in space the reach will be directed and how one's grip will be formed. Ellis and Tucker (2000) referred to these distinct components of potential actions as microaffordances. There is good reason to think that these aspects are controlled differently. Grip form is controlled by the distal musculature, whereas location is controlled by the proximal musculature, and these are associated with different cortical circuits (Haaxma & Kuypers, 1974; Berlucchi, Aglioti, & Tassinari, 1994). Grip form is likely to be consistently associated with an object type—grasping a pencil will almost always entail a precision grip, whereas grasping a coconut will nearly always entail a power grip. Location, on the other hand, is less likely to be consistently associated with an object type. Pencils and coconuts can both appear at many different locations relative to the body. Therefore, different aspects of the motor control system may be recruited, depending on whether a movement requires fine control over location or grip parameters. These two aspects of motor control may be sensitive to different features of visually presented stimuli. This raises an important question about the role of object representations in action control: Do semantic representations of objects contribute differently to the control of movement location and fine motor parameters? Two previous studies have addressed this question

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using action priming paradigms. Both found a reduction or elimination of action priming effects when responses were differentiated by target location rather than grip form (Pavese & Buxbaum, 2002; Bub & Masson, 2010). However, in both cases the grip form effects were measured using tasks in which participants responded by grasping a manipulandum, whereas the location-based effects were measured using tasks in which the participant pressed a response button or a key on a keyboard. So, although these data support the proposal that the identity of visually presented objects affects grip form more than location, an alternative possibility is that a button-pressing response produces a weaker priming effect because it less closely resembles naturalistic interactions with objects. Bub and Masson argued that key-press responses, which lack the transport component of a reach-and-grasp response, only elicit priming effects when the task further requires participants to pay attention to the identify or form of the object. In many laboratory experiments, button-press responses are made on keyboards that are some distance from the display. Placing the hands near a display can alter various attentional phenomena, such as visual search rate, inhibition of return, and attentional blink (Abrams, Davoli, Du, Knapp, & Paull, 2008). Wilf, Holmes, Schwartz, and Makin (2013) found stronger location-based priming effects with response buttons near pictured objects, and when the task required naturalistic reaching. We asked participants to respond using buttons placed on a computer monitor near pictures of objects, either by reaching to the buttons (Experiments 1c, 2a, and 2b) or by holding their hands near the buttons throughout the task (Experiment 1b).

Although we set out to investigate whether an object's ability to prime the location of an action depended on the spatial configuration of the response task, it will be seen in the following experiments that we found very little evidence for automatic location priming. We were able to obtain robust location priming only when coercive and explicit task demands were established (Experiment 3). Thus, object affordances appear to be much less effective in priming the gross motor components of action than they are in priming grip form. Our results reveal important limitations on the priming of actions by viewed objects and suggest that the action planning system is only sometimes susceptible to task-irrelevant distracters.

Experiment 1

In Experiment 1, participants judged whether a depicted item was manmade or natural. In three subexperiments we manipulated the manner in which responses were made by pressing keys on a keyboard (Experiment 1a), pressing buttons on the side of the display (Experiment 1b), or reaching to press buttons on the front panel of the display (Experiment 1c). In all three experiments, the critical items were tools that afforded grasping a handle on one end of the object. In this paradigm, the action priming effect is the degree to which responses are faster when they are made to the side of the picture with the handle than to the opposite side. We expected to observed action priming effects in Experiment 1a, which was a conceptual replication of experiments by Tucker and Ellis (1998) and predicted that any such effects would be amplified in Experiments 1b and especially 1c, where the hands and arms were situated in more natural positions for grasping and manipulating the manmade items (as if they had been real objects). We hypothesized that our button-press responses, distinguished by their position in space, would be more susceptible to priming by the orientation and proximity of an object's handle than would key-press responses. We expected this action priming effect to manifest in lower response times (RTs) and increased accuracy for compatible trials, where the appropriate response was to press the button on the same side as the object's handle. Furthermore, we expected greater priming when the hands were placed near the objects (Experiment 1b), and even greater priming when participants had to reach out to the response buttons near the life-sized object images (Experiment 1c). Contrary to our hypotheses, we observed no evidence of action priming in any of the three experiments.

Method

Participants. In Experiment 1a, 32 participants from the Washington University Psychology Department's participant pool took part for course credit. Data from one participant were discarded due to slow responding (mean RT of 2,151 ms), and from another due to experimenter error. In Experiment 1b, 32 participants took part. Data from one participant were discarded due to a high error rate (12.3%), and from another due to a hardware error. In Experiment 1c, 31 participants took part and one was excluded for failure to follow the task instructions. For each experiment, we analyzed data from 30 participants (Exp. 1a: 25 female, 4 left-handed, mean age 19.8 years; Exp. 1b: 17 female, 3 left-handed, mean age 19.1 years; Exp. 1c: 17 female, 3 left-handed, mean age 19.8 years).

Apparatus. Stimuli were presented on a 19-in. CRT monitor at a distance of approximately 45 cm in Experiments 1a and 1b. The display was placed at a distance of approximately 30 cm in Experiment 1c in order to allow participants to respond with only their dominant hand. The resolution of the display was 1,280 × 1,024 pixels. In Experiment 1a, participants responded by pressing the "z" and "/" keys on a computer keyboard placed 30 cm in front of the display. In Experiment 1b, participant responses were obtained from two circular buttons with a diameter of approximately 9 cm (AbleNet, Inc.). One button was attached to each side of the monitor. In Experiment 1c, the response buttons were attached to the lower part of the display's front panel, approximately 15 cm to the left and right of the center of the screen.

Stimuli. The stimulus set consisted of 56 color images of manmade tools and 56 color images of natural items such as animals and fruits. Each item was cropped from its background, scaled to fit within a 440-pixel-diameter circle, and presented upright on a completely white background. Each item spanned approximately 13° of visual angle in Experiments 1a and 1b, and 20° in Experiment 1c. Each unique image was reflected about its vertical axis to produce a mirrored version, resulting in a total set of 224 images. The tools were selected to be naturally graspable on one side but not the other. The stimuli used in each of the experiments are depicted in the Appendix.

Design and procedure. The experiment consisted of four blocks, each consisting of 112 trials. Stimuli depicted manmade items in one half of all trials and depicted natural items in the other half. Each unique item was presented once in each block. At the beginning of each trial a fixation cross was presented for 500 ms, and then replaced with a pseudorandomly selected stimulus item.

Participants were asked to judge whether the image depicted a natural or manmade item, and to press either the left or right button to make their response. Participants in Experiment 1c were asked to start each trial by holding down the space bar with their dominant hand and to respond by reaching out to press either the left or right button with that hand. Button assignment was counterbalanced across participants. Feedback was given on error trials, in the form of a message appearing on the screen for 5 s.

Results

We trimmed the data by excluding RTs from error trials, trials with responses faster than 300 ms, and trials with responses slower than the mean plus 2 standard deviations for each subject. In Experiments 1a, 1b, and 1c, 6.0%, 6.2%, and 3.3% of trials were excluded, respectively. (We also conducted follow-up analyses in which all RTs were analyzed and whether the response was correct was included as an additional predictor variable; results were similar to those reported.) *Compatible* trials were those with a manmade object in which the appropriate response button was on the same side of the screen as the handle of the object; *incompatible* trials were defined as those where the button was on the opposite side; *natural* trials were all trials with natural objects. Mean RTs and error rates were then calculated for the compatible, incompatible, and natural conditions for each subject. RTs in Experiment 1c consisted of the time from the presentation of the stimulus to the pressing of the response button and hence included the time required to move the hand from the starting position to the response button. Figures 1 and 2 depict the RTs and error rates for Experiments 1a, 1b, and 1c. Across all experiments, comparisons of RTs and error rates for compatible and incompatible trials are reported as paired *t* tests. Effect sizes are reported as Cohen's *d* values, corrected for within-subjects comparisons (Dunlap, Cortina, Vaslow, & Burke, 1996).

Experiment 1a. Contrary to our predictions, RTs were significantly longer for compatible trials relative to incompatible trials (544 ms for compatible trials vs. 537 ms for incompatible trials), $t(29) = 2.2$, $p = .03$, Cohen's $d = 0.07$, though error rates did not differ between compatible and incompatible trials (1.9% vs. 1.6%), $t(29) = 0.82$, $p = .42$, Cohen's $d = 0.16$.

Experiment 1b. Once again RTs were longer in the compatible than in the incompatible condition (528 ms vs. 522 ms), $t(29) = 2.9$, $p < .01$, Cohen's $d = 0.07$, meaning that responses were *slower* for compatible trials. As in Experiment 1a, no significant action priming effects were observed in error rate scores (2.2% vs. 1.6%), $t(29) = 1.5$, $p = .14$, Cohen's $d = 0.34$.

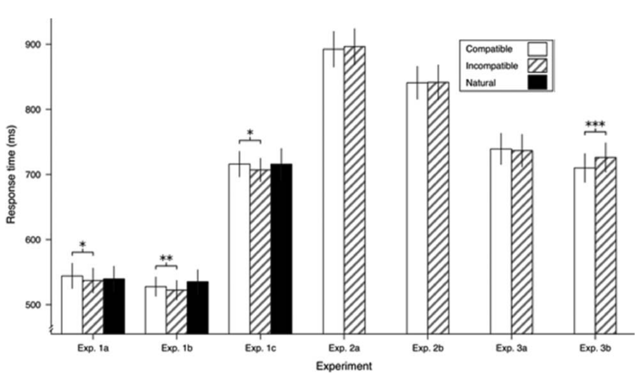

Figure 1. Response times for the compatible, incompatible, and natural trials in Experiments 1, 2, and 3. Error bars represent the standard error of the mean. * $p < .05$. ** $p < .01$. *** $p < .001$.

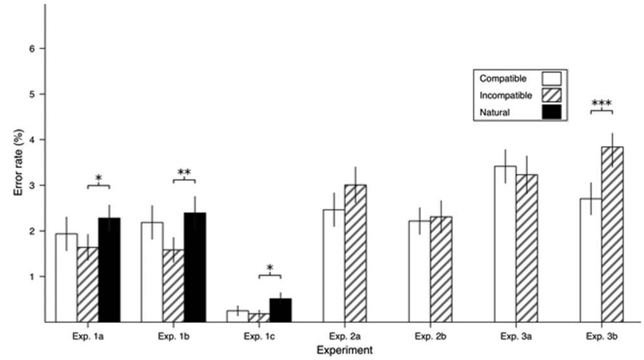

Figure 2. Error rates for the compatible, incompatible, and natural trials in Experiments 1, 2, and 3. Error bars represent the standard error of the mean. * $p < .05$. ** $p < .01$. *** $p < .001$.

Experiment 1c. Even in a paradigm involving reaching responses toward the display, neither RTs nor error rates showed the expected action priming effects. Again, RTs were longer on compatible trials (716 ms vs. 707 ms), $t(29) = 2.3$, $p < .05$, Cohen's $d = 0.08$, and error rates did not differ significantly (0.2% vs. 0.2%), $t(29) = 0.49$, $p = .63$, Cohen's $d = 0.12$. An additional analysis was conducted on distinct components of the reaching responses. The response on each trial was divided into two components: the *movement initiation time*, measuring the time from stimulus onset to the onset of the response, and the *reach time*, measuring the time taken for the hand to move from the starting position to the response button. Movement initiation times did not differ across compatible and incompatible trials (305 ms vs. 304 ms), $t(29) = 0.58$, $p = .57$, Cohen's $d = 0.01$, though reach times were longer for compatible trials (411 ms vs. 403 ms), $t(29) = 2.1$, $p = .047$, Cohen's $d = 0.08$.

Discussion

We failed to observe the expected action priming effects in a paradigm incorporating images of manmade objects and lateralized button press responses, whether the response was a button-press far from the object (Experiment 1a), a button-press near the object (Experiment 1b), or a reaching response to a button near the object (Experiment 1c). Instead, *inverse* effects were consistently found, as characterized by greater RTs when the response button was situated on the same side as the depicted object's handle. This indicates that merely observing an object is not sufficient to activate action representations in a fashion that produces action facilitation for compatible responses. This failure was even more surprising given that we designed Experiments 1b and 1c to increase the tendency for participants to view the objects as valid targets for a grasping motion. Thus, we were unable to replicate the action priming effect reported by Tucker and Ellis (1998). Our manipulation of hand proximity did not modulate action priming effects, though Yang and Beilock (2011) recently reported such an effect with lateralized responses to a rotating teacup. Costantini, Ambrosini, Tieri, Sinigaglia, and Committeri (2010) also observed action priming when objects were presented in (virtual) peripersonal space using a head-mounted display, but not when they were presented in extrapersonal space or when the objects were presented behind a translucent Plexiglas barrier. However, their participants responded by pantomiming a predefined precision grip, and the appearance of the object served as a go-signal. Matheson, White, and McMullen (2013) obtained action priming effects with life-sized objects but failed to show such effects with objects presented at smaller sizes. We increased the size of stimulus images in Experiment 1c to near life-size.

Bub and Masson (2010) also failed to replicate the basic findings of Tucker and Ellis (1998), using a paradigm involving color judgments and lateralized responses. Pictures of beer mugs and teapots primed actions when the lateralized responses included grasping as part of the response, but not when the responses merely involved pressing a key. Bub and Masson (2010) argued that the key-press responses were too far removed from any action that was compatible with the mug to evoke lateralized motor responses. Alternatively, it has been suggested that action priming effects may build up over time (Symes, Ellis, & Tucker, 2005) or that they are influenced on different timescales by two action planning systems (Jax & Buxbaum, 2010). Thus, it is possible that the viewing times in Experiment 1 were too brief to allow for action priming to occur. However, the mean RTs in Experiments 1a, 1b, and 1c (541 ms, 525 ms, and 712 ms, respectively) bracket the approximately 630 ms RTs originally reported by Tucker and Ellis (1998), suggesting that sufficient time was available for priming to occur. Our mean error rates, however, were lower (1.8%, 1.9%, and 0.2%, compared to approximately 5% in Tucker & Ellis, 1998).

What should be made of the inverse compatibility effect observed in all three experiments? One possibility is that the goal-directed parts of each manmade object, such as the spout of a teapot, attracted attention to that side of the object (Anderson, Yamagishi, & Karavia, 2002; Pellicano, Iani, Borghi, Rubichi, & Nicoletti, 2010; for counterarguments see Symes, Ellis, & Tucker, 2007; Matheson, White, & McMullen, 2013; and Riggio et al., 2008). This attentional bias may have facilitated responses to the same side of the display. Cho and Proctor (2011) studied objects with opposing protrusions, such as teapots, and found that their teapot stimuli produced larger cuing effects in the direction of the spout. However, the magnitude of our inverse compatibility effect was much smaller, and unlike Cho and Proctor's results, did not increase as a function of RT quartile within a participant.[1] Matheson, White, and McMullen (2013) observed the expected compatibility effects when participants judged whether objects were upright, but then observed inverse compatibility effects in a task requiring participants to identify objects as either animals or artifacts. They argued that categorization judgments may be facilitated by an attentional bias to the functional end of artifacts, producing an apparent inverse compatibility effect with respect to the handle end.

Vainio, Hammaréna, Hausena, Rekolainena, and Riskilä (2011) proposed an inhibition-based mechanism for explaining inverse compatibility effects. They found that irrelevant prime objects could produce inverse compatibility effects on lateralized responses when they were presented for 30 to 70 ms, while the typical (positive) compatibility effects were found when objects were displayed for 370 ms. They explained these findings by proposing a model where viewed affordances can gradually activate their associated motor representations. While the prime remains on the screen, this activation builds until it eventually reaches a threshold where it can produce a positive compatibility effect. When the prime is removed from the screen, this interruption causes the nascent motor representation to be actively inhibited because the prime is no longer a valid action target, hence leading to inverse compatibility effects. Bub and Masson (2012) proposed another mechanism to explain the presence of inverse compatibility effects. They experimentally manipulated the onset time of an irrelevant prime (an auditorily presented object name) relative to the onset time of a task-relevant cue (a visually depicted grasp). They found an inverse compatibility effect on grasping responses when the prime and target were presented simultaneously but a typical compatibility effect when the visual target stimulus was displayed at the middle or end of the word's enunciation. They proposed that any competition between potential actions triggers a conflict resolution mechanism to select the appropriate action. When there is only weak competition between potential actions, the appropriate action is easily selected and the engagement of the frontal conflict resolution mechanism even speeds up this response relative to situations where there is no competition, producing the inverse compatibility effect. However, these mechanisms do not explain our numerical trend for inverse compatibility effects in trials with slow responses.

The present results stand in contrast to the findings and conclusions of Tucker and Ellis (1998), who argued that actions could automatically be primed by task-irrelevant affordances. Indeed, the distracting influence of an irrelevant object has been shown to depend upon the overlap between the observer's intended action and the object's afforded actions (Pavese & Buxbaum, 2002). We hypothesized that action priming effects would be more likely to be observed in tasks requiring judgments about the spatial arrange-

[1] Distributional analyses were performed on total RTs in each experiment by dividing each participant's trimmed total RTs into quartiles. There were no significant compatibility-by-quartile interactions in Experiments 1a, 1b, 1c, 2a, 2b, or 3b. There was a marginal compatibility by quartile interaction in Experiment 3a, $F(3, 87) = 2.34$, $p = .079$. Follow-up t tests showed that there was a significant negative action priming effect only for the responses in the third quartile, $t(29) = 2.2$, $p = .039$; responses in the first, second, and fourth quartiles showed a numerical, but not statistically significant, positive action priming effect. Both movement initiation times and reach times in Experiments 1c, 2a, and 2b were also examined in this fashion. There were no interactions between compatibility and quartile in movement initiation times or reach times in Experiments 1c, 2a, and 2b. Our results indicate that our failure to observe the expected action priming effect is not specific to the movement initiation or reaching components of the response, nor is it specific to a particular speed of response. Aside from our results in Experiment 3a, we are aware of several other demonstrations of a timecourse-dependent inverse priming effect. Vainio, Hammaréna, Hausena, Rekolainena, and Riskilä (2011) found inverse priming when primes were presented for 30 or 70 ms briefly before the onset of a response cue, but not when objects were presented for 170 or 370 ms. They argued that actions associated with briefly presented objects were suppressed because they were invalid action targets. Vainio and Mustonen (2011) reported a similar effect where pictures of hands produced inverse priming when they were presented briefly. Bub & Masson (2012) used a paradigm that was quite different from ours in several ways: (a) participants made grasping responses that were cued by photographs of those responses; (b) object names were presented separately as distractors; (c) the timecourse was experimentally manipulated by adjusting the onset time of the object names relative to the response cue, rather than examined via quartiles in a post hoc analysis; and (d) the inverse priming effect was only observed in situations where participants made volumetric grasps, and not when they made functional grasps.

ment of objects. Therefore, we tested spatial arrangement judgments in Experiments 2a and 2b.

Experiment 2

Following our inability to elicit the expected action priming effects in Experiment 1 using manmade-natural judgments, we attempted a closer replication of the paradigm used by Tucker and Ellis (1998). Participants here judged whether objects were upright or inverted, rather than making a semantic judgment. We reasoned that making judgments about the spatial configuration of an object would be more likely to evoke action representations that included the spatial location of the object's handle, which should then facilitate reaching movements to the same location and interfere with reaching movements to a conflicting location. We also adopted a stimulus set consisting only of manmade objects with handles located on one side to more closely correspond to the one described by Tucker and Ellis.

In Experiment 2 we used a modified version of the reaching responses from Experiment 1c by requiring participants to reach with their left hand to make responses to the left button, and with their right hand to make responses to the right button. In doing so, we tested a prediction made by Bub and Masson (2010), who argued that the act of selecting and transporting the left or right hand to a response element should produce action priming effects even when the end-goal is merely a button press. Experiments 2a and 2b also were designed to assess whether action priming facilitates only movement initiation or continues to affect reaching once it is initiated. One might hypothesize that visually presented affordances would influence the reaching component of responses more strongly if they are visible throughout the response. Stimuli in Experiment 2a disappeared from the screen after the onset of the response, whereas those in Experiment 2b remained on the screen throughout the duration of the reaching response. If action priming depends on the visibility of an object's affordances, then action priming effects should be stronger in Experiment 2b than in Experiment 2a.

Method

The procedure was similar to that used in Experiment 1c. The changes are described in the following sections.

Apparatus. In Experiment 1c, the response buttons were attached the front panel of the display and participants were asked to press both buttons with their dominant hand. In Experiment 2, participants were asked to respond to the left button with their left hand and to the right button with their right hand. The two response buttons were attached to the sides of the display, near the screen, facing sideways, so that the rest position for each hand was a fixed distance from its corresponding button.

Participants. A combined total of 63 participants were recruited for Experiments 2a and 2b. Two were removed due to experimenter error, while another was removed for failure to follow task instructions. The reported data are from 30 participants in Experiment 2a (23 females, 26 right-handed) and 30 participants in Experiment 2b (20 females, 30 right-handed).

Stimuli. The stimulus set consisted of 96 images of manmade tools with well-defined handles. Four versions of each image were created using image manipulation software: one for each of the combinations of handle direction (left, right) and inversion (upright, inverted). This method for creating inverted stimuli differs slightly from that used by Tucker and Ellis (1998), who photographed objects in both upright and inverted positions. As in Experiment 1c, each image spanned approximately 20° of visual angle.

Task. Participants were asked to determine whether each stimulus was presented in an upright or inverted orientation. At the start of the experiment, each participant was informed that the upright/inverted orientation of each object was defined based on the typical way in which one would see or use the object in real life. Participants were asked to start each trial by depressing and holding the "z" and "/" keys on a keyboard and to make their responses by reaching out with the appropriate hand to press one of the two display-mounted buttons. Button assignment was counterbalanced between participants. Each of the four blocks of the experiment consisted of a presentation of all 96 tools, making a total of 384 trials. By the end of the experiment, each tool had been presented in each orientation exactly once. In Experiment 2a, the stimulus disappeared when the participant lifted their finger from the keyboard to initiate their response. In Experiment 2b, the stimulus remained visible throughout the response period.

Results

Individual trials were trimmed from Experiments 2a and 2b using a method identical to the one described for Experiment 1 (7.3% and 6.8% of trials were excluded from Experiments 2a and 2b, respectively). Also excluded were a small number of trials where the task instructions were not correctly followed, such as trials where participants accidentally pressed a key on the keyboard while reaching for the response buttons (0.2% of all trials from both Experiments 2a and 2b). Mean RTs were numerically greater than those in the previous experiments (Experiment 2a: 894 ms; Experiment 2b: 841 ms), likely reflecting the slightly greater difficulty of the task or the greater distance to the buttons mounted on the side of the display. Error rates remained quite low (mean error rate in Experiment 2a: 2.7%; Experiment 2b: 2.2%). Figures 1 and 2 depict the RTs and error rates for Experiments 2a and 2b. As in Experiment 1c, RTs reflect the total RTs including the time required to move from the starting position to the response button mounted on the monitor.

In Experiment 2a, neither RTs (892 ms vs. 896 ms), $t(29) = 1.2$, $p = .26$, Cohen's $d = 0.03$, nor error rates (2.5% vs. 3.0%), $t(29) = 1.7$, $p = .10$, Cohen's $d = 0.26$, were reliably affected by compatibility. Similarly, in Experiment 2b neither RTs (841 ms vs. 841 ms), $t(29) = 0.15$, $p = .88$, Cohen's $d = 0.00$, nor error rates (2.2% vs. 2.3%), $t(29) = 0.34$, $p = .74$, Cohen's $d = 0.05$, were affected by compatibility.

As previously described in Experiment 1c, we separately analyzed the movement initiation and reaching components of the response. Movement initiation times did not differ across compatible and incompatible trials in Experiment 2a (382 ms vs. 380 ms), $t(29) = 1.0$, $p = .33$, Cohen's $d = 0.01$, or in Experiment 2b (307 ms vs. 306 ms), $t(29) = 0.76$, $p = .45$, Cohen's $d = 0.01$. Reach times were marginally faster for compatible trials in Experiment 2a (429 ms vs. 435 ms), $t(29) = 1.9$, $p = .07$, Cohen's $d = 0.05$, but not in Experiment 2b (492 ms vs. 494 ms), $t(29) = 0.47$, $p = .64$, Cohen's $d = 0.01$. Distributional analyses are reported in Footnote 1.

Discussion

We hypothesized that we would increase the likelihood of action priming by employing an upright-inverted judgment like the one reported by Tucker and Ellis (1998) and also by using lateralized reaching responses as suggested by Bub and Masson (2010). Contrary to our predictions, we only detected a marginal compatibility effect in the reach times for Experiment 2a, where objects were removed from the screen during the reaching response, but not in Experiment 2b, where objects were visible throughout the response. In an attempt to elicit a more robust action priming effect, we ran a final set of experiments in an even closer replication of the Tucker and Ellis paradigm.

Experiment 3

It is possible that the instructions used by Tucker and Ellis (1998) may have inadvertently introduced demand characteristics in their participants. This may have been the case if their instructions placed a strong emphasis on the functional definition of uprightness, which was described as follows in their article: "In the case of objects such as a knife or saw, participants were told that upside down or upright was defined with regard to the object's normal use" (p. 834). One strategy to determine whether objects were upright or inverted would be to imagine using each object as it appears and to report the object as being upright if the imagined action was sensible. Such a strategy may have been responsible for the priming effects that Tucker and Ellis reported. To test this possibility, in the present experiment, participants were explicitly told to think about picking up each object.

Experiments 3a and 3b were similar to Experiments 2a and 2b, with changes to correspond yet more closely to the paradigm used by Tucker and Ellis (1998). While using the same upright-inverted judgment task, we changed the response method by asking participants to press buttons mounted directly in front of them on the table, on which they rested their hands. This removed the requirement of reaching for the buttons. We also replaced the larger stimulus set in Experiment 2 with a smaller number of items to match the number used in the original Tucker and Ellis study. Finally, we induced strong task demands in Experiment 3b by asking participants to imagine picking up each object while performing the task.

Method

Apparatus. Response buttons were located on the surface of the table, approximately 30 cm in front of the display.

Participants. Thirty-two participants took part in Experiment 3a. Data from two were excluded for having high error rates (11.4% and 14.8%), leaving a total of 30 participants with usable data (13 female, 29 right-handed). Thirty-five participants took part in Experiment 3b. Data from four participants were discarded because they failed to follow the task instructions, and data from one were discarded for having a high error rate in incompatible trials (10.7%). Data were obtained for a total of 30 participants in Experiment 3b (16 female, 29 right-handed).

Stimuli. We selected a set of 22 manmade objects that corresponded to the list of objects used by Tucker and Ellis (1998). As in Experiment 2, four stimuli were produced for each object by using rotated and flipped versions of each photograph. Unlike in Experiments 1 and 2, the stimulus images were scaled to preserve the relative differences in their true sizes (Tucker & Ellis, 1998), and spanned from approximately 6° to 15° of visual angle.

Task. As in Experiments 2a and 2b, participants were told to judge whether manmade tools were presented in an upright or inverted orientation. Each experimental session consisted of four blocks of 88 trials each. Initial button assignment was counterbalanced between subjects and manipulated within participants, in that the assignments were switched at the start of the third block. Every stimulus item was presented once in each block. To better mimic the Tucker and Ellis (1998) paradigm, we removed the fixation cross used in preceding experiments, reduced the duration of the visual feedback message and added a buzzer tone as an auditory feedback message. Experiment 3b differed from Experiment 3a in that participants were instructed to think about picking up each object after it appeared on the screen. The experimenter described this as part of a strategy for making the upright/inverted judgment. At the end of each block, the experimenter asked the participant whether they were able to imagine picking up each object. Participants who were unable to do so were excluded from further analysis. We emphasized to participants that they should keep their hands on the buttons during the trials, so as to respond as quickly as possible.

Results

RTs were slightly reduced, and error rates were slightly greater than those in previous experiments (untrimmed mean RTs: 771 ms, 756 ms; mean error rates: 3.3%, 3.3% in Experiments 3a and 3b, respectively). These differences may have resulted from the fact that participants pressed buttons near their hands rather than reaching to buttons, or because the shortened error feedback message led participants to be less conservative in making their responses. RTs from Experiment 3 are plotted in Figure 1, while error rates are plotted in Figure 2.

In Experiment 3a, neither RTs (compatible: 739 ms vs. incompatible: 737 ms), $t(29) = 0.67$, $p = .51$, Cohen's $d = 0.12$, nor error rates (3.4% vs. 3.2%), $t(29) = 0.45$, $p = .66$, Cohen's $d = 0.08$, were reliably affected by action compatibility. In Experiment 3b, unlike the preceding experiments, a substantial action priming effect was observed in both RTs (710 ms vs. 726 ms), $t(29) = 3.8$, $p < .001$, Cohen's $d = 0.13$, and in error rates (2.7% vs. 3.8%), $t(29) = 3.7$, $p < .001$, Cohen's $d = 0.51$. An ANOVA including compatibility and experiment as factors confirmed that the effect of action compatibility differed by experiment for both RTs, $F(1, 58) = 10.6$, $p < .01$, partial $\eta^2 = .15$, and error rates, $F(1, 58) = 6.6$, $p < .05$, partial $\eta^2 = .10$. Distributional analyses are reported in Footnote 1.[1]

Discussion

In the present experiment, location priming was observed only after explicitly instructing the participants to imagine picking up each object. The priming effect in Experiment 3b is in the appropriate direction and numerically comparable to those reported by Tucker and Ellis (1998), which indicates that our replication was successful. However, the striking difference between Experiments 3a and 3b highlights the effect of demand characteristics on manual responding. A majority of participants in Experiment 3b reported being able to imagine picking up each object, and only a small number (2 out of 35 participants) were discarded for failing to do so. The similarity of our results to the original Tucker and Ellis findings raises the possibility that their task instructions may have induced a strong task demand to imagine interacting with the object.

General Discussion

The results from seven experiments indicate that action priming for button-pressing actions is difficult to obtain, despite our attempts to do so with multiple response methods, experimental tasks, and stimulus sets. In contrast to the abundant evidence for grip form priming (e.g., Ellis & Tucker, 2000; Tucker & Ellis, 2001; Grèzes, Tucker, Armony, Ellis, & Passingham, 2003; Tucker & Ellis, 2004; Bub & Masson, 2006; Bub, Masson, & Cree, 2008; Vainio, Symes, Ellis, Tucker, & Ottoboni, 2008; Bub & Masson, 2010; Makris, Hadar, & Yarrow, 2011), the present results indicate that task-irrelevant object affordances do not always prime the location of an action. This suggests that object affordances may primarily affect the distal aspects of motor responses, such as the specific configuration of the hand, rather than the grosser aspects such as the choice of which hand to use.

Inhibition of Competing Responses

We observed unexpected but consistent *inverse* action priming effects in Experiments 1a–c. Vainio, Hammaréna, Hausena, Rekolainena, and Riskilä (2011) proposed that inhibitory mechanisms for action selection can explain inverse priming effects, though unlike their results, in our case we did not see a reduction of inverse priming in trials with long RTs in Experiments 1a, 1b, and 1c. Neither did we see a substantial difference between Experiments 2a and 2b, where we manipulated object visibility during the reaching response. However, there was a fundamental difference between our study and the one reported by Vainio et al.; in our paradigm, participants made judgments about the upright-inverted nature of each stimulus, while the objects displayed by Vainio et al. were irrelevant to the main experimental task, which involved pressing a key corresponding to the direction of an arrow. It may be that processing the task-relevant spatial features of objects can quickly override the prepotent but irrelevant response associated with reaching for and grasping their handles. Indeed, Ellis, Tucker, Symes, and Vainio (2007) failed to observe an action priming effect on grasping responses when distracters were unattended and targets were centrally located. This supports the idea that only spatially proximal or potentially task-relevant action plans need to be inhibited in order to select a final course of action. We predict that the likelihood of observing action priming, either positive or negative, will be reduced when a task can be accomplished without considering the potential actions associated with a target object, as when judging the color of an object.

Automaticity

Our results suggest that in the case of location-based responses, the influence of an irrelevant affordance is weak unless there is a secondary task that specifically calls for the formation of an action plan to interact with the object (see also Bub & Masson, 2010). If so, then grasp priming should not be considered automatic because it depends on task-specific mental sets. One possibility is that priming of object location reflects covert simulation of picking up the object. A potential explanation of previous findings of action priming is that demand characteristics can inadvertently affect how presentation of an object picture evokes aspects of actions that might be directed toward that object. This possibility was directly assessed in the final experiment, which produced results in good accordance with the results reported by Tucker and Ellis (1998). Additional evidence supporting this view can be found in two studies in which participants were shown video clips depicting actions on objects. Vainio, Symes, Ellis, Tucker, and Ottoboni (2008) found that viewing a video depicting the execution of a power or precision grip facilitated the identification of small or large objects congruent with the depicted action. Tipper, Paul, and Hayes (2006) found that viewing door handles primed left- and right-hand responses for participants who had previously viewed video clips of a hand opening door handles. The priming effect appeared only when participants made judgments about the shape of the handle, rather than its color, and the magnitude of the effect was increased when the door handles were depicted as partly turned, as if in use. Participants in their second experiment, who did not view the video, did not show such priming effects when viewing abstract, handle-shaped objects. Their conclusion was that covert simulation played a role in producing action priming effects. Future experiments could determine which factors can induce experimental participants to spontaneously engage in covert simulation of actions when faced with graspable objects.

Grip Form and Response Location

Priming of grip form may be quite different than priming of reach location. As we have previously noted, grip form and reach location may be controlled quite differently. Across situations, interacting with a particular object will tend to require a consistent grip. In contrast, the location of the object is less likely to be consistent. Thus, it would be reasonable if the visual appearance of objects primed grip formation more strongly and automatically than priming reach location. The fact that the proximal and distal musculature have distinct representations at the cortical, subcortical and spinal levels provides a potential means by which differential priming could be implemented. Relatively few studies have employed both response methods in similar paradigms. Bub and Masson (2010) directly compared these response types and only found action priming effects when responses were differentiated by grasp shape, though Vainio et al. (2008) found effects with both types of responses. The use of lateralized button-press responses in the present study places it in the minority, and in this situation we observed action priming only when participants were given motor imagery instructions. Grip-based responses may make it more likely for participants to perceive affordances in a task-relevant manner, and thus lead to a greater degree of action priming. Bub and Masson (2010) also failed to observe action priming effects with button-press responses, arguing that unlike reach and grasp responses such responses did not lead participants to activate the action representations associated with their objects. They found action priming only when the responses required reaching for and grasping a response manipulandum.

Judgment Tasks and Object Features

The ability of object affordances to prime irrelevant actions may also depend upon the judgment required of the participant. In Experiments 1 and 2, it may have been that categorizing items as manmade or natural required only a simple identification of each item but did not prompt participants to activate information about the item's spatial characteristics. Access to such semantic information may only invoke limited processing of object affordances, though Symes, Ellis, and Tucker (2005) present evidence where a semantic task led to action priming, whereas a color judgment did not. Within the realm of physical properties, action priming has been shown to occur when an observer makes judgments about object shape but not color (Tipper et al., 2006), suggesting that the surface properties of an object may be perceived independently of its structural properties. Another study showed that action-related knowledge only affects manual responding when participants made judgments about the appropriateness of a gesture with a given manmade item, but not when they were asked to determine whether an item was made of plastic (van Elk, van Schie, & Bekkering, 2009). Pellicano, Iani, Borghi, Rubichi, and Nicoletti (2010) demonstrated priming effects with upright-inverted judgments but inverse priming effects with color judgments. In particular, they found priming effects in upright-inverted judgments only when the object (a flashlight) was depicted in the switched-on state. Hence, it may not be sufficient to present an inert object to elicit action priming—an object's ability to prime actions may also depend on whether its affordances are salient to an observer. Valyear, Chapman, Gallivan, Mark, and Culham (2011) observed action priming when participants viewed real objects and were instructed to use each object, but not when the instructions were merely to move the object. Our results provide further evidence that action plans are task-dependent and not automatically evoked by viewing manmade tools. In the current study, responses were primed only when the orientation-judgment task was paired with a concurrent task designed to elicit motor imagery. One potential commonality throughout the studies reported in the literature is that the tasks that are successful at eliciting action priming emphasize the action-relevant aspects of an object,[2] relative to those tasks that fail to elicit priming. Therefore, novel tasks that lead observers to consider an object's affordances may be particularly suitable for eliciting action priming. For example, such tasks may involve estimations of object size or weight distribution, a possibility suggested by Cant, Westwood, Valyear, and Goodale (2005). These may also happen to be the tasks that promote motor imagery-based strategies, a possibility that awaits further evaluation. In a similar fashion, certain stimuli may be more likely to prime actions. These may include objects with depth cues (Symes, Ellis, & Tucker, 2007), objects preprimed with videos of interactions with similar objects (Tipper et al., 2006), or dynamic stimuli where object affordances become more or less salient over time, such as rotating teacups (Fischer & Dahl, 2007; Yang & Beilock, 2011).

In sum, it may be that perceived object affordances can influence behavior by priming the spatial location of action, but only when location is made relevant to the observer. Other researchers have demonstrated that task-irrelevant affordances can influence behavior, and concluded that affordances can automatically prime their associated actions (e.g., Craighero, Fadiga, Umiltà, & Rizzolatti, 1996; Tucker & Ellis, 1998; Grèzes, Tucker, Armony, Ellis, & Passingham, 2003). This statement must be amended to reflect the fact that action priming occurs under only limited circumstances and, particularly, that the priming is sensitive to the experimental task. Characterizing the boundary conditions under which to expect action priming effects is a critical step in building a theory of how action and object representations interact.

[2] Cant, Westwood, Valyear, and Goodale (2005) demonstrated object-based priming of movement onset times when participants reached out to an object that was occluded from view, but not when the object was visible. This led them to suggest that object-based priming is a memory-based phenomenon, rather than a phenomenon influencing online action production.

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(*Appendix follows*)

Appendix

Stimuli Used in Experiments 1, 2, and 3

Figure A1. Stimuli depicting manmade objects in Experiment 1. The color version of this figure appears in the online article only.

(*Appendix continues*)

Figure A2. Stimuli depicting natural objects in Experiment 1. The color version of this figure appears in the online article only.

(*Appendix continues*)

Figure A3. Stimuli from Experiment 2. The color version of this figure appears in the online article only.

(*Appendix continues*)

Figure A4. Stimuli from Experiment 3. The color version of this figure appears in the online article only.

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