Form Follows Function:
The Time Course of Action Representations Evoked by Handled Objects

by

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B. A. A., Kwantlen Polytechnic University, 2013

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Supervisory Committee

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Abstract

Supervisory Committee

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To investigate the role of action representations in the identification of upright and rotated objects, we examined the time course of their evocation. Across five experiments, subjects made vertically or horizontally oriented reach and grasp actions primed by images of handled objects that were depicted in upright or rotated orientations, at various Stimulus Onset Asynchronies: -250 ms (action cue preceded the prime), 0 ms, and +250 ms. Congruency effects between action and object orientation were driven by the object's canonical (upright) orientation at the 0 ms SOA, but by its depicted orientation at the +250 ms SOA. Alignment effects between response hand and the object's handle appeared only at the +250 ms SOA, and were driven by the depicted orientation. Surprisingly, an attempt to replicate this finding with improved stimuli (Experiment 3) did not show significant congruency effects at the 0 ms SOA; a further examination of the 0 ms SOA in Experiments 4 and 5 also failed to reach significance. However, a meta-analysis of the latter three experiments showed evidence for the congruency effect, suggesting that the experiments might just have been underpowered. We conclude that subjects initially evoke a conceptually-driven motor representation of the object, and that only after some time can the depicted form become prominent enough to influence the elicited action representation.
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1. Introduction

Semantic representations of manipulable objects – such as a ballpoint pen – include motor information on how to manipulate them (Bub & Masson, 2006; Campanella & Shallice, 2010). Using a ballpoint pen to write implies a certain kind of grasp for handling it, with the fingers and thumb in a specific orientation. However, rather than writing with it, one might want to simply hold the pen with the intention of transporting it, resulting in a “pinching” grasp instead of a “writing” grasp. Both of these grasps are part of the semantic representation of the object; mental representations of these grasps can be evoked by simply viewing a manipulable object (Handy, Grafton, Shroff, Ketay, & Gazzaniga, 2003). Not only are they evoked, but these action representations appear to play some role in the understanding of objects; Tucker & Ellis (2001) demonstrated that viewing objects primed actions compatible with the ones involved in manipulating them (see also Helbig, Graf, & Kiefer, 2006).

Handled objects, however, have a single grasp that is automatically afforded upon being perceived (Handy et al., 2003). Objects such as beer mugs and frying pans have a handle that is the automatic target for any grasping action. Bub & Masson (2010) showed that when subjects are cued to make a reach and grasp response while being exposed to images of handled objects, they are faster to respond with the hand that is aligned with the handle of the object; in other words, if the hand used for the response is the same as the hand that would be used to grasp the object being depicted, then subjects respond more quickly. In a similar series of experiments, Masson, Bub, & Breuer (2011) showed a parallel effect with grasp type; subjects are faster to respond with a grasp that is congruent with the grasp type that would be required to interact with the handled object. Importantly, they found that when the object is rotated 90° from its canonical orientation, subjects are similarly primed by the grasp that is congruent with the rotated image,
but with object handle alignment playing an important role – the hand that is primed is the hand that could be comfortably used to handle the object once it is rotated back into its canonical orientation. For example, if a beer mug with its handle pointing to the right were rotated 90° counter clockwise, the subject would be primed to respond with a horizontal power grasp with their right hand. That the rotated image primes a specific hand suggests that subjects are mentally rotating the object images back into their canonical orientation before making their grasp response, instead of simply responding to the handle while ignoring the meaning of the object. Mentally rotating objects takes time (Shepard & Metzler, 1971), and it has long been established that identifying a rotated object requires first mentally rotating it to a canonical orientation (Tarr & Pinker, 1989), with larger initial angles resulting in more time needed for the rotation (Jolicoeur, 1985). Thus, the required mental rotation should result in a slower response time for rotated objects.

The work of Till, Masson, Bub, & Driessen (2014) provides a possible mechanism for the priming effects demonstrated by Bub & Masson (2010) and Masson et al. (2011). In their study, Till et al. used a motion monitor to track the path the hand takes through space while performing a cued reach-and-grasp task after being exposed to an object prime. They found that the grasp afforded by the object prime caused small perturbations in the course of the hand in flight; in the case where the cued grasp response was incongruent with the grasp afforded by the object (e.g., a horizontal power grasp while being primed with a beer mug), the hand had a tendency to deviate towards a response element that matched the primed, incorrect grasp (here, a vertical power grasp). Such deviations could result in the increase in response time seen in Bub & Masson (2010) and Masson et al. (2011). Although Till et al did not examine alignment effects in their
task, it is not a stretch to suppose that similar deviations would occur when the response hand did not match the hand that would be used to grasp the object.

In the current research, we examined the time course of the hand action representations evoked by upright and rotated handled objects. Bub & Masson (2012) previously examined the time course of action representations evoked by the names of non-handled objects; in their study, subjects were exposed to an auditory prime consisting of the name of a manipulable object that either did or did not match a cued hand grasp. The hand cue was presented at one of four stimulus onset asynchronies (SOAs) – 150ms before the prime, at the start of the object name, halfway through it, or as it ended. This approach revealed that different grasp types (related either to using or moving the object) were evoked at different times in the time course, and lasted for different durations; a grasp associated with the function of the object (a “functional” grasp) was evoked even when the hand cue was presented very early in the presentation of the object name, which provides support for its automatic activation. Meanwhile, the grasp associated with simply moving the object (the “volumetric” grasp) exhibited a very different time course, and died out very quickly – in cases where the hand cue was presented at the end of the object name, the volumetric grasp had no effect on the results at all.

We use a similar method to examine the time course of handled objects, albeit using images of objects instead of aurally presented object names. This allows us to capture information on handle alignment effects, but presents a new difficulty – since the object prime and the hand cue are presented in the same medium, they are competing for attention. Till et al. (2014) used a similar design; in their study, the response cue (a picture of the target grasp type) replaced the object on screen. This was not a problem in their study, since they were not
examining the time course of the effect, and thus did not need conditions where the object prime and the response cue were presented simultaneously.

In order to make possible simultaneous presentation of both stimuli, we superimposed the hand cue on the object prime, controlling the relative sizes of the stimuli to ensure that both could be easily perceived. Similar methods – with colour and text, instead of two images – have been used to examine the time course of the activation of the colour naming component of the Stroop effect, as compared to the word reading component (M. O. Glaser & Glaser, 1982; W. R. Glaser & Düngelhoff, 1984). Glaser & Glaser (1982) systematically varied SOAs (much like Bub & Masson, 2012) to do this; Glaser and Glaser had seven levels of SOA, from -400 ms to +400 ms, where negative SOAs represented conditions where the relevant component (be it colour or word) was presented prior to the irrelevant component, while positive SOAs represent the reverse. They accomplished this separation by displaying the words in black (when only the text needed to be visible) or displaying a coloured rectangle (when only the colour was to be visible). This design allowed simultaneous presentation of the stimuli in the same medium, in a manner not dissimilar to the approach we use here.

1.1 Research Question

The goal of the current research was to examine the time course of the action representation evoked by upright and rotated handled objects and the role these action representations play in the identification of those objects. We measured evocation of action representations by examining differences in response time for trials where the object handle and the hand used were aligned vs. misaligned, and trials where the orientation of the object's handle was either congruent or incongruent with the grasp being made.
2. Experiment 1

2.1 Method

2.1.1. Subjects. Thirty-one subjects, primarily first year undergraduate students, participated in exchange for bonus credit in a psychology course.

2.1.2. Materials. The study was conducted using SuperLab 4.5. Stimuli consisted of hand cues and object primes. The hand cue on a given trial consisted of a grayscale photograph of a hand performing one of two possible hand actions: a horizontal power grasp, or a vertical power grasp. Half the hand cues were for the left hand, and the other half for the right hand; thus there were a total of four possible hand cues – left-vertical, left-horizontal, right-vertical, and right-horizontal. The object prime consisted of a grayscale photograph of an everyday handled object. Each object image had a handle suited for being grasped by either the horizontal power grasp (e.g., a frying pan) or the vertical one (e.g., a beer mug); there were four objects corresponding to each kind of handle (see Appendix A). The objects were depicted with their handles positioned for grasping with either the left or the right hand, and were presented in either their typical, upright orientation, or rotated 90°. For objects with horizontal handles, the object was rotated such that the handle pointed down; objects with vertical handles were instead rotated such that the handle pointed up; these orientations were determined to be most suited for comfortable grasping with the hand. There were thus a total of eight possible object conditions – vertical vs. horizontal handle type, left or right handle alignment, and upright or rotated.

Subjects were instructed to hold down two buttons on a button box with their left and right index fingers; when responding to the hand cues, they lifted up the appropriate hand (thereby releasing the button) and grasped one of two metal elements on a grasping apparatus. The elements were designed to be grasped by the two types of grasps being cued. A weak
electric current ran through the elements; when the subject touched the element, this broke the circuit, and their response time was measured. Response time was calculated as the time from hand cue onset to completion of grasp response.

2.1.3. Procedure. The study began with two training phases. In the first phase, subjects were exposed to the hand cues in a random sequence, and were required to respond by grasping one of the grasping elements; this served to ensure that all subjects knew the correct response for each hand cue. Specifically, each trial began with the subject holding down two buttons on a button box with their left and right index fingers. Upon doing this, the hand cue appeared on screen; the subject responded by lifting up the hand being cued, and then grasping the element which matched the grasp type being cued. The hand cue disappeared the moment the subject released either button on the button box, which was the moment at which motion began. The second training phase exposed subjects to the object primes, which they named in sequence. The precise names used varied from subject to subject; accuracy was not emphasized as much as consistency, to ensure that it was clear what the subject called each of the objects. Thus, when presented with a beer mug, one subject might say “mug,” while another might say “glass;” either of these were accepted, as long as the subject was consistent in the term used to describe the object.

For the experiment itself, subjects went through 768 trials distributed over two sessions. The study was split into two sessions to avoid excessive fatigue from completing too many trials in one sitting. On each trial, subjects began by pressing the buttons on the button box with their left and right index fingers. Upon doing so, they were exposed to a hand cue and an object prime; they were required to respond to the hand cue by grasping the correct element with the correct hand, as in the first training phase. Both stimuli vanished the moment the subject began motion.
(i.e., lifted their index finger from the button box, thereby releasing one of the buttons). For 25% of trials, after the grasping action, subjects were required to name the object prime that had been presented – this was done to ensure that subjects were paying attention to the object prime, and was not of experimental interest. This was followed by a fixation cross, which marked the end of the trial, and indicated that subjects were to once again place their index fingers on the button box.

On a given trial, the hand cue was presented either 250 ms prior to the object prime, at the same time as the object prime, or 250 ms after it. There were thus three stimulus onset asynchrony (SOA) conditions – -250 ms, 0 ms, and +250 ms, wherein “-250 ms” represents the condition where the hand cue was presented prior to the object prime, and “+250 ms” represents the condition where it was presented after the object prime.

Object alignment was defined as the relation between the hand the subject was using, and the appropriate hand that would need to be used in order to comfortably manipulate the object prime. For example, in the case of an upright beer mug with its handle pointed to the right, the aligned hand would be the right hand. In the case of the same beer mug rotated 90° counter-clockwise – so that its handle pointed upward and its top pointed left – the aligned hand would still be the right hand, as that would be the hand which would be commensurate with rotating the mug into a functional position. The second variable was orientation congruency; this referred to the congruency between the orientation of the grasp afforded by the object, and the orientation of the grasp cued by the hand cue. Congruency was defined with respect to the canonical, upright orientation of the object (e.g., a beer mug was defined as being congruent with a vertical power grasp, independent of whether it was presented upright or rotated 90°).
Thus, there were four variables of interest in the experiment: the rotation of the object (upright or rotated), alignment (aligned or misaligned), congruency (congruent or incongruent), and the SOA (-250ms, 0ms, or +250ms). Subjects went through every possible combination of hand cue condition and object prime condition for each SOA in each session; there were 32 trials per condition, for a total of 768 trials.

2.2. Results

The slowest 0.5% of responses were excluded as outliers. 1.1% of trials across all subjects involved an incorrect or invalid response, or were otherwise rendered unusable for analysis. Thus, a total of 1.6% of trials were removed prior to analysis.

The mean response times for each condition can be found in Figure 13 in Appendix D.

The data were analyzed via a four-way within subjects factorial ANOVA; the factors were alignment (aligned / misaligned), congruency (congruent / incongruent), rotation (upright / rotated), and SOA (-250 ms / 0 ms / +250 ms). The dependent measure was the total response time (RT) in milliseconds, which was measured from hand cue onset to grasp response completion. Subjects were faster in responding to trials with upright, as opposed to rotated objects (1680 ms < 1688 ms, $F[1, 30] = 13.79, MSE = 932.5, p = .001$), for aligned vs. misaligned trials (1681 ms < 1687 ms, $F[1, 30] = 11.10, MSE = 663.1, p = .002$), and for congruent vs. incongruent trials (1682 ms < 1686 ms, $F[1, 30] = 4.97, MSE = 616.2, p = .033$).

There was also a main effect of SOA; RTs were longest in the -250 ms SOA, and shortest in the +250 ms SOA (1723 ms > 1697 ms > 1632 ms, $F[2, 60] = 72.11, MSE = 7418.8, p < .001$).

There were three significant interaction effects – rotation x congruency ($F[1, 30] = 10.30, MSE = 534.8, p = .003$), alignment x SOA ($F[2, 60] = 3.49, MSE = 693.9, p = .037$), and a three-way interaction between rotation, congruency, and SOA ($F[2, 60] = 8.36, MSE = 877.4, p$...
The two-way interaction between rotation and congruency can be more fully explained by the three-way interaction; thus we focus on the latter, plotted in Figure 1. There were no significant effects of rotation or congruency at the -250 ms SOA (All $F$s < 1). At the 0 ms SOA, there were significant main effects of rotation (upright < rotated, $1691 < 1703$, $F[1, 30] = 10.59$, $MSE = 371.2$, $p = .003$) and congruency (congruent < incongruent, $1691 < 1702$, $F[1, 30] = 4.38$, $MSE = 672.7$, $p = .045$), but no interaction between the two ($F < 1$). In the +250 ms SOA, there were no significant effects of rotation or congruency (All $F$s < 1).
was a main effect of rotation (upright < rotated, 1627 < 1638, $F[1, 30] = 10.92, \text{MSE} = 389.5, p = .002$), but no effect of congruency ($F < 1$). Most interestingly, we see a crossover interaction between congruency and rotation ($F[1, 30] = 37.96, \text{MSE} = 256.6, p < .001$); subjects were faster to respond on congruent trials when the object was presented upright (1618 ms < 1635 ms), but were faster to respond in incongruent trials when the object was presented rotated 90° (1627 ms < 1648 ms). The alignment x SOA effect is plotted in Figure 2; as can be seen, there were no alignment effects in the -250 ms or 0 ms SOAs; the alignment effect is visible only at the +250 ms SOA, where aligned trials were faster than misaligned ones (1626 ms < 1638 ms).

Figure 2. Alignment effects in Experiment 1, captured by the Alignment x SOA interaction. As seen here, alignment effects appear in the +250 ms SOA only. Error bars are 95% confidence intervals.
The very low error rates make an analysis thereof difficult due to a floor effect, but we attempted to run a four-way ANOVA on the error rates, just as we did with the RTs. The only significant effect was in SOA ($F[1,130] = 4.27$, $MSE = .0004$, $p = .048$), whereby subjects made fewer errors in the -250ms SOA (0.60% of trials) than in the 0 ms or +250 ms SOA trials (1.22% and 1.61% of trials, respectively). Presumably, this is a consequence of subjects being able to process the hand cue free of any distracting object prime for the initial 250 ms.

2.3. Discussion

It is useful to break down the results of this experiment by SOA. In the earliest SOA, -250 ms, there is no congruency, rotation, or alignment effect; consequently, we set it aside from future discussion. At the 0 ms SOA, we see congruency effects with no interaction between congruency and rotation; both upright and rotated objects elicit faster responses on congruent trials than incongruent ones. Recall that congruency was defined with respect to the canonical (typical) view of the object; this means that subjects are seemingly ignoring object rotation and simply responding faster when their grasp is congruent with the object's canonical representation. But in the +250 ms SOA, we see a very different picture; here there is a crossover interaction between congruency and rotation, with subjects responding faster on congruent trials for upright objects, and on incongruent trials for rotated objects. This means that subjects are now faster to respond when their grasp type is congruent with what is actually being displayed onscreen, the depicted view.

Harris, Dux, Benito, & Leek (2008) demonstrated masked repetition priming of objects which was unaffected by the rotation of the priming object; this suggests that the initial processing of an object is based on orientation-independent information. We posit that this is what is happening here; the canonical representation of the object is effectively the result when
working with orientation-independent information. The action representation evoked at the 0 ms SOA is thus based on this canonically oriented version of the object, resulting in both upright and rotated objects showing congruency effects. As time passes, orientation-dependent information becomes available and an action representation based on the depicted view begins to take over. Thus at the longer SOA, we see congruency effects for upright objects and reversed congruency effects for rotated objects.

The pattern of effects seen for alignment are also amenable to this explanation; the canonically oriented version of the object shows no strong bias toward the left or right hand – all of the objects seen in this study are regularly seen with their handles pointing in either direction. Consequently, there is no alignment effect seen at the 0 ms SOA, with an alignment effect emerging at the +250 ms SOA; this late alignment effect is a consequence of the action representation now being evoked by the depicted orientation of the object.

But perhaps the lack of an initial alignment effect is because of the experimental context with its emphasis on using both hands in making responses. If subjects responded with only their dominant hand – as has been the case in several previous experiments – might we expect to see an alignment effect at the 0 ms SOA?

3. Experiment 2

Several previous experiments (such as Till et al., 2014) have demonstrated congruency effects when testing using only the dominant hand. In Experiment 2, we examined whether subjects would continue to treat the object prime as a canonical entity (i.e. ignoring superficial details like handle alignment and rotation) at the 0 ms SOA even when only the dominant hand was used to make responses; this finding would be captured by the rotation x congruency x SOA interaction.
3.1. Method

3.1.1. Subjects. 25 subjects, primarily first year undergraduate psychology students, participated in exchange for bonus credit.

3.1.2. Materials. Experiment 2 used the same materials as Experiment 1, except now only half the hand cues were used; for right handed subjects, only the two right-hand cues (right-vertical and right-horizontal) were used, whereas for left handed subjects only the left-hand cues were used.

3.1.3. Procedure. The procedure was largely unchanged from Experiment 1. Since the number of hand cues were cut in half relative to Experiment 1, this experiment also had half as many trials. Consequently, instead of splitting the experiment across two sessions, the entire experiment was conducted in a single session.

3.2. Results

As in Experiment 1, we excluded all response times above the 99.5th percentile as outliers. A total of 0.7% responses were incorrect or invalid; thus 1.2% of responses in total were excluded from analysis.

The mean response times for each condition can be found in Figure 14 in Appendix D.

We found similar effects as in Experiment 1 for rotation (upright < rotated, 1550 ms < 1563 ms, $F[1,24] = 24.35$, $MSE = 1148.5$, $p < 0.001$) and SOA (+250 ms < 0 ms < -250 ms; 1467 ms < 1565 ms < 1639 ms, $F[2,48] = 255.70$, $MSE = 5923.0$, $p < 0.001$). There was a main effect of congruency, but it’s direction was reversed relative to Experiment 1: Subjects were faster to respond on incongruent than congruent trials (1553 ms < 1560 ms, $F[1,24] = 6.35$, $MSE = 1193.1$, $p = 0.02$); this reverse effect may be explained by the rotation x congruency interaction detailed below. There was no main effect of alignment ($F[1,24] = 2.10$, $MSE = 465.3$, $p = 0.16$).
Curiously, there were rotation x congruency ($F[1,24] = 12.62, \textit{MSE} = 971.3, \textit{p} = 0.002$) and rotation x SOA ($F[2,48] = 5.61, \textit{MSE} = 801.7, \textit{p} = 0.006$) interactions, but no rotation x congruency x SOA interaction; there was, however, a four-way interaction ($F[2,48] = 3.35, \textit{MSE} = 1304.3, \textit{p} = 0.044$). The four way interaction is relatively weak, however, and we suspect that it might be a statistical artifact. The rotation x congruency and rotation x SOA interactions are plotted in Figure 3 and Figure 4; the congruency effect is stronger for upright objects than for rotated ones, and the advantage for upright objects is greater at the 0 ms SOA than at the +250 ms SOA.

![Figure 3. Rotation x SOA effect observed in Experiment 2. The rotation effect is the difference score, calculated as (rotated trials – upright trials). The advantage when responding to upright trials is stronger at 0ms than at +250 ms. Error bars are 95% confidence intervals.](image)
Examining the error rates in a four-way ANOVA revealed a significant alignment x congruency x SOA interaction ($F[1,24] = 4.44, MSE = .0003, p = .046$). Like the interaction found in Experiment 1, this effect is suspect, due to the borderline $p$ value; examining the confidence intervals of the congruency effect in error rates shows that the effect is driven by the alignment by congruency interaction at the 0 ms SOA. At this SOA, subjects are most accurate on aligned-congruent trials (0.38%), and least accurate on misaligned-congruent trials (1.13%); on incongruent trials, alignment makes no difference (0.88% vs 0.75%).

3.3. Discussion

Compared to Experiment 1, there are two critical differences in these findings: the lack of any kind of alignment effect, and the lack of the critical rotation x congruency x SOA interaction.
interaction. One possible explanation for the lack of an alignment effect could be that, in a context where only one hand is used for all responses, the direction of the objects’ handle is largely ignored, and does not prime responses. Contrast this with Masson et al. (2011), who tested a similar paradigm using only dominant hand responses; Masson et al. did not test alignment as we did here, but they did examine a closely related concept, “commensurability.” Commensurability, as used by Masson et al., would be equivalent to alignment in rotated objects; a commensurate rotated object would be aligned, while an incommensurate one would be misaligned. Experiments 1 and 2 in Masson et al. (2011) compared upright primes with commensurate rotated primes, while Experiment 3 used incommensurate ones. Masson et al. found a difference between commensurate and incommensurate rotated primes (which we do not), a difference which has since been replicated in as yet unpublished research; this is likely a result of the difference in methods. In Masson et al.’s study, the object prime was onscreen for 300ms, and was then replaced by the hand cue; contrast this with the current study, where the hand cue was instead superimposed upon the object prime. Furthermore, the RTs in this experiment (~1500 ms) are much higher than the ones in Masson et al. (< 1000 ms), the difference possibly being a result of the stimuli in this stimuli being smaller and less salient than the ones used by Masson et al.; this possible concern with the stimulus materials is addressed later, in Experiment 3. For now, the much larger RTs in this experiment cast some doubt on the current findings.

The lack of the rotation x congruency x SOA interaction is more interesting, since two of the component two-way interactions – rotation x congruency and rotation x SOA – are significant. The weaker congruency effect for rotated objects, compared to upright ones, may reflect the influence of the depicted view at the +250 ms SOA; despite the lack of a three-way
interaction, examination of the raw means reveals a general trend for the congruency effect for rotated objects to change in sign from the 0 ms SOA to the +250 ms SOA. This would suggest that the weak congruency effect for rotated objects is a result of the positive effect at the 0 ms SOA and the negative effect at the 250 ms SOA cancelling out, which is not something that occurs for upright objects (since the change in sign does not occur with those stimuli).

Finally, the rotation x SOA interaction shows that subjects are faster to respond to upright objects, relative to rotated ones at the 0 ms SOA, and that this difference decreases over time. We can think of this as the depicted view becoming more prominent at the later SOA. Assuming that subjects are primed by the canonical representation at 0 ms, it could be that the views are conflicting with each other – possibly because the task is easier (due to only using one hand), subjects might be able to begin accessing the depicted view earlier. This conflict between the canonical representation and the depicted view for rotated objects at the 0 ms SOA results in slower response times for rotated objects at this SOA. By the time of the longer, +250 ms SOA, the depicted view has become stronger (as explained in Experiment 1), resulting in the advantage for upright objects decreasing.

4. Experiment 3

One of the problems with Experiment 1 was that the response times were much higher than we are used to seeing; other experiments in related paradigms typically show response times around 1000 ms. In contrast, the average response time in Experiment 1 was 1600 ms. In order to reduce the response times, we made the components of the stimuli in Experiment 3 more distinct – the hand cues were presented in colour in order to pop out, and both the hand cues and the object primes were larger, covering a greater portion of the screen.
Thus the primary purpose of Experiment 3 was to replicate the findings from Experiment 1 with response times closer to the typical range of values.

4.1. Method

4.1.1. Subjects. Forty-one subjects, primarily first year undergraduate psychology students, participated in exchange for bonus credit.

4.1.2. Materials. The grayscale hand cues from Experiment 1 were replaced by coloured versions – these coloured versions were obtained from the same base photograph as the grayscale images, and were thus comparable. Furthermore, one of the object primes (strainer) was replaced with a new token, due to visible pixilation in the original image used. All stimuli were increased in size by 50%, in order to make them more visible and easily processed. The size of the hand cue relative to the object prime was unchanged. The final change was to use Adobe Photoshop to remove the background of the hand cue; the hand cues used in Experiment 1 included a small white square background, which partially occluded some of the features of the object prime. With this removed, more of the object was visible at all times, hopefully increasing its salience.

4.1.3. Procedure. The procedure was largely identical to Experiment 1, with two differences. First, the -250 ms SOA was dropped, which reduced the total number of trials in the study from 768 to 512. The reduced number of trials allowed us to conduct the entire study in a single 1-hr session, instead of breaking it up into two 45-min sessions.

4.2. Results

As in previous experiments, we excluded all response times above the 99.5th percentile as outliers. A total of 1.6% of responses were incorrect or invalid; thus 2.1% of responses in total were excluded from analysis.

The mean response times for each condition can be found in Figure 15 in Appendix D.
We found similar effects as in Experiment 1 for rotation (upright < rotated; 1041 ms < 1052 ms, $F[1,40] = 18.73$, $MSE = 1156.6$, $p < 0.001$), SOA (250 ms < 0 ms; 1009 ms < 1085 ms, $F[1,40] = 263.72$, $MSE = 3560.6$, $p < 0.001$), and alignment (aligned < misaligned; 1039 ms < 1054 ms, $F[1,40] = 58.02$, $MSE = 665.3$, $p < 0.001$). There was no main effect of congruency ($F[1,40] = 3.44$, $MSE = 851.9$, $p = 0.071$).

![Experiment 3: Congruency Effects](image)

Figure 5. Congruency effects in Experiment 3, captured by the Rotation x Congruency x SOA interaction. The 250 ms SOA behaves the same as in Experiment 1, with a crossover interaction between rotation and congruency. In the 0ms SOA, however, we see no congruency effect for upright objects, and only a marginal effect for rotated objects; this is inconsistent with the results of Experiment 1. Error bars are 95% confidence intervals.
There were four significant two-way interactions: rotation x alignment, rotation x congruency, rotation x SOA, and alignment x SOA. These interactions are best captured by the two three-way interactions: rotation x congruency x SOA ($F[1,40] = 11.69, MSE = 884.7, p = 0.001$) and rotation x alignment x SOA ($F[1,40] = 5.01, MSE = 627.6, p = 0.031$). As seen in Figure 5, while the results in the 250 ms SOA paralleled the results from Experiment 1 (subjects were faster to respond to congruent trials on upright trials and incongruent trials on rotated trials), the congruency effect at the 0 ms SOA seen in Experiment 1 was not replicated here.

Figure 6 reveals a similar partial replication for the alignment effects; whereas alignment effects

![Experiment 3: Alignment Effects](image)

Figure 6. Alignment effects in Experiment 3, captured by the Rotation x Alignment x SOA interaction. We see that alignment effects increase in strength from the 0ms to the 250 ms SOA; however, unlike in Experiment 1, there is still a (small) alignment effect for upright objects at 0 ms. Error bars are 95% confidence intervals.
increased significantly from the 0 ms to the 250 ms SOA, there is a significant effect of alignment at the 0 ms SOA for upright objects that was not observed in Experiment 1.

Examining the error rates in a four-way ANOVA revealed a significant alignment x SOA interaction ($F[1,40] = 4.09, MSE = .0006, p = .050$), and a significant rotation x congruency x SOA interaction ($F[1,40] = 7.91, MSE = .0005, p = .008$). The former effect has only borderline significance, but examining the means shows that there is no advantage for aligned trials at the 0 ms SOA (1.72% vs 1.56% error rates, an effect of -0.15%), while there is one at the 250 ms SOA (1.24% vs 1.85% error rates, an effect of 0.61%); these data suggest a pattern parallel to the one seen in response times. As for the rotation x congruency x SOA interaction, as Figure 12 in Appendix D shows, subjects make fewer errors in congruent than in incongruent trials when primed with upright objects in the 250 ms SOA (i.e. when they have had more time to view the object, and no mental rotation was required in order to parse it).

4.3. Discussion

The results of this experiment came as a surprise to us; unlike Experiment 1, we no longer see a significant congruency effect at the 0 ms SOA, and upright objects at the 0 ms SOA now display a significant alignment effect. However, it is important to note that the effects are trending in the same direction as Experiment 1; it is possible that with enough power, the congruency effect at the 0 ms SOA would become visible once more, and the alignment effect might turn out to be a statistical fluke. Experiments 4a and 4b were intended to address these possibilities by increasing the power of the 0 ms SOA, to see whether the effects would replicate the findings from Experiment 1.
5. Experiment 4

The differences between Experiment 1 and Experiment 3 were driven by the data at the 0 ms SOA. In this study, we took a more intensive look at that condition, by administering only that SOA, and not the +250 ms SOA. We also sought to increase the power in this SOA, to see whether the congruency effect would emerge.

5.1. Method

5.1.1. Subjects. Forty subjects, primarily first year undergraduate psychology students, participated in exchange for bonus credit.

5.1.2. Materials. We used largely the same materials as in Experiment 3. One of the objects (the coffee pot) was replaced with a token that was more easily identified by subjects.

5.1.3. Procedure. The procedure was largely identical to Experiment 3, save that the +250 ms SOA was dropped, and the number of trials per condition were doubled. This resulted in 64 trials per condition, for a total of 512 trials.

5.2. Results and Discussion

As in previous experiments, we excluded all response times above the 99.5th percentile as outliers. A total of 2.0% of responses were incorrect or invalid; thus 2.5% of responses in total were excluded from analysis.

The mean response times for each condition can be found in Figure 16 in Appendix D.

We found significant main effects of rotation (upright < rotated; 1047 ms < 1071 ms, \( F[1,39] = 79.47, \text{MSE} = 594.4, p < 0.001 \)) and alignment (aligned < misaligned; 1054 ms < 1064 ms, \( F[1,39] = 22.41, \text{MSE} = 324.6, p < 0.001 \)). There was no main effect of congruency (\( F[1,39] = 3.95, \text{MSE} = 527.4, p = 0.054 \)). There was also a significant interaction between rotation and
alignment \( (F[1,39] = 17.15, \text{MSE} = 393.5, \ p < 0.001) \). As seen in Figure 7, there was a significant alignment effect for upright trials, but not for rotated ones.

There were no effects of any of the variables on error rates in this experiment.

Both the rotation x alignment interaction and the lack of a congruency effect are consistent with Experiment 3 rather than Experiment 1; increasing power failed to yield a significant congruency effect.

Figure 7. Alignment effect in Experiment 4, captured by the alignment x rotation interaction. There is a significant alignment effect for upright trials, but not for rotated ones. Error bars are 95% confidence intervals.
6. Experiment 5

In order to pursue the null effect from Experiment 4, we decided to try reducing the number of distinct objects; this should have the effect of making object identification easier. We also reduced the number of trials, which would reduce fatigue.

6.1. Method

6.1.1. Subjects. Forty-one subjects, primarily first year undergraduate psychology students, participated in exchange for bonus credit.

6.1.2. Materials. The hand cues were unchanged from Experiment 3. However, in this experiment we cut the number of object primes used in half; in previous experiments, there had been a total of eight distinct object primes (beer mug, teapot, coffee pot, saw, frying pan, saucepan, strainer, knife), four for each handle type (vertical or horizontal); in this study, we had only four (beer mug, teapot, frying pan, saucepan), two for each handle type.

6.1.3. Procedure. The procedure was identical to Experiment 4, but we returned to having only 32 trials per condition, as in Experiments 1-3, resulting in a total of 256 trials per subject.

6.2. Results and Discussion

As in previous experiments, we excluded all response times above the 99.5th percentile as outliers. A total of 1.7% of responses were incorrect or invalid; thus 2.2% of responses in total were excluded from analysis.

The mean response times for each condition can be found in Figure 17 in Appendix D.

We found significant main effects of rotation (upright < rotated; 1089 ms < 1111 ms, $F[1,32] = 28.91, MSE = 1174.2, p < 0.001$) and congruency (congruent < incongruent; 1096 ms < 1103 ms, $F[1,32] = 9.50, MSE = 429.7, p = 0.004$). There was no main effect of alignment.
There were significant interactions between rotation and alignment ($F[1,32] = 7.34, MSE = 571.0, p = 0.011$) and rotation and congruency ($F[1,32] = 4.58, MSE = 570.9, p = 0.040$). As seen in Figure 8 and Figure 9, the congruency and alignment effects are visible on upright trials, but not in rotated ones.

The rotation x alignment interaction is consistent with the results from Experiment 3; however, the rotation x congruency interaction shares greater similarity with Experiment 1.

Clearly, object identification difficulty and fatigue played little role in determining the results. Despite the task being easier and shorter, we once again failed to find a significant effect of congruency for rotated objects.

![Figure 8. Rotation x Congruency interaction in Experiment 5. We see significant congruency for upright but not rotated trials. Error bars are 95% confidence intervals.](image)
Examining the error rates in a four-way ANOVA revealed significant main effects for rotation (rotated > upright, 2.04% > 1.40%, $F[1,32] = 6.41$, $MSE = .0004$, $p = .016$) and alignment (misaligned < aligned, 1.48% < 1.97%, $F[1,32] = 8.04$, $MSE = .0002$, $p = .008$), as well as a significant alignment x congruency interaction ($F[1,32] = 11.21$, $MSE = .0004$, $p = .002$), and a significant rotation x congruency interaction ($F[1,32] = 5.21$, $MSE = 5.25 \times 10^{-4}$, $p = .029$). The interactions reveal that on congruent trials, subjects showed a steady error rate of approximately 1.50% independent of condition; on incongruent trials, however, subjects made fewer errors when primed with upright rather than rotated objects (1.17% < 2.46%), and on misaligned trials than in aligned trials (1.17% < 2.46%). The alignment x congruency interaction
is odd; the fact that it appears in this experiment and in no other (especially Experiment 4) might indicate that this is nothing more than noise, a statistical fluke from the large number of comparisons being made across experiments. The rotation x congruency interaction is similar to the pattern of the error rates found at the 0 ms SOA in Experiment 3 – no congruency effect for upright objects (-0.08% in Experiment 3, -0.45% in this experiment), and a congruency effect that approaches significance for rotated objects (0.69% in Experiment 3, 0.83% in this one).

7. Meta-Analysis

Although the data at the 250 ms SOA were relatively stable, the results at the 0 ms SOA varied widely between experiments – crucially, the findings from Experiment 1 differed from those of Experiments 3, 4, and 5. The range of RTs differ between the first two and the last three experiments; Experiments 1 and 2 had RT above 1500 ms, while Experiments 3, 4, and 5 had RTs closer to 1000 ms. This difference is presumably a result of the change in materials, with the latter experiments using larger, more salient stimuli. Given that experiments in this paradigm tend to yield RTs in the 1000 ms range, it is most useful to examine the latter experiments. Consequently, we sought to examine the story that emerged when aggregating the 0 ms SOA data across the latter three experiments. For these analyses we used the BEST package in R to conduct a Bayesian analysis on the data. The BEST package is designed for comparisons between two condition means or a comparison between a single mean and some specified value such as zero, exactly like the t test it supersedes; however, unlike the t test, Bayesian analyses like BEST allow us to estimate the size of an effect using a highest density interval (HDI). Unlike standard confidence intervals, which cannot be readily interpreted as providing evidence for the most likely values of an effect (Kruschke, 2013), HDI's show the range of the most likely effect sizes, given the obtained data. Consequently, we used the BEST procedure to analyze the
Meta-analysis at 0ms SOA: Experiments 3, 4 & 5

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<td>95% HDI</td>
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<table>
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<th>Alignment Effect: Rotated Objects</th>
</tr>
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Figure 10. BEST HDI plots of the alignment and congruency effects at the 0 ms SOA, aggregating across Experiments 3, 4 and 5. Removing Experiment 1 from the analysis yielded essentially the same distributions, though the congruency effect for rotated objects is now a marginal one.

alignment and congruency effects separately for upright and rotated trials. This yields a set of Bayesian Highest Density Interval (HDI) plots, indicating the strength of evidence in support of the effect. In Figure 10, which combines data from the 0 ms SOA for Experiments 3, 4, and 5,
the HDI’s show strong evidence for an effect of congruency at the 0 ms SOA for upright objects, and weak evidence of an effect for rotated objects. Although weak, the congruency effect for rotated objects is consistent with the congruency effect found in Experiment 1. Unlike 95% confidence intervals, Bayesian HDI’s indicate that the mean of the distribution is probably located near the center of the interval; consequently, the marginally significant effect of congruency for rotated objects is stronger evidence than the comparable 95% confidence interval would be. As for the alignment effect, the HDI’s in Figure 10 show a significant alignment effect for upright trials, but not rotated ones – which is unlike Experiment 1, where there were no alignment effects at the 0 ms SOA.

The meta-analysis suggests that, when the data across Experiments 3, 4, and 5 are combined there is a congruency effect for both upright and rotated objects at the 0 ms SOA, though the evidence for the effect in rotated objects is relatively weak. We take this as evidence for the canonical representation determining initial action representations, which are then replaced by action representations emerging from the depicted view.

8. General Discussion

Across five experiments, we examined the role action representations play in the time course of the identification of upright and rotated handled objects. In Experiment 1, we found that subjects were initially primed by the canonical representation of the object, ignoring its depicted rotation; after some period of time passes, in the later SOAs, subjects were primed by the depicted view of the object, which takes into account its rotation. Experiment 3 once again showed that responses at the long SOA were primed by the depicted view, but did not show strong evidence for priming by the canonical representation at the short, 0 ms SOA; this failure to show canonical priming at the 0 ms SOA repeated itself in Experiments 4 and 5. However, a
meta-analysis of Experiments 3, 4 and 5 revealed that the overall pattern of results was consistent with the initial finding in Experiment 1, at least with regards to congruency. The alignment effects were less stable, and we found that although the alignment effect grew stronger when going from the 0 ms SOA to the 250 ms SOA, there was still a significant alignment effect for upright objects at 0 ms.

These findings tie in nicely with those of Kobelsky (2015). Kobelsky also examined the time course of action representations evoked by rotated objects; however, unlike the current research, she used objects without handles (such as spray cans and cellphones). While the general pattern of results in that study are consistent with the idea of early access to the canonical representation of an object and late access to the depicted view, an intriguing difference is the size of the congruency effects found; the congruency effects in these experiments were in the range of 5-10 ms. In contrast, Kobelsky’s were approximately 30 ms. The obvious difference between the two studies is the fact that Kobelsky’s objects did not have handles. But why would using objects with handles result in such weak effects – so weak, in fact, that the effects did not reach significance in several of the experiments in this study?

One possible explanation is that, rather than each view being evoked at different times, both the canonical and the depicted views are evoked at the same time, when the object is first presented. However, the strength of this evocation is not the same for both views; the canonical representation starts relatively strong, and either declines over time or remains activated. The depicted view, on the other hand, begins weak, and then grows over time. This would result in the pattern of results seen in both the present research and in Kobelsky’s – in the shorter SOAs, the action representations that prime subjects’ actions are rooted in the canonical representation. Once some amount of time has passed, the depicted view becomes strong enough that the
priming action representation is dominated by it. This ties in nicely with the findings of Bub and Masson (2010), where alignment effects appeared only in the later SOAs (a finding which is partially replicated here). Bub and Masson suggested that viewing a handled object generates competition between left- and right-hand representations, which must be resolved before one hand can be favoured. The resolution of this conflict could be the mechanism by which the depicted view could gain in strength. Extending this further – in the current research, there were only two grasp types, vertical or horizontal. It is possible that after becoming habituated to the task (which could happen as early as the training phase), a similar kind of conflict could occur between the two grasp types, resulting in a similar strengthening of the depicted view over time as is the case with alignment.

But how can we account for the significant alignment effects for upright objects at the 0 ms SOA? One possibility ties in to the fact that the handle is an immediate focus of attention (Handy et al., 2003). This makes grasping a handled object relatively easy, since the site at which the hand must be placed is already located (namely, the handle). Upright objects naturally require no mental rotation in order to be identified, reducing the time required to identify them; this could result in the left- vs. right-hand conflict resolving very quickly, leading to the depicted view growing more quickly for upright than for rotated objects. This idea of the handled object being easier to grasp – resulting in the decision conflict being resolved sooner – is also our proposal for an explanation of the differences between the congruency effect sizes here, relative to those found in Kobelsky (2015). The fast resolution of the decision conflict would result in the depicted view growing earlier than would be the case with non-handled objects; for rotated objects, this would result in the depicted view providing stronger competition for the canonical representation at the 0 ms SOA, reducing overall congruency effect sizes. In contrast, the
relatively slow resolution of the decision conflict in non-handled objects – and the correspondingly late arrival of the depicted view – would mean that the congruency effect at the 0 ms SOA would be more pronounced with these stimuli – as was the case.
9. References


10. Appendix A – Response Apparatus and Hand Cues

Each response element corresponded to one kind of hand grasp (vertical or horizontal), and could be grasped with either the left or the right hand.

Experiment 2 used only two of the four possible hand cues, since subjects responded on all trials with only their dominant hand.

Experiments 1 and 2 used the black-and-white hand cues; Experiments 3, 4, and 5 used the colour versions instead.
11. Appendix B – Experiment 1 & 2 Stimuli

Objects were of two categories: canonically vertical handles, and canonically horizontal handles. Stimuli are not shown to scale.
12. Appendix C – Experiment 3, 4 & 5 Stimulus substitutions

In Experiment 3, one of the stimuli (the strainer) was replaced with a better quality token.

In Experiment 4, another stimulus (the coffeepot) was replaced with a more easily recognized token. This stimulus was not included among the stimuli used in Experiment 5.

Otherwise, the object primes were the same as in Experiment 1.
Figure 11. Congruency effects in error rates for Experiment 2 (captured as % error in incongruent trials - % error in congruent trials) as a function of alignment and SOA. While the interaction is signification ($p = .046$), the conditions differ only slightly, lending credence to the possibility that this was a statistical fluke. Error bars are 95% confidence intervals.
Figure 12. Congruency effect in error rates for Experiment 3 (captured as % error in incongruent trials - % error in congruent trials) as a function of rotation and SOA. Subjects make fewer errors on congruent trials relative to incongruent ones when primed with upright objects in the 250 ms SOA. Error bars are 95% confidence intervals.
Figure 13. Mean response times for each condition in Experiment 1.
Figure 14. Mean response times for each condition Experiment 2.
Figure 15. Mean response times for each condition in Experiment 3.
Figure 16. Mean response times for each condition in Experiment 4.
Figure 17. Mean response times for each condition in Experiment 5.