

An Exploration of Limb-Specific and Spatial Codes Triggered by Pictures of  
Graspable Objects

by

Emma K. Ullrich  
Bachelor of Science (Honours), University of Victoria, 2018

A Thesis Submitted in Partial Fulfillment  
of the Requirements for the Degree of

MASTER OF SCIENCE

in the Department of Psychology

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**Supervisory Committee**

Dr. Daniel N. Bub (Department of Psychology)

**Supervisor**

Dr. Michael E. J. Masson (Department of Psychology)

**Co-Supervisor**

## **Abstract**

There is much debate in the field of cognition on the nature of affordances; a concept originally invoked by Gibson (1986, as cited in Chong & Proctor, 2019) in reference to the possible actions furnished by a solid object to an embodied agent. Gibson's notion of an affordance has been substantially revised. It is now widely proposed that even images of objects automatically trigger affordances in perceptual tasks (Tucker & Ellis, 1998). Stimulus-response compatibility effects have been used to provide evidence for this claim; however, it has been repeatedly found that spatial compatibility and not anatomical compatibility contributes to these effects. This large body of evidence stands against the claim that the images of objects evoke limb-specific representations. In this thesis, I establish that specific task conditions do indeed trigger motor-based effects to an image of a graspable object with a keypress response. In a set of six experiments, participants were required to make laterality judgments via keypress responses to the image of a hand superimposed on the image of a graspable object. Our results show that participants are consistently faster when the depicted hand is the one that would be used to act on the depicted handled object, but only when they are using a spatio-anatomical frame of reference. The presence of these alignment effects demonstrates that some of our effects are limb-specific and not spatial in nature. The current set of experiments establishes results that have implications for the contemporary notion of an affordance.

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## Acknowledgments

I would like to thank:

**Dr. Daniel Bub** For his dedicated mentorship and extensive knowledge base and for fostering my critical thinking to help me shape my current understanding of cognition.

**Dr. Michael Masson** For his detailed insight into my results and always providing clear answers to my many questions about statistics.

**Marnie Jedynak** For her help creating the programs, collecting the data, and analyzing the data, as well as making the experiments in this thesis possible.

**Morgan Teskey** For helping me to learn the language of R to produce the figures used in this thesis and providing valuable advice to help me over the course of my masters.

## Introduction

A great deal of evidence indicates that the spatial location of a depicted object can induce automatic effects on speeded responding. For example, in the well-known Simon effect the relevant dimension assigned to a keypress response (say, the colour of a target object) is not spatial in nature, and the location of the object is task-irrelevant (see Proctor & Vu, 2006 for a review). Nonetheless, responses to the task-relevant attribute are faster when the irrelevant stimulus location matches the location of the cued response. In a more complex variant of this procedure, referred to as the spatial Stroop task, the relevant dimension also has spatial properties: for example, the direction of an arrow pointing to the left or right serves as the relevant cue. Responses are faster when arrow direction (say, pointing to the left) matches its spatial location (in this instance, the arrow would be on the left of a central reference point).

As Proctor and Vu have noted, the Simon effect and other analogous phenomena have received much emphasis because they offer valuable insight into perception-action relationships (also see Hommel, 2011). A hallmark of the spatial codes responsible for all of these effects is that their impact on the selection of a left/right-sided response is largely unaltered when the hands are crossed to the opposite sides of the body, so that a left keypress, for example, is produced by the right hand and vice versa. Thus Wallace (1971) used shape as the relevant dimension; a square versus circle required a left/right keypress response with hands uncrossed in one block of trials and crossed hands in another. The Simon effect was based entirely on the relationship between the location of the keypress response and the target object, irrespective of the hand assigned to a particular key. In other words, a left-sided keypress to the target object was faster (by about 30 ms) when

the location of the target was also on the left rather than the right of midline, regardless of whether the keypress was made with the left hand (in an uncrossed condition) or the right hand (in the crossed condition). This outcome occurred even when observers were prevented from seeing the keys so that the coding of response location was not based on visual cues. A comparable result was reported by Umiltà and Nicoletti (1985, as cited in Proctor & Vu, 2006) with colour as the relevant dimension; the Simon effect was 23 ms when the hands were crossed and 21 ms when the hands were positioned in the more natural uncrossed position (also see Roswarski & Proctor, 2003; Wascher, Kuder, Schatz, & Verleger, 2001). More recently, Pfister and Kunde (2013) have used a straight versus crossed hands comparison to establish that the correspondence effects induced by the visual outcome of an action - an object appearing on the left or right side of a computer screen immediately after a keypress response - are determined by the spatial location of a response rather than the laterality of the hand assigned to a key.

To summarize what appears to be a general principle: spatial correspondence effects triggered by an object are mostly based on the relation between the location of the stimulus and the keypress, and there is little or no contribution of the left/right status of the hand producing a response (see Proctor and Vu, 2006 for a discussion of additional evidence). Despite the robustness of this principle, it has frequently been claimed that pictures of graspable objects centrally displayed, with handles positioned on the left or right, trigger limb-specific effects on keypress responses.

Evidence put forward by Tucker and Ellis (1998) has been widely taken as support for the claim that it is the hand best suited to grasp a depicted object like a teapot by the handle that has an automatic influence on left/right keypress responses, not the

relative coding of the spatial location of the key. Observers were required to indicate by means of a left/right handed keypress response whether a depicted object was upright or inverted. Performance was found to be faster and more accurate when the handle of the object, though task irrelevant, was aligned rather than misaligned with the responding hand. To show that this effect depended on limb-specific representations, Tucker and Ellis (1998) went on to report that the alignment effect induced by the handle was substantially weaker for keypress responses to the upright/inverted status of depicted objects made with the index/middle fingers of the right hand.

The inference that the more robust correspondence effect of the handle on between-hand keypress responses must reflect the influence of limb-specific codes rests on the assumption that the handle of the depicted object should have “no preferential effect on the actions that can be carried out by the index and middle fingers of the right hand” (Tucker & Ellis, p. 836). We should point out that this assumption, though widely endorsed, is hardly straightforward. Why should the handle not trigger two kinds of effects: a limb-specific effect on the selection of a right/left-handed response (keypresses involving a choice between the two hands) and a spatial effect on a left/right-sided response (keypresses involving a choice between two fingers of a single hand)? Indeed, this kind of interplay between different frames of reference (body- or limb-centred representations, as well as an externally-based coordinate system) is to be expected if proprioceptive and visual cues about body posture are to be integrated with objects in extra-personal space (Colby, 1998).

At an empirical level, the differential effects reported by Tucker and Ellis have in any case not withstood careful scrutiny. Alignment effects induced by the task- irrelevant

handle of a depicted object when they do occur are generally of equal magnitude for between- and within-hand keypress responses (Cho & Proctor, 2010). In some studies a *reverse* handle alignment effect has been reported (keypress responses were in fact *slower* when the handle was aligned with the effector for example Yu, Abrams, & Zacks, 2014), and this outcome is if anything, bigger for within than between-hand keypress responses (e.g. Cho & Proctor, 2011). So entrenched is the view that Tucker and Ellis must be correct that this negative alignment effect has been taken as evidence that limb-specific effects induced by the handle are inhibited, so that responding with the hand aligned with the handle are now slower than keypresses that are misaligned with the handle (Vainio, Hammarén, Hausen, Rekolainen, & Riskilä, 2011). This view has been articulated despite the fact that reverse alignment effects have invariably gone against the requirement originally invoked by Tucker and Ellis, that limb-specific effects should yield greater effects on between-hand responses than within-hand responses (Cho & Proctor, 2011).

To complicate matters further, there are in fact two reports besides the result by Tucker and Ellis that have indeed found bigger alignment effects induced by the handle of a depicted object on between- than within-hand keypress responses (Pappas, 2014; Proctor, Lien, & Thompson, 2017). Both of these results have relied on the picture of a single object (a frying pan or skillet) to yield bigger effects of the handle on between than within-hand keypress responses, leaving open the possibility that the difference (greater alignment effects of between than within-hand keypress responding) has to do with the properties of this particular object in combination with the task demands of judging whether the object is depicted as upright or inverted. The image of a skillet or frying pan

when the base of the object is centred about fixation, has depth cues that vary in their position along a vertical axis (with position along this axis depending on whether the object is upright or inverted), while at the same time the position of the handle varies on the left or right.

Attention to these depth cues will ensure that the up/down dimension is more salient than the horizontal dimension. Under these task conditions, substantial evidence from studies of spatial correspondence effects indicates that the position of the hands on keys placed some distance apart can generate an external frame of reference that enhances the salience of horizontal spatial codes (e.g. Rubichi, Nicoletti, Pelosi, & Umiltà, 2004; Vu & Proctor, 2002). The influence of this dimension is reduced when the distinction between left versus right keypress options is less well marked (Rubichi et al., 2004; Vu & Proctor, 2002). More than one possibility is available to limit the salience of the horizontal dimension, including the assignment of left/right responses to a uni-manual joystick (Hommel, 1996), or to keys operated with the hands placed one on top of the other (Vu & Proctor, 2001). Another way is to ensure that left/ right keypresses depend on only the index and middle fingers of a single hand (Vu & Proctor, 2001).

The greater effect of handle alignment on between- than within-hand keypress responses is based on a narrow set of preconditions induced by upright/inverted judgments to the greyscale image of a frying pan. Responses to a silhouette of the object show no differences in the magnitude of the alignment effect on between- versus within-hand keypress responses (Pappas, 2014; Proctor et al., 2017). According to Pappas, this latter result occurs because only realistic greyscale images of graspable objects and not silhouettes of these same objects can trigger motor affordances. The reality is that the

effect of response mode induced by the greyscale image of a frying pan (with the base centred at fixation) occurs because these images have depth cues that vary along a vertical axis, reducing the salience of the left/right position of the handle. It is clear that the original result by Tucker and Ellis - involving a set of different objects presented for upright/inverted judgments - is simply not replicable even when greyscale images are used (Thomas, Stötefalk, Pecher & Zeelenberg, 2019; Yu et al., 2014). The original result, despite numerous failed attempts to replicate, has been cited repeatedly in the literature as evidence supporting the idea that images of graspable objects automatically trigger limb-specific motor codes. In a recent book, Ellis (2018) confidently asserts that the notion has been well substantiated, without addressing the fact that: (a) the logic of what is responsible for a weaker alignment effect on within- than between-hand keypress responses has never been substantiated, and (b) the evidence in support of the claim is nugatory.

### **The Importance of Keypress Responses with Crossed Hands**

We have already noted that a more straightforward, less theory-laden approach is available to determine whether limb-specific codes contribute to the effect of an object on response selection: a comparison of correspondence effects on crossed versus straight hand responding. If the depicted object generates effects driven by the hand best suited to grasp the object, then keypress responses should be faster for the hand aligned with the handle (for example, a right hand enlisted to grasp an object with the handle on the right), regardless of whether the hand is located in the ipsilateral or contralateral hemispace.

Surprisingly, we know of only two published studies that have examined the nature of the correspondence effects generated by the image of a graspable object on

keypress responses made with straight versus crossed hands. Phillips and Ward (2002) used the image a frying pan with a handle pointing to the right or left and a symbol (III-I or I-III) superimposed on the image, near the handle. The symbol cued a left/right-handed keypress. The results showed faster responses when the handle was on the same side as the response key, in both straight and crossed hand conditions. Phillips and Ward (2002) correctly inferred that the results were entirely due to spatial compatibility effects. If the effects were limb-specific, the results would have followed the hand, and the correspondence effect seen in the straight hands condition would have reversed in the crossed hands condition.

Janyan and Slavcheva (2012) relied on a very similar experimental design; the stimulus was again the image of a frying pan with a symbol indicating a right- or left-handed response (e.g I-III or III-I). In one block, participants responded with their hands straight and in the other block, hands were crossed. When the hands were positioned straight on the buttons, responses were faster when the handle was on the same side as the responding hand. This outcome replicates the effect obtained by Phillips and Ward (2002) under straight hands responding.

In the crossed hands condition, when the handle pointed to the left, responses on the left key (made by the right hand) were considerably faster than responses on the right key (entailing a left-handed keypress). When the handle was on the right, however, there was no difference in reaction times between responses on the right and left keys. The authors argued that they failed to replicate the findings of Phillips and Ward (2002). They claimed instead that their results showed both spatial and motor effects, and they attributed the motor effects to the advantage of the right hand in motor planning.

According to this account, when the right hand is positioned on the left key, the handle on the right induces both limb-specific and spatial effects on response selection. These effects are in opposition as argued by Janyan and Slavcheva: a spatial effect of the handle on right-sided keypresses (made with the left hand), and a limb-specific effect of the handle on right-handed responses (assigned to the left key). The net outcome is that no alignment effects occur for the object depicted with the handle on the right in the crossed hands condition.

The inference arrived at by Janyan and Slavcheva is erroneous, however, and is simply due to the fact that responses with the right hand in the crossed hands condition are much faster than left-handed responses. The same mistake has already been noted by Seibold, Chen, and Proctor (2016) in regard to claims that the Simon effect is often larger for the stimulus location on the side where the person's dominant hand is operating. As these authors have pointed out, any advantage in the speed of responding for the dominant hand would equally benefit corresponding and non-corresponding trials. An apparent (though spurious) asymmetry in the Simon effect would emerge, though, when "the data are analyzed as a function of correspondence for each stimulus location because the corresponding and non-corresponding response times that are compared come from different hands" (p. 437).

In the case of Janyan and Slavcheva, faster response times for right-handed than left-handed responses in the crossed hand condition would yield the mistaken impression that correspondence effects are much enhanced when the handle is on the left (and performance on spatially corresponding trials depends on a right-handed keypress response), and considerably reduced when the handle of the object is on the right (and

performance on spatially corresponding trials depends on a left-handed keypress response). If comparisons are instead made separately for each hand, as they should be, the results obtained by Janyan and Slavcheva are exactly the same as those reported by Phillips and Ward (2002). Responses on the left key (made with the right hand) are faster when the handle is on the left rather than the right. Responses on the right key (made with the left hand) are faster when the handle is on the right instead of the left. These correspondence effects are of equal magnitude and are spatial in nature; they are determined by the location of a keypress rather than the hand assigned to a response.

In what follows, we take up a different approach to the nature of the codes evoked by images of graspable objects. There is strong evidence that the image of a grasp posture on its own generates limb-specific codes in a Simon-like task. Previous experiments in our laboratory found alignment effects when participants executed a left/right keypress in response to a coloured dot superimposed on the image of a grasp posture. Participants make faster responses when using the hand that corresponds to the depicted hand, even though the depicted hand is irrelevant to the task of judging the colour of the dot. These effects remain regardless of response mode (e.g. hands straight or crossed). This suggests that the image of a hand automatically triggers the formation of limb-specific representations even in the absence of any requirement to classify the image. Other evidence shows that images of hands activate the extrastriate body area (EBA) of the occipital temporal cortex (OTC) (Zimmermann, Mars, de Lange, Toni, & Verhagen, 2018). This area connects with the parietal lobe which has functional connectivity that is relevant for action planning (Zimmermann et al., 2018). Further research shows that from images of hands, the EBA can predict hand-related actions and potentially the sensory

consequences associated with them (Gallivan, Adam McLean, Valyear, & Culham, 2013). Given that images of hands provide unique information to the viewer based on their functional properties and generate codes that are limb-specific in nature, we turn to our question of interest. Does the image of a grasp posture superimposed on a graspable object elicit representations that differ from the typical spatial codes that determine alignment effects on keypress responses?

In previous work, van Noordenne (2017) had participants respond to the laterality of a hand depicting a closed grasp posture, using their hands positioned in the conventional way (straight hands) on the response box. A left-handed grasp posture required a left-handed keypress and vice versa. The image of the hand was presented superimposed over the image of a handled object (teapot, frying pan, saucepan, or beer mug). All depicted objects were positioned so that the whole object (base plus handle) was centred on the screen. To ensure the object was attended to, on 20% of trials participants were asked which object was shown immediately after they produced a keypress response. Participants made faster responses when the depicted hand was aligned with the object's handle. Faster responses were also made when the wrist orientation of the depicted hand matched the orientation of the grasp invited by the handled object.

In a second experiment, a new group of subjects completed the same experiment but with their hands crossed (van Noordenne, 2017). Responses were faster on aligned trials than misaligned trials and this effect was larger at a longer stimulus-onset asynchrony (SOA). As compatible or aligned responses were defined in terms of the depicted hand that would most readily interact with the object (e.g right hand and handle

aligned to the right), the effect followed the hand. An important conclusion from this experiment is the nature of the effects could not be spatially based; the effect did not remain with the location of the key, but followed the hand.

A further experiment was conducted replacing the imperative cue of the hand with an arrow (van Noordenne, 2017). Participants responded with a left/right-handed keypress to the direction of the arrow. If images of a grasp posture in combination with the depiction of a graspable object are responsible for limb-specific effects, then the arrow should result in a different outcome than the previous two experiments. Results indeed showed a reversal of the alignment effect; participants made faster responses on trials when the arrow was pointing away from the handle. The magnitude of the alignment effect decreased across the range of response times. These results suggest that left/right-handed keypress responses to the laterality of a hand versus the direction of an arrow induce quite different codes when presented on the same image of a graspable object.

When we look more specifically at each object, we can see that three objects have prominent spatial features along a horizontal axis. With the teapot, both the handle and spout protrude on the left and right of the base. The same is true for the frying pan and the saucepan. To ensure results seen in the experiments were triggered by the handle and not just the most salient spatial feature, van Noordenne (2017) calculated the alignment effect individually for each object. For the straight hands and crossed hands experiments involving responses to the laterality of the hand, there was no difference in effect size for each object. More importantly, there was little difference in the effect of each object on responses made with crossed versus straight hands. When the arrow was the imperative

stimulus, however, there is variation in the alignment effect induced by different objects. The teapot and the frying pan showed the largest reversal of the alignment effect, as they had the most spatially prominent protrusion of the base along the horizontal axis. The beer mug showed no effect, as the base appeared more symmetrically about fixation. This discrepancy in the nature of the correspondence effects on left/right-handed keypress responses provides further evidence that laterality judgments to images of grasp postures alter the nature of the codes generated by the depicted object.

These initial results provide evidence for the presence of effects on keypress responses induced by images of graspable objects that are not merely spatial in nature. In the six experiments presented in this thesis, we will continue to pursue the question of the task conditions that produce limb-specific effects on keypress responses. Using similar stimuli and procedures to van Noordenne (2017), we will explore different response modes to further support the claim that certain task conditions will trigger motor-based representations from images of graspable objects. In these experiments, we used the two objects that generated the greatest discrepancy in correspondence effects on responses to the direction of an arrow versus the laterality of a hand; a frying pan and a teapot. These experiments also included the same images of four hands (left/right-handed closed grasp postures with the palm either in a vertical or a horizontal orientation) displayed at two different time intervals after the onset of the depicted object (0 ms and 250 ms). The four hands were always presented from an egocentric (first person) perspective. To determine the presence of limb-specific codes, we relied on the traditional manipulation of straight versus crossed hands.

This thesis will provide further evidence that the representations we are documenting are different than the codes typically responsible for spatial correspondence effects. We will show alignment effects evoked by images of handled objects when a laterality judgment is made with a keypress response, regardless of how the hands are positioned. Consistent evidence will support our claim that under the right task conditions, pictures of graspable objects generate limb-specific effects on keypress responses. In this thesis, we will demonstrate the subtle presence of these effects, and capture the nuances of their temporal dynamics.

## Experiments

### 2.1 Experiment I

This first experiment was designed as a within-participants replication of van Noordenne's (2017) first and third experiments, but with some further conceptual refinements. In two experiments with different groups of participants, she used a straight hand and crossed hand manipulation to test for limb-based representations when left/right-handed keypress responses were made to the laterality of a closed grasp posture superimposed on the image of a graspable object. She demonstrated alignment effects with both response modes. Therefore, we anticipate that an alignment effect determined by the correspondence between the depicted hand and the left/right position of the handle would be present in both the straight and the crossed hands conditions. We should note that correspondence effects induced by the stimulus ensemble include the possibility of physical or conceptual overlap between the left/right location of the handle of the depicted object and the laterality of the grasp posture. Indeed, there is good evidence that analogous stimulus-stimulus (SS) compatibility effects occur when responses are made to visual objects like an arrow with inherent spatial properties that are congruent or incongruent with its location (Lupiáñez & Funes, 2005). This first experiment will provide a foundation to establish that under suitable task conditions, the image of a graspable object does induce indirect limb-based effects on keypress responses that cannot be attributed to SS compatibility effects.

### 2.1.1 Method

**Participants.** 62 participants completed this experiment for extra credit in their undergraduate psychology courses. Of these participants, 15 were male and seven were left-handed. The average age of participants was 22.50 years (standard deviation  $\pm$  5.02 years). The University of Victoria Human Research Ethics Board approved all experiments presented in this thesis.

**Materials.** We used two objects for the images in this experiment; a frying pan with a handle that afforded a horizontal grasp and a teapot with a handle that afforded a vertical grasp. To create these images, we positioned the object so the whole-object was centred on the screen. There were two greyscale images for each object; one with the handle on the left and one with the handle on the right. Our experiments also used four images of hands. The hands in these images were flesh-coloured and showed either a horizontal or a vertical grasp posture with either the left or right hand. We superimposed the images of the hands over the images of the objects (see Figure 2.1.1 for an example). For reference, Appendix C contains all stimuli used in the experiments reported in this thesis. Our experiment ran on a Macintosh computer using the SuperLab5 program. Participants viewed the experiment on a monitor and a horizontally oriented Cedris button box collected participants' responses (see Figure 2.1.2).



*Figure 2.1.1.* Example of final stimulus used (Experiments I-VI). This hand-object pairing is aligned and congruent with both the laterality of the handle and the hand and the orientation of the handle and the hand matching.



*Figure 2.1.2.* Laboratory setup for Experiments I and III-VI

**Design.** We created sixteen unique images using the images of the hands superimposed over images of the objects (4 hands x 2 objects x 2 handle locations). The image of the hand was either presented immediately with the object in the 0-ms SOA condition or 250 ms after the object in the 250-ms SOA condition. There were two blocks of trials for each experiment; one where participants responded with hands straight and one where participants responded with hands crossed on the button box. Our critical

factors were alignment (comparing handle side and hand laterality), orientation (comparing handle position and hand position), SOA (0 ms and 250 ms), instruction type (key-based and hand-based), and response mode (straight and crossed hands).

Before each block, participants completed 16 practice trials. Each block consisted of 160 critical trials, with self-paced breaks every 40 trials. We counterbalanced block order between participants. Participants completed a total of 320 critical trials.

**Procedure.** Before beginning the experiment, each participant signed a consent form. The experiment was held in a quiet room. Participants sat about 50 cm away from the computer monitor and the experimenter instructed them to place their index fingers on the two outermost buttons of the button box, with their hands either straight or crossed. Participants followed one of two possible sets of instructions. Instructions asked half of the participants to respond to the laterality of the hand in the image using their corresponding hand. If it was a left hand in the image, they responded with their left hand and vice versa for a right hand. The other half of the participants read instructions asking them to respond with the key that corresponded to the laterality of the hand in the image. If the image was of a left hand, participants responded by pressing the left key and vice versa for a right hand. At no point were participants asked to judge the relationship between the hand and the object; it was not relevant to the task demands.

Each trial began with the presentation of a fixation cross in the center of the screen for 250 ms. The image of an object with a hand superimposed over top (either immediately or after a 250-ms delay) replaced the fixation cross on the screen (see Figure 2.1.3). The image remained on the screen until participants indicated their laterality judgment by responding with a keypress. On 20% of trials, we probed participants for

which object was just shown; they gave a verbal response indicating which object and the experimenter scored them using a Macintosh keyboard. In each trial, the pictured hand could match in both features to the object shown (laterality and orientation); mismatch one feature, but match the other; or mismatch both features. The object was not relevant to the task of judging the laterality of the hand.

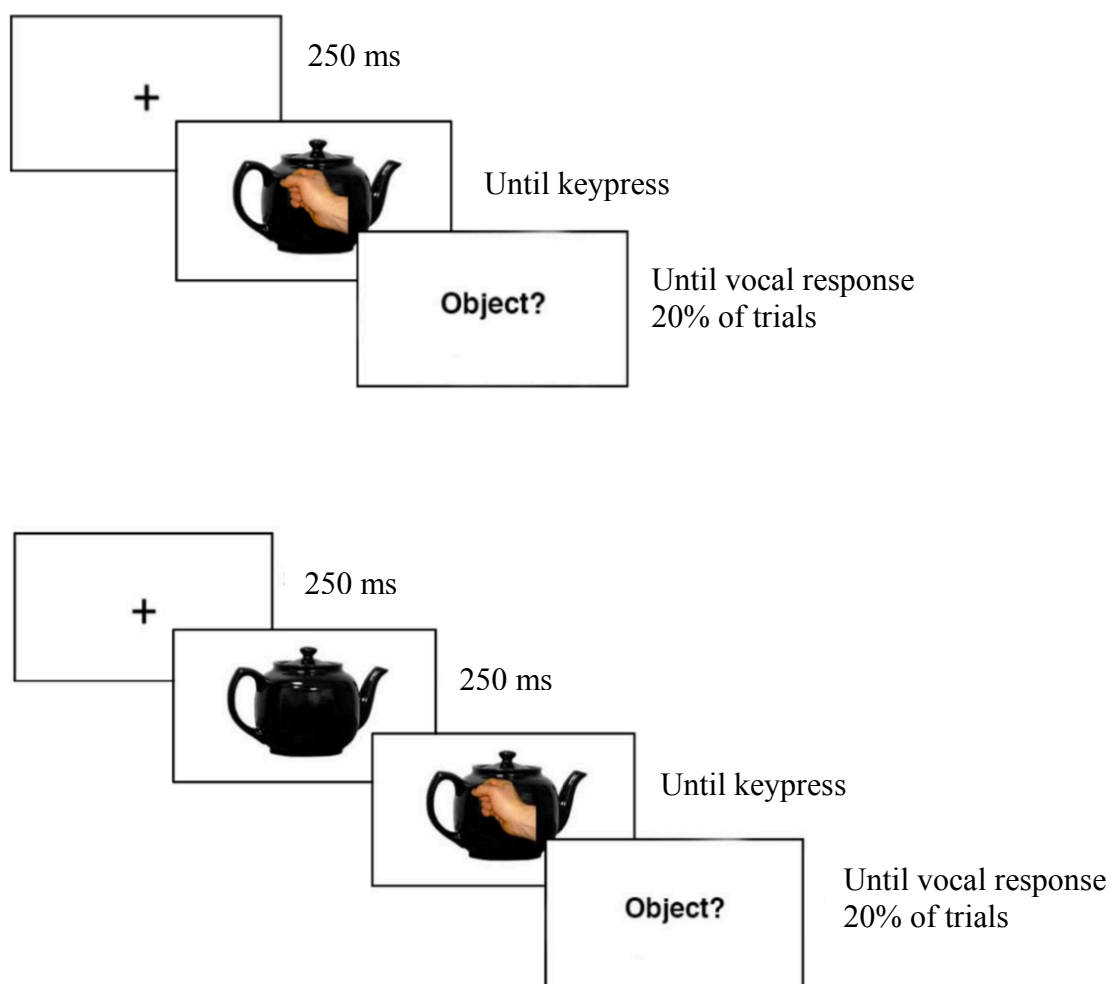


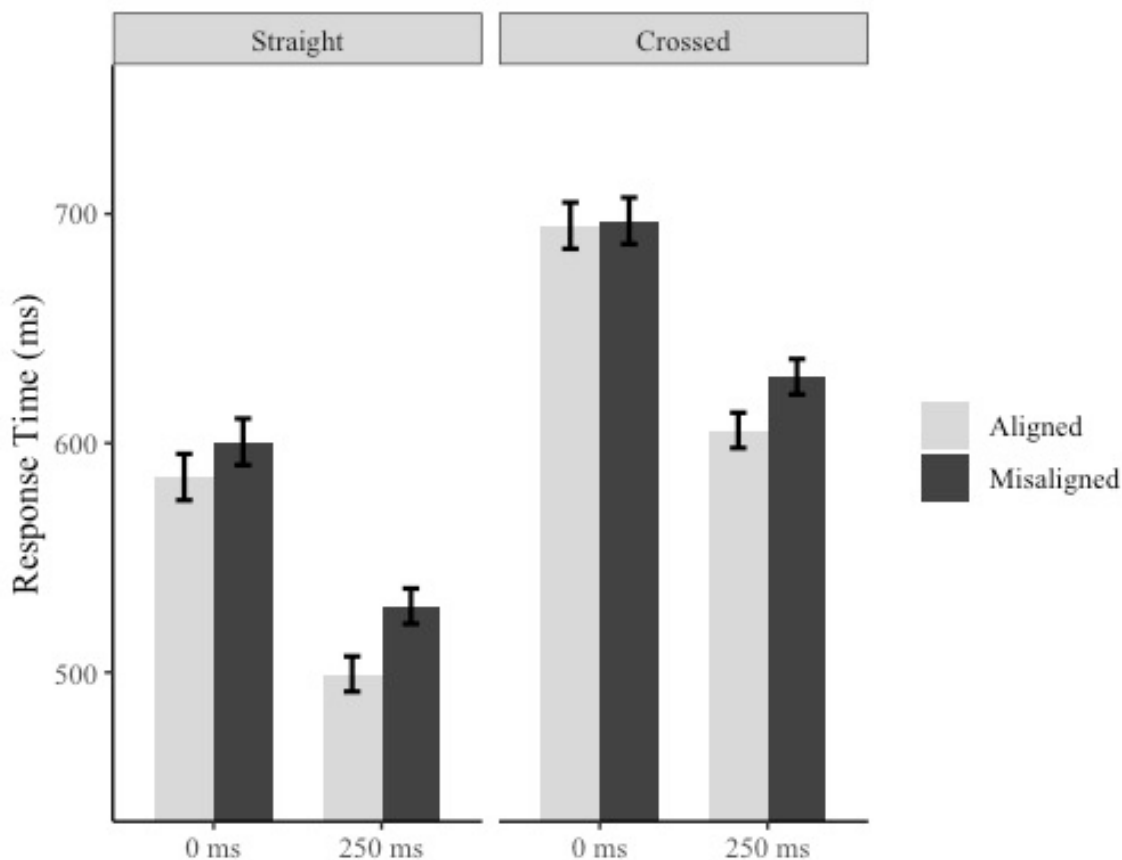
Figure 2.1.3. Trial procedure; 0-ms SOA condition (*top*), 250-ms SOA condition (*bottom*).

### 2.1.2 Results and Discussion

The mean percent accuracy for keypress classification of the hands was approximately 97.5%. For the identification of the object, the mean percent accuracy was approximately 97.8%. We excluded two participants due to error rates of 100%, as they made keypress responses opposite to what was required; the final sample used for analysis contained 60 participants.

We calculated response times from the moment the image of the hand appeared on the screen to the press of the response key. Any response times shorter than 100 ms and longer than 2,300 ms we excluded from the data. We set the upper bound at 2,300 ms so no more than 0.5% of observations would be excluded, as recommended by Ulrich and Miller (1994).

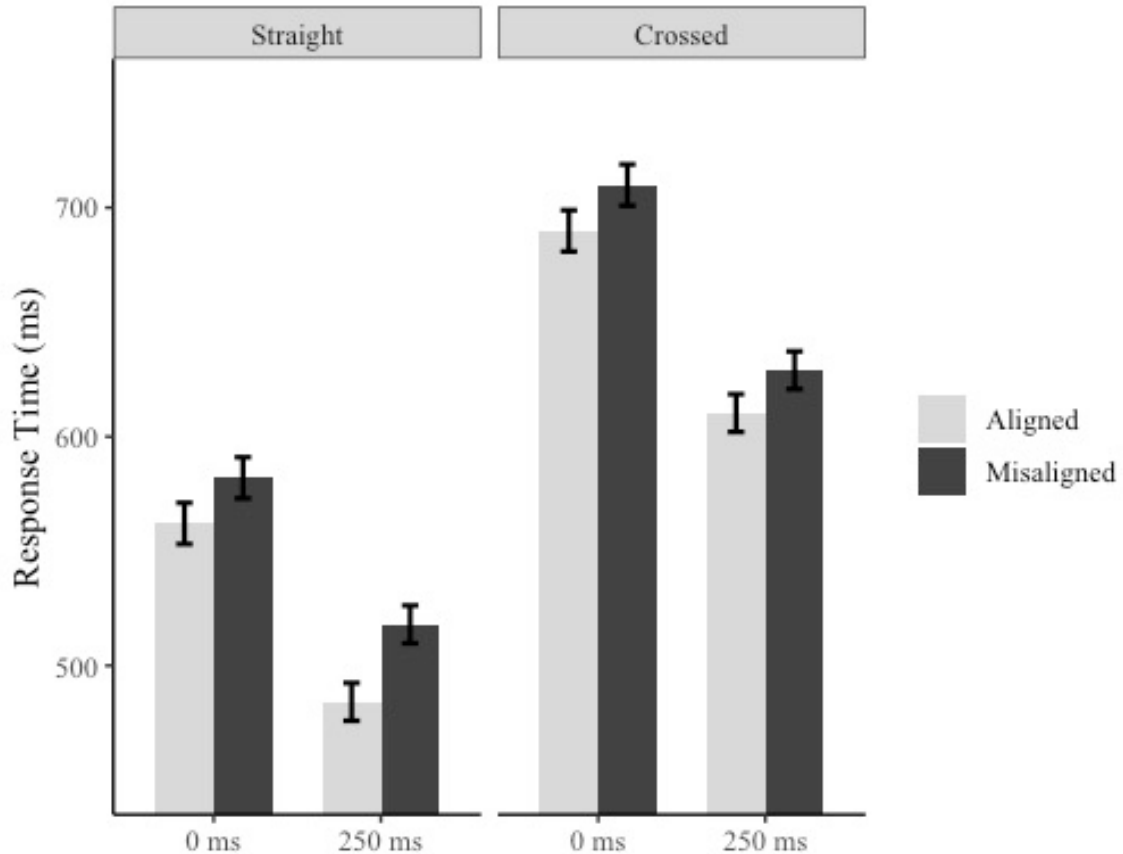
We computed an analysis of variance (ANOVA) for the factors of alignment, SOA, and response mode as repeated-measures, and instruction type as a between-participant factor (see Figures 2.1.4 and 2.1.5 for mean response times). Block order and orientation (horizontal or vertical hand orientation) were included in the initial analysis. Neither factor showed a main effect nor did the interactions provide further insight into our results, so we did not include these in the main results section. Significant results including these factors can be found in Appendix A.



*Figure 2.1.4.* Mean response times in Experiment I as a function of alignment, SOA, and response mode for the hand instructions. Error bars represent 95% confidence intervals.

For both sets of instructions, aligned is defined as when the depicted hand is the one that you would use to act on the object. For example, an object with its handle on the right side would be aligned with a right hand. An object with its handle on the left side would be aligned with a left hand. For hand instructions, there was a main effect of alignment ( $F[1, 28] = 18.06$ ,  $MSE = 2,021$ ,  $p < .001$ ); faster responses were made on aligned trials. There was also a main effect of SOA ( $F[1, 28] = 182.80$ ,  $MSE = 4,001$ ,  $p < .001$ ); participants were faster at responding in the 250-ms SOA condition. Finally, we

found a main effect of response mode ( $F[1, 28] = 19.29$ ,  $MSE = 67,457$ ,  $p < .001$ ); response times were longer in the crossed hands condition.

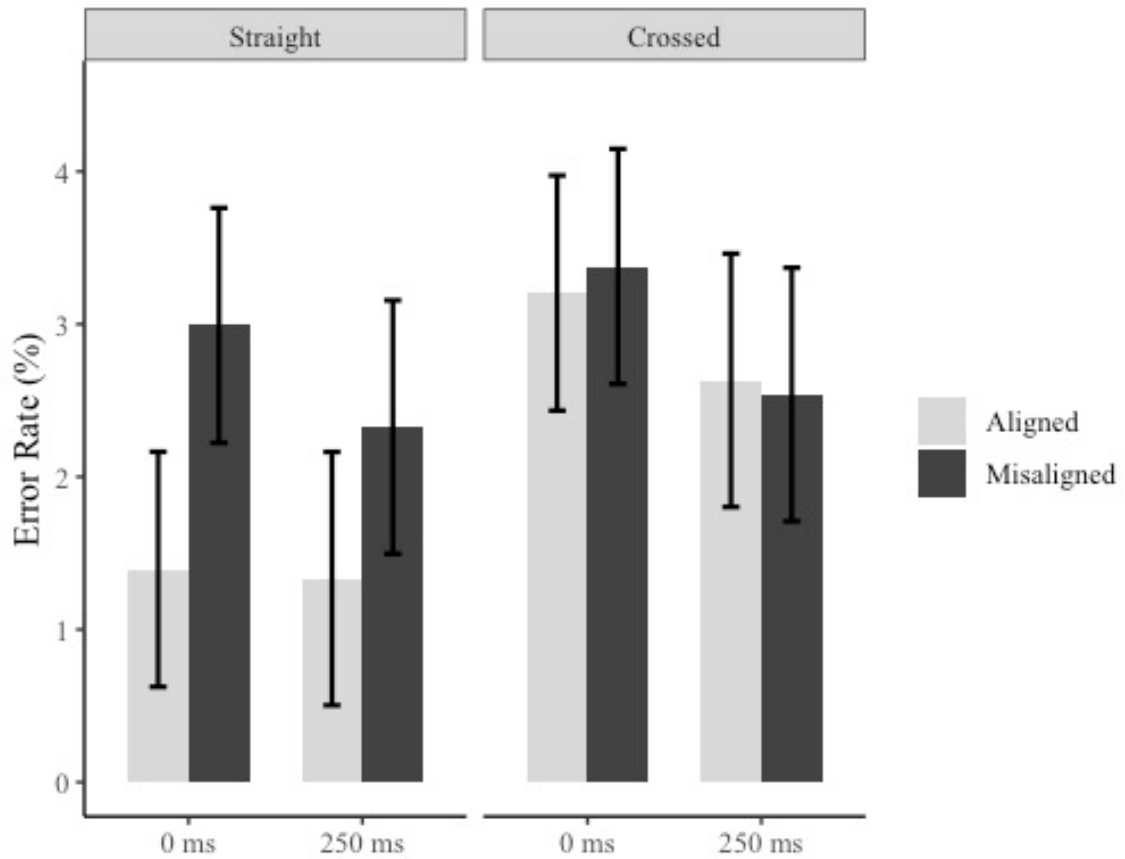


*Figure 2.1.5.* Mean response times in Experiment I as a function of alignment, SOA, and response mode for the key instructions. Error bars represent 95% confidence intervals.

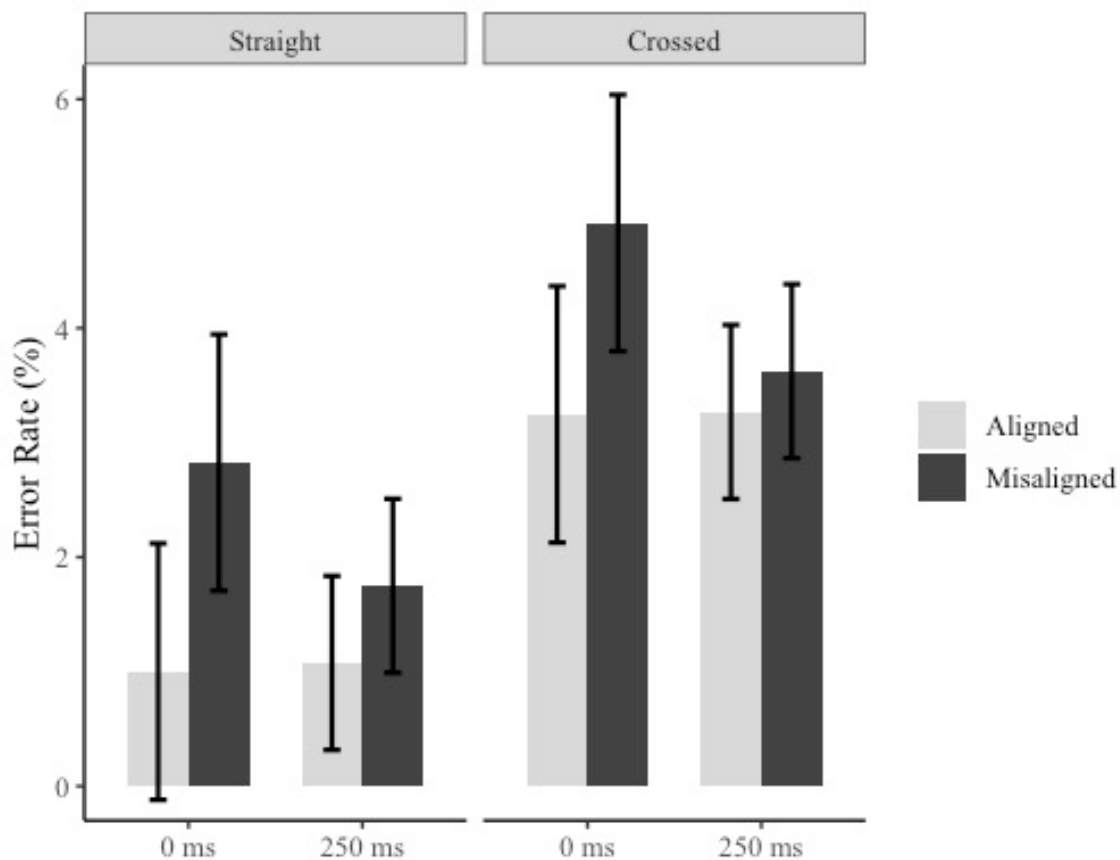
For key instructions, there was a main effect of alignment ( $F[1, 28] = 25.42$ ,  $MSE = 2,517$ ,  $p < .001$ ); faster responses were made on aligned trials. There was also a main effect of SOA ( $F[1, 28] = 209.38$ ,  $MSE = 3,274$ ,  $p < .001$ ); participants were faster at responding in the 250-ms SOA condition, as they were with the hand based instructions. Finally, we found a main effect of response mode ( $F[1, 28] = 29.37$ ,  $MSE = 61,727$ ,  $p < .001$ ); response times were, again, longer in the crossed hands condition.

It is important to note that there was no reliable interaction between any of the factors and instruction type. This demonstrates that it does not matter how participants were instructed; whether they responded according to the corresponding key or hand, it did not impact the effect of alignment. The interaction between alignment and response mode was also not significant. There was a significant effect of alignment with hands straight ( $F[1, 58] = 67.90$ ,  $MSE = 539$ ,  $p < .001$ ) and with hands crossed ( $F[1, 58] = 11.78$ ,  $MSE = 1315$ ,  $p = .0011$ ).

The error rate effects were in the same direction as the response time effects, so there were no speed-accuracy trade-offs (see Figure 2.1.6 and 2.1.7). For hand-based instructions, there were no main effects in the error rates; significant interactions involving block order and orientation can be found in Appendix A. For key-based instructions, there was a main effect of orientation in the error rates ( $F[1, 28] = 32.77$ ,  $MSE = 6.21$ ,  $p = .024$ ). Participants made more errors on congruent trials when the orientation of the handle and the hand matched. A main effect of alignment was also seen ( $F[1, 28] = 5.72$ ,  $MSE = 27.306$ ,  $p = .004$ ); more errors were made on misaligned trials. There was a main effect response mode ( $F[1, 28] = 19.49$ ,  $MSE = 27.20$ ,  $p < .001$ ); participants made more errors on crossed hand trials. No significant interactions were found between these factors with key-based instructions.



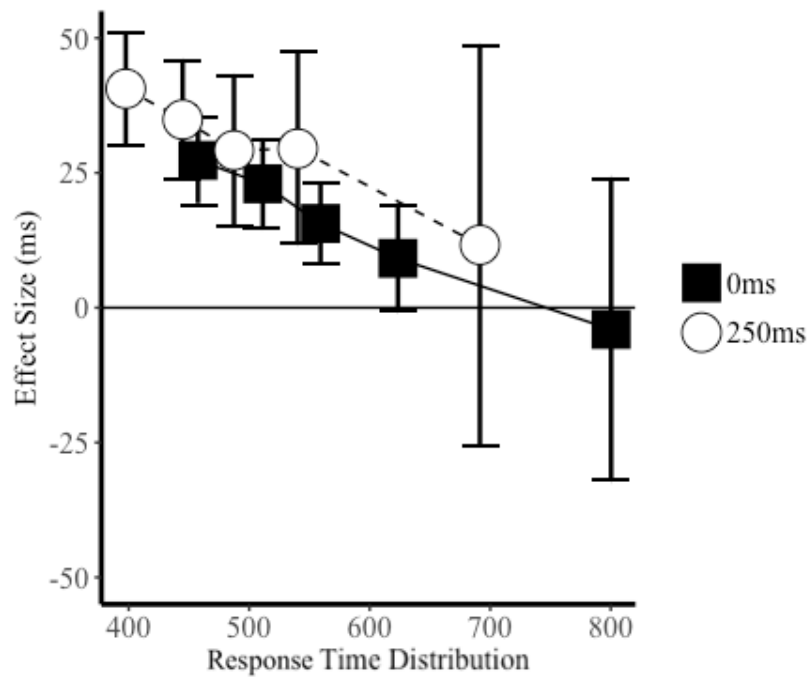
*Figure 2.1.6.* Mean percent error rate in Experiment I as a function of alignment, SOA, and response mode for the hand instructions. Error bars represent 95% confidence intervals.



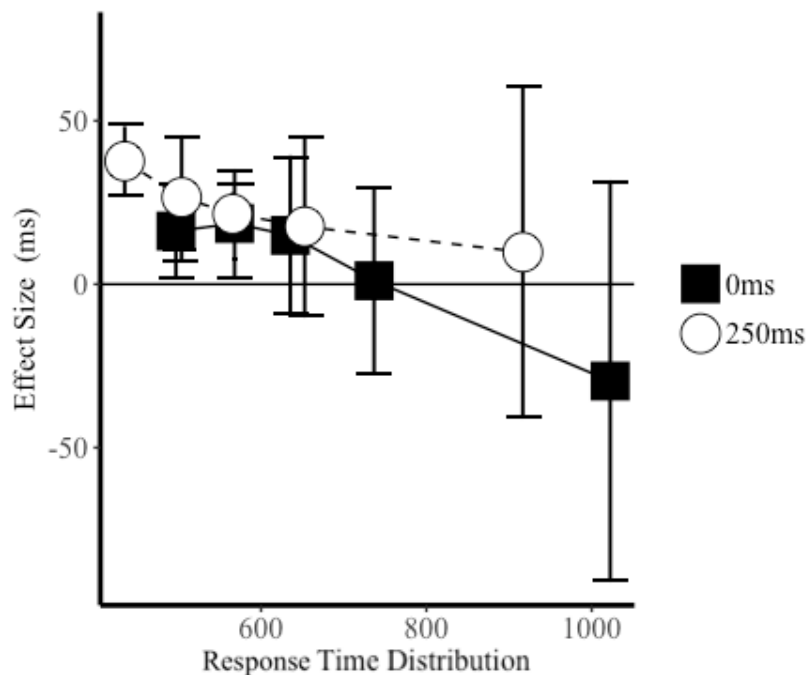
*Figure 2.1.7.* Mean percent error rate in Experiment I as a function of alignment, SOA, and response mode for the key instructions. Error bars represent 95% confidence intervals.

We evaluated the effect of alignment over the response time distribution through delta plots separately for the key instructions and the hand instructions. Participants' response times for aligned trials were sorted from shortest to longest. The same was done for misaligned response times. These times were then separated into five equal-sized bins, called quintiles. The mean was calculated for each quintile and the effect size was calculated by subtracting the mean for an aligned quintile from the mean for the corresponding misaligned quintile (see De Jong, Liang, & Lauber, 1994). The final graphs showed the change in effect size of alignment over the response distribution

broken down by instruction type and response mode. The fourth and fifth quintiles are prone to a large degree of error, so we ran further analysis correcting for violated assumptions of sphericity using Greenhouse-Geisser correction and present those outcomes. For hand instructions with either response mode, the alignment by quintile interaction was not significant (see Figures 2.1.8 and 2.1.9). This means that the alignment effect was flat across the response distribution.

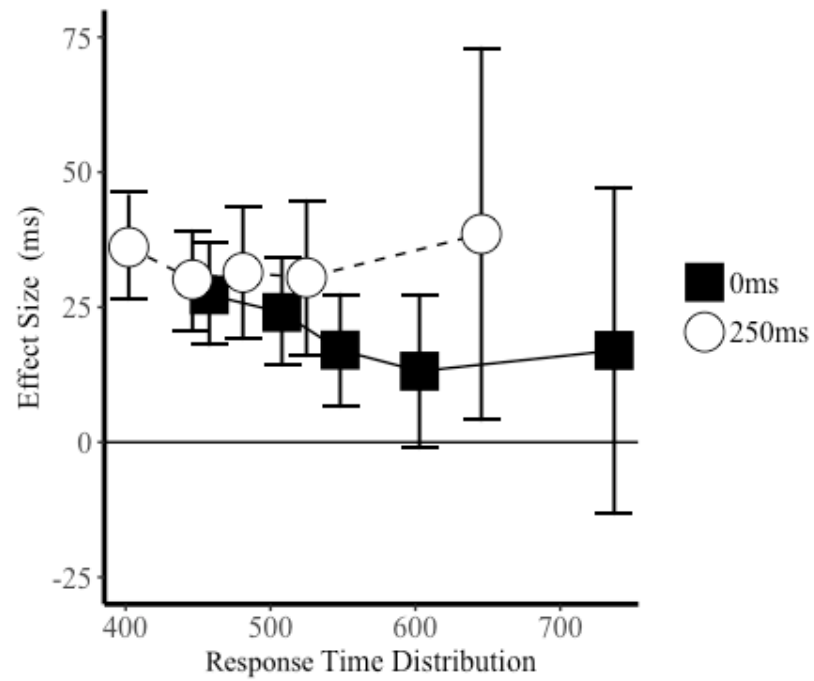


*Figure 2.1.8.* Delta plot of alignment effect size across the response time distribution in Experiment I for the hand instructions with hands straight separated by the 0-ms and 250-ms SOAs. Error bars represent 95% confidence intervals.

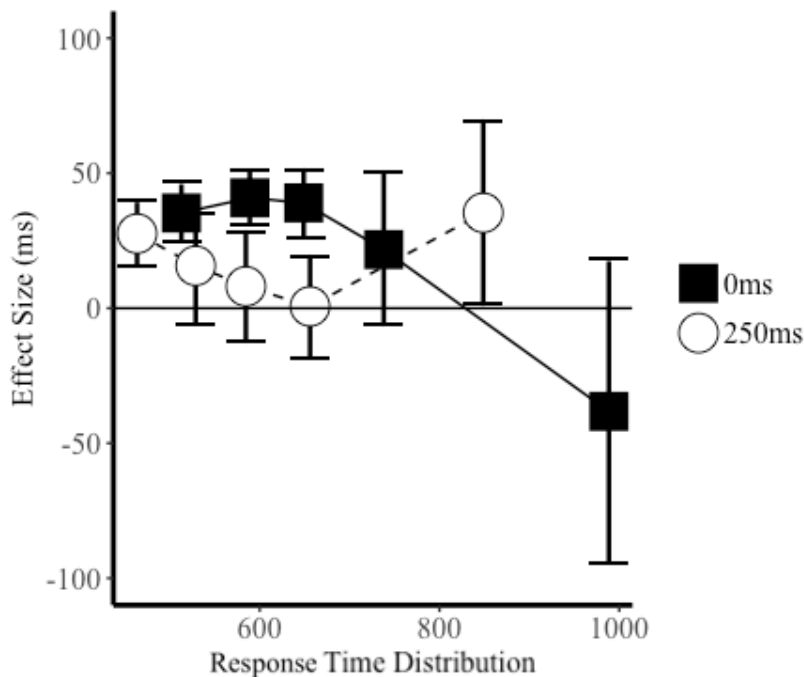


*Figure 2.1.9.* Delta plot of alignment effect size across the response time distribution in Experiment I for the hand instructions with hands crossed separated by the 0-ms and 250-ms SOAs. Error bars represent 95% confidence intervals.

For key instructions with hands straight, the quintile by alignment effect was not significant (see Figure 2.1.10). Again, this non-significant alignment by quintile effect means that the size of the alignment effect did not change over the response time distribution. With hands crossed, a significant quintile by alignment effect was present (see Figure 2.1.11) ( $F[4, 116] = 3.76$ ,  $MSE = 2,817.77$ ,  $p[GG] = .036$ ) and the only significant interaction between quintile, alignment and SOA was present in this condition ( $F[4, 116] = 8.48$ ,  $MSE = 3,768.56$ ,  $p[GG] = .0035$ ). The time course shows a pattern that is different from the crossed hands alignment effect with hand-based instructions; this may be attributed to the spatial influence on response selection with our key-based instructions.



*Figure 2.1.10.* Delta plot of alignment effect size across the response time distribution in Experiment I for the key instructions with hands straight separated by the 0-ms and 250-ms SOAs. Error bars represent 95% confidence intervals.



*Figure 2.1.11.* Delta plot of alignment effect size across the response time distribution in Experiment I for the key instructions with hands crossed separated by the 0-ms and 250-ms SOAs. Error bars represent 95% confidence intervals.

The results from this first experiment demonstrated that asking participants to respond with the key that matched the laterality of the depicted hand versus the hand that matched the laterality of the depicted hand did not impact the presence of the alignment effect, but it did impact the temporal dynamics of the effect. With straight hand responses, it is not possible to differentiate between spatial and limb-based effects and indeed, regardless of instruction type, we see a positive alignment effect at both SOAs that is stable across the response distribution. With crossed hands, however, there is a clear difference in the nature of the alignment effect between the two instruction types.

The overall pattern of results, which we will shortly discuss in more detail, certainly provides relevant evidence against the idea that the effect of alignment on left/right keypress responses is only due to the perceptual relationship between the

depicted object and the grasp posture. Good evidence differentiating between the effects of SS and SR compatibility can also be found by looking at the temporal dynamics of these two effects. First, we note that Lupiáñez & Funes (2005) have argued that S-S compatibility effects driven by spatial codes depend on the perceptual integration of the task-irrelevant features of the stimulus ensemble and the task-relevant features. At a longer SOA of 250 ms, this integration would not take place, substantially limiting the influence of S-S compatibility on the correspondence effect induced by the handle of a depicted object.

Kornblum, Stevens, Whipple, and Requin (1999) found a clear difference in the temporal dynamics of SR and SS compatibility effects. These authors varied the stimulus-onset asynchrony (SOA) from 0 ms to 800 ms between the task-irrelevant attributes of a stimulus ensemble and the task-relevant dimension. They developed experimental conditions allowing them to separately track the time course of S-R and S-S compatibility effects across these different SOAs. The effect of S-S compatibility (based on Stroop-like color/word interference) increased over time, reaching a maximum at an SOA between 200 and 400 ms, before diminishing as the SOA was extended beyond this interval to 800 ms. Crucially, however, the effect of S-R compatibility proved much less durable, decreasing rapidly as soon as an SOA greater than 0 ms intervened between the irrelevant and relevant features of the stimulus ensemble. Distributional analyses of response time (delta plots) confirmed the limited duration of effects driven by S-R compatibility. At an SOA of 0 ms, this effect increased across the response-time distribution. The insertion of even a short delay (100 or 200 ms), however, between the

task- irrelevant and relevant features of the display led to a progressive reduction in the magnitude of the S-R compatibility effect across response-time bins.

When we consider the temporal dynamics of our effects, the effects we see also tend to decrease across the RT distribution, especially at the longer SOA.

SR correspondence effects are moreover apparent in the discrepant temporal dynamics of the alignment effect under hand- versus key-based instructions for responses made with crossed hands. The alignment effect for crossed hands under hand-based instructions is hardly apparent at an SOA of 0 ms but emerges clearly at an SOA of 250 ms. In contrast, under key-based instructions a robust alignment effect is observed at both SOAs. The delta plot at the 250-ms SOA has an unusual form; the magnitude of the alignment effect diminishes systematically across the first four quintiles and then increases substantially at the last quintile. What accounts for these diverse results?

We introduce the following two assumptions to account for the discrepant effects of the object on left/right keypress responses under key- versus hand-based instructions. First, we assume that keypress responses to the laterality of a grasp posture can be based either (a) on a direct mapping between a left/right classification of the hand and the corresponding location of a key (the depiction of a right hand enlists a right-sided keypress), or (b) a mapping between the laterality of the depicted hand and the corresponding limb of the observer. For responses made with crossed hands and key-based instructions, the image is mapped directly to the corresponding key; i.e. the depiction of a right-handed grasp posture is mapped directly to a right-sided keypress response made with the left hand. Hand-based instructions require a mapping to the

opposite key; the image of a right-hand enlists the right hand assigned to a left-sided keypress.

Our second assumption is that the handle of the depicted object automatically triggers both key-based and limb-specific responses, yielding distinct SR correspondence effects with different time courses. Thus, an object depicted with the handle on the right quickly triggers the selection of a right-sided keypress (made with the left hand for crossed hands), along with a slower right-handed response (left-sided keypress for crossed hands). The spatial impact of the handle on response selection is rapid and persists, while the limb-specific effect accrues more slowly and fades over time.

Now consider how this framework accounts for the discrepant alignment effects of the object on responses under different mapping instructions. When responses to the laterality of a grasp posture are hand-based, the image of a right hand requires a keypress with the corresponding limb; the right hand of the observer is assigned to a left-sided keypress. We can think of the assignment between the grasp posture and a keypress response as being directly analogous to the effect of a reverse mapping between arrow direction and the response in a spatial Stroop task. For example, responding to an arrow pointing to the left with a right-sided keypress yields much weaker effects of arrow location on left/right keypress responses (Lupiáñez & Funes, 2005).

We likewise see no alignment effect at an SOA of 0 ms when keypress responses are assigned to a key that is spatially incompatible with the laterality of a depicted grasp posture. The absence of any effect is due to the same principle that accounts for the marked reduction in the spatial Stroop effect when responses are incompatibly mapped to the direction of an arrow: any impact of SS compatibility between say, a right-handed

grasp posture superimposed on an object with the handle on the right is counteracted by the SR incompatible relationship between the side of the handle and the left-sided position of the intended keypress response.

At a longer SOA of 250 ms, enough time has elapsed for the handle of the depicted object to automatically trigger a limb-specific response. An object appearing with the handle on the right, for example, now automatically evokes a response with the corresponding hand assigned to a left-sided keypress. The combination of a right-handed grasp posture and an object depicted with the handle on the right is SS compatible, but is also SR compatible with a right-handed keypress response. The result is that alignment effects are clearly apparent, driven by a limb-specific correspondence between the handle of the object and the laterality of the hand assigned to a keypress response.

Applying the same set of assumptions to the alignment effects under key-based instructions, the laterality of the depicted grasp posture is now directly assigned to a corresponding key (e.g. the image of a left hand requires a left-sided keypress, made by the right hand in the crossed-hands condition). The assumption that observers can directly map the laterality of the hand to the location of the keypress is in keeping with the fact that responses under key-based instructions are no slower nor more error-prone than responses under hand-based instructions. If the depicted grasp posture (say a right hand) was obligatorily mapped first to the corresponding limb (i.e. the right hand assigned to a left-sided keypress) and then via a reverse mapping to a right-sided keypress response, we should have observed a difference in the speed and accuracy of performance given key- versus hand-based instructions. The fact that no such difference occurred is

consistent with our assumption that key-based instructions depended on a direct mapping between the laterality of a grasp posture and the location of a keypress response.

The image of a right-handed grasp posture is assigned directly to a right-sided keypress response (made with the left hand). Recall that the task-irrelevant handle of the depicted object is assumed to rapidly generate a spatial correspondence effect on the selection of a left/right-sided keypress response, followed by a slower, less durable limb-specific effect on the selection of response made with the left versus right hand. It follows that at a short SOA, an object shown with a handle on the right is both SS compatible with the image of a right-handed grasp posture and SR compatible with a right-sided keypress response (even though the left hand is assigned to this key under crossed-hand responding). The result is that a clear alignment effect occurs at the 0-ms SOA whereas none was observed when laterality judgments depended on hand-based instructions.

At the longer SOA of 250 ms under key-based instructions, the depicted object automatically triggers a limb-specific correspondence effect driven by the relationship between the side of the handle and laterality of the responding hand. This effect is once again in conflict with the intended keypress responses on SS compatible trials; an object with the handle on the right triggers a keypress response with the right hand assigned to the left key. This response is in opposition to the intended right-sided keypress to the image of a right-handed grasp posture. Limb-specific effects oppose the spatial effects of the handle on keypress responses made with crossed hands. The net result will be a substantial weakening of the alignment effect as the limb-specific influence gains in strength over the spatial effect driven by the correspondence between the side of the handle and the location of the keypress response. Indeed, the second, third and fourth

quintiles show no reliable alignment effects at an SOA of 250 ms, but a surprising re-emergence of a substantial effect for the slowest quintile. This result makes sense given the assumption that limb-specific effects take some time to accrue before fading away; as they grow in strength, they compete with the spatial effect of the handle on responses made with crossed hands under key-based instructions. For the slowest responses (i.e. the fifth quintile), these limb-based effects have dissipated, allowing the reappearance of the spatial effects induced by the handle on left/right-sided keypress responses.

## 2.2 Experiment II

We have replicated the results obtained by van Noordenne (2017) indicating that limb-specific codes, triggered by the image of a graspable object, can affect the selection of a left/right-handed keypress with either response mode. In our first experiment, the response apparatus was horizontally aligned in both conditions. Our goal in a second experiment was to remove any visuo-spatial compatibility between the responses and the stimuli. We achieved this by vertically orienting the response box. This is an interesting manipulation because any spatial compatibility between the left/right location of the handle and the positioning of the keys no longer can play a role in the observed correspondence effects. Any limb-specific influence of the handle on keypress responses should still occur when the response box is vertically oriented.

### 2.2.1 Method

**Subjects.** Forty-three subjects completed this experiment to receive extra credit in their undergraduate psychology courses. Seven of the subjects were male and three subjects were left-handed. Subjects had an average age of 21.42 years (standard deviation  $\pm$  4.29 years).

**Materials.** The materials used in this experiment were identical to those in the first experiment, except the Cedris button box was vertically oriented (see Figure 2.2.1).



*Figure 2.2.1.* Laboratory setup for Experiment II

**Design.** The design of this experiment was identical to the design of the first experiment, except in one block participants had their right hand on the top button and left hand on the bottom button of the button box. In the other block, the hand position was reversed. Block order was counterbalanced between participants. Our critical factors were alignment (comparing handle side and hand laterality), orientation (comparing handle position and hand position), response mode (right hand top or left hand top), block order, and SOA (0 ms and 250 ms).

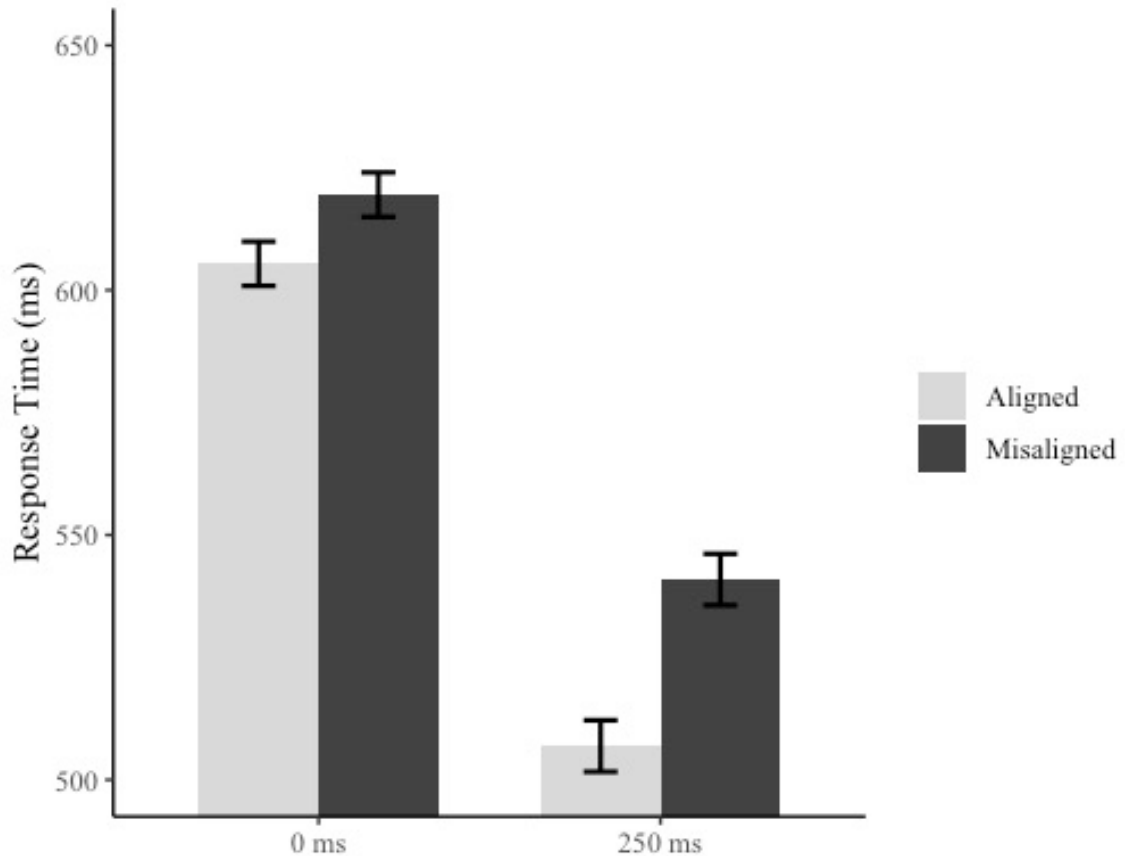
**Procedure.** The procedure for Experiment II was identical to that of Experiment I, except we only had one set of instructions. Participants simply responded with the hand that matched the laterality of the hand shown in the image. There were no changes made to the format of the trials or trial numbers.

### 2.2.2 Results and Discussion

The mean percent accuracy for keypress classification of the hands was approximately 98.6%. For identification of the object, the mean percent accuracy was approximately 98.8%. Data from 42 subjects were used for the analysis, as one was removed to have an equal number of subjects in each counterbalanced condition.

Like the exclusion criteria from Experiment I, we excluded response times shorter than 100 ms and longer than 1,400 ms from the data.

We computed an analysis of variance (ANOVA) for the factors of alignment, SOA, orientation, response mode, and block order as repeated-measures (see Figure 2.2.2 for mean response times). Like Experiment I, neither block order or orientation showed a significant main effect and the interactions did not provide further insight to our results, so we did not include these in the main results section and they can be found in Appendix A.



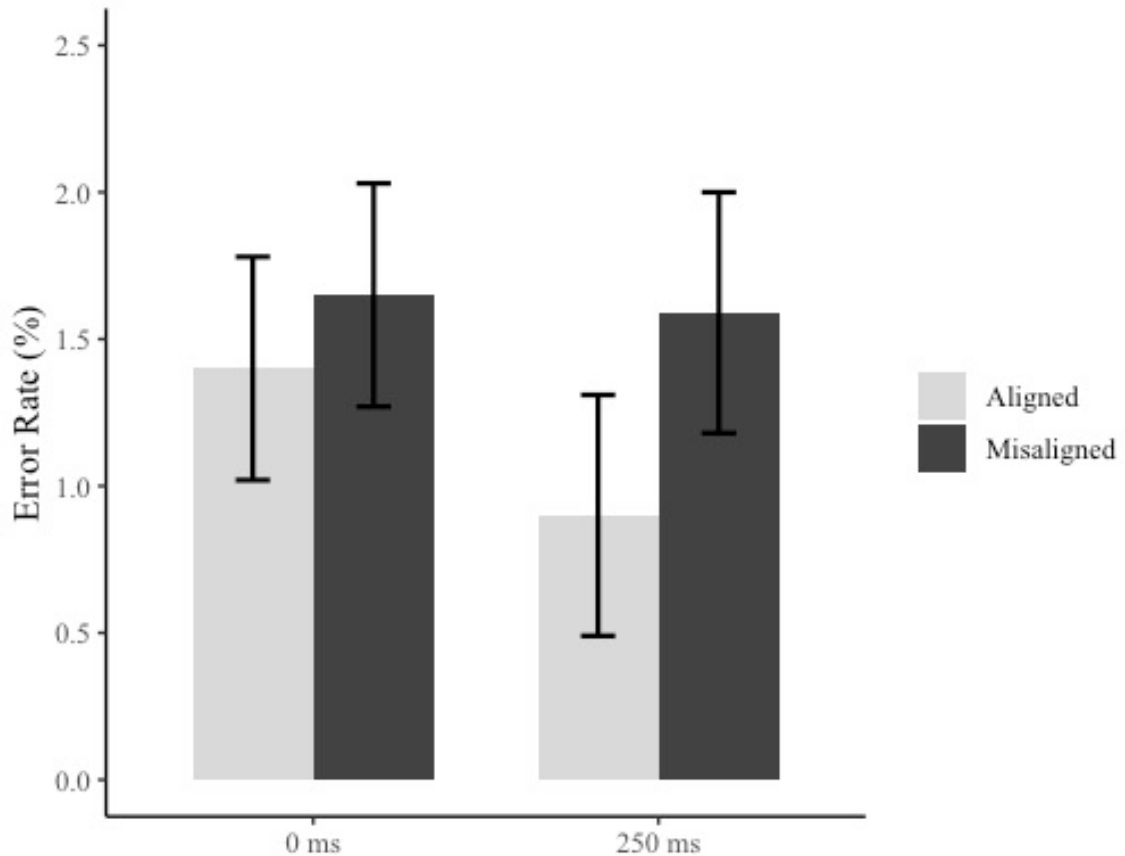
*Figure 2.2.2.* Mean response times in Experiment II as a function of alignment and SOA. Error bars represent 95% confidence intervals.

Response times showed a significant main effect of alignment ( $F[1, 40] = 92.40$ ,  $MSE = 513$ ,  $p < .001$ ). Participants made faster responses on aligned trials. There was also a significant effect of SOA ( $F[1, 40] = 454.28$ ,  $MSE=1,447$ ,  $p < .001$ ). Results showed faster responses in the 250-ms SOA condition.

There was a significant interaction between alignment and SOA ( $F[1, 40] = 15.11$ ,  $MSE = 521$ ,  $p < .001$ ). With a 0-ms SOA, there was an alignment effect of 14.1 ms and for the 250-ms SOA the effect size was 33.5 ms. There was also a significant response time by alignment effect ( $F[1, 41] = 5.40$ ,  $MSE = 203.20$ ,  $p < .026$ ) (see Table 1 in

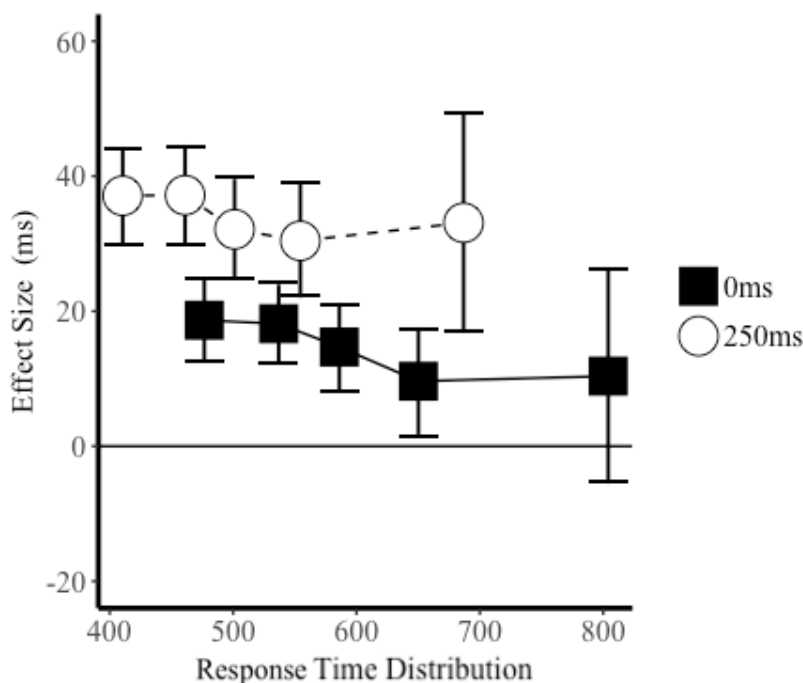
Appendix B). The alignment effect was slightly bigger when the right hand responded on the top button. However, there was also a significant interaction between alignment, response mode, and block order ( $F[1, 41] = 7.06$ ,  $MSE = 203.20$ ,  $p < .011$ ). The alignment effect size was about 20 ms in all conditions (left hand top and right hand top when the right hand top block was first, as well as the left hand top when the left hand top block was first) except when the right hand responding on the top button was in the second block; the effect size in this case was about 34 ms. As the alignment effect was not eliminated nor did it become negative, our results though quantitatively different are not qualitatively different with the two different response modes.

With respect to error rates, error rate was slightly higher on trials with the 0-ms SOA (see Figure 2.2.3) ( $F[1, 40] = 4.24$ ,  $MSE = 1.73$ ,  $p = .046$ ).



*Figure 2.2.3.* Mean percent error in Experiment II as a function of alignment and SOA. Error bars represent 95% confidence intervals.

We evaluated the effect of alignment over the response time distribution. There was no effect of quintile on alignment effect size (see Figure 2.2.4). This indicates that the effect of alignment was flat across the distribution of responses.



*Figure 2.2.4.* Delta plot of alignment effect size across the response time distribution in Experiment II separated by the 0-ms and 250-ms SOAs. Error bars represent 95% intervals.

In this experiment, there was no longer any left/right compatibility between the position of the keys and handle of the depicted object, as the response box was vertically orientated. These results converge with those of the first experiment providing evidence for limb-specific effects.

### 2.3 Experiment III

In our first two experiments, we showed effects that are limb-specific in addition to spatial effects due to the spatial compatibility between the stimuli and the responses. Our third experiment was designed to show that the combination of grasp posture and depicted object generates codes that are not present when the same object is combined with another cue that also automatically evokes a left/right response. In van Noordenne's

(2017) second experiment, she looked at the alignment effect when the imperative stimulus of the hand was replaced with an arrow. She showed a reversal of the alignment effect. Participants were faster at responding when the arrow was pointing away from the handle and responding with the hand aligned with the spout (the hand that was responding was not the one they would have used to act on the handle of the object).

We used this same imperative stimulus of an arrow, which has very clear spatial features and is unambiguous in its directionality. The current experiment, unlike Van Noordenne's work, is a within-subjects design; the imperative stimulus in one block is a hand and in the other block is an arrow. Our goal in this experiment is to establish that the presence of limb-based effects require specific task conditions that are not captured by a generic spatial cue.

### 2.3.1 Method

**Subjects.** Thirty-five subjects (eight males and two left-handed) completed this experiment to receive extra credit in their undergraduate psychology courses. Subjects had an average age of 21.63 years (standard deviation  $\pm$  4.47 years).

**Materials.** The materials used in this experiment were identical to those in the first experiment, with one exception. In one of the two blocks, two images of arrows (right or left) were the imperative stimuli instead of images of hands (see Figure 2.3.1).



*Figure 2.3.1.* Example of stimuli used in Experiment III

**Design.** The design of the third experiment was identical to the design of the first experiment, except in one block participants would view images of hands superimposed over the objects and in the other, arrows superimposed over the objects. Block order was counterbalanced between participants. Our critical factors were alignment (comparing handle side and hand laterality or arrow direction), orientation (comparing handle position and hand position in hand block), block order, imperative stimulus (arrow or hand) and SOA (0 ms and 250 ms).

**Procedure.** The procedure for Experiment III was similar to that of Experiment I, but only straight hand responding was used. Participants were instructed to respond with a keypress using the hand that matched the hand shown in the image in one block and respond with a keypress to the direction of the arrow in the other block. If the arrow pointed left, press the left key and if the arrow pointed right, press the right key.

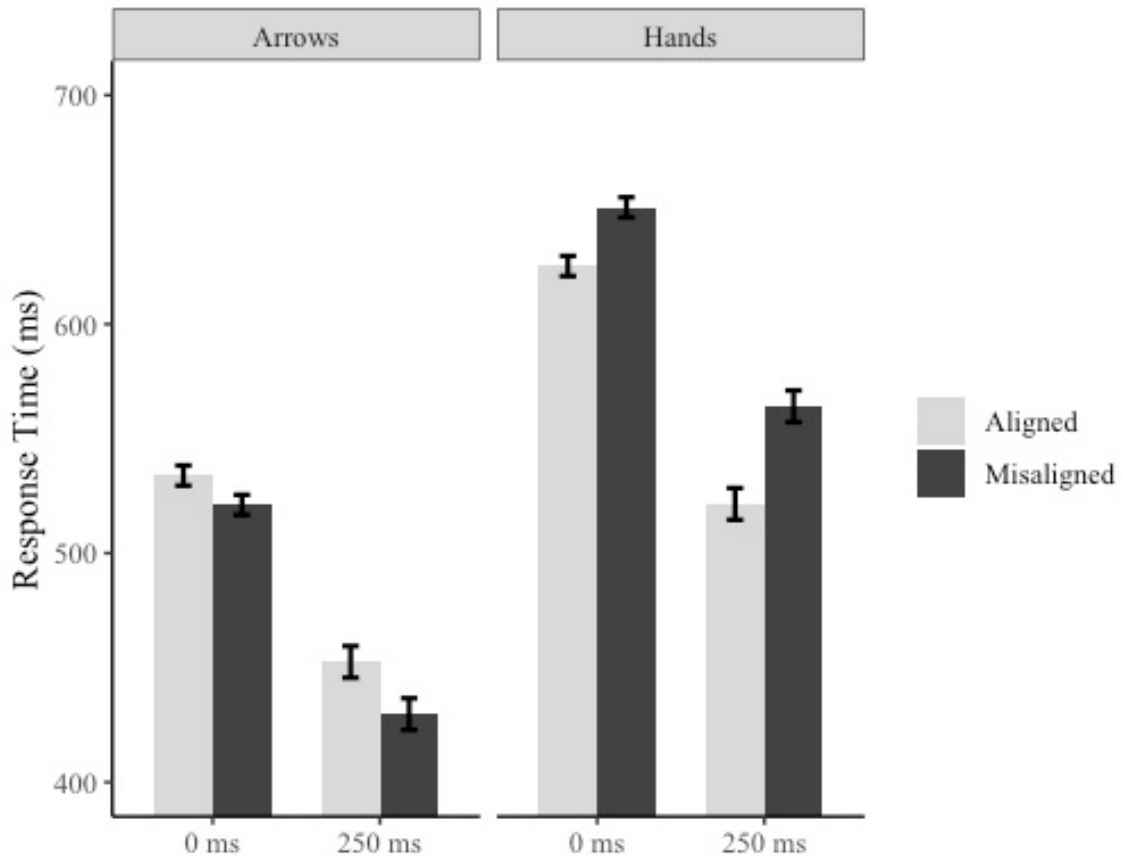
### 2.3.2 Results and Discussion

The mean percent accuracy for keypress classification of the hands and arrows was approximately 97.2%. For identification of the object, the mean percent accuracy

was approximately 97.4%. We removed one subject from the analysis, as their error rate for keypress classification of hands was 100%. Data from the remaining 34 subjects were analyzed.

Like the exclusion criteria from Experiment I, we excluded response times shorter than 100 ms and longer than 1,700 ms from the data.

We computed an analysis of variance (ANOVA) for the factors of alignment, SOA, imperative stimuli, and block order as repeated-measures (see Figure 2.3.2 for mean response times). Like the previous two experiments the factor of block order provided little meaning to the results and is not included in the main results, but we have provided significant block order effects in Appendix A.



*Figure 2.3.2.* Mean response times in Experiment III as a function of alignment, SOA, and imperative stimulus. Error bars represent 95% confidence intervals.

Response times showed a significant main effect of alignment ( $F[1, 32] = 11.10$ ,  $MSE = 398$ ,  $p = .0022$ ). Participants made faster responses on aligned trials. There was also a significant effect of SOA ( $F[1, 32] = 307.66$ ,  $MSE = 1,821$ ,  $p < .001$ ). Results showed faster responses in the 250-ms SOA condition. We also found a main effect of imperative stimulus ( $F[1, 32] = 90.06$ ,  $MSE = 8,507$ ,  $p < .001$ ). Responses were faster when the imperative stimulus was an arrow.

There was a significant interaction between alignment and imperative stimulus ( $F[1, 32] = 68.79$ ,  $MSE = 662$ ,  $p < .001$ ). The alignment effect was positive when the

imperative stimulus was a hand and negative when the imperative stimulus was an arrow. With arrows, misaligned trials were faster than aligned trials. A significant three-way interaction between alignment, SOA, and imperative stimuli was present ( $F[1, 32] = 4.58$ ,  $MSE = 677.10$ ,  $p = .040$ ).

With respect to error rates, there was an interaction between alignment and SOA (see Figure 2.3.3) ( $F[1, 32] = 31.76$ ,  $MSE = 3.87$ ,  $p = .0074$ ). There was a significant interaction between SOA and imperative stimulus ( $F[1, 32] = 6.85$ ,  $MSE = 2.85$ ,  $p = .013$ ); more errors were made on trials at the 0-ms SOA in the hand block and more errors were made on trials at the 250-ms SOA in the arrow block.

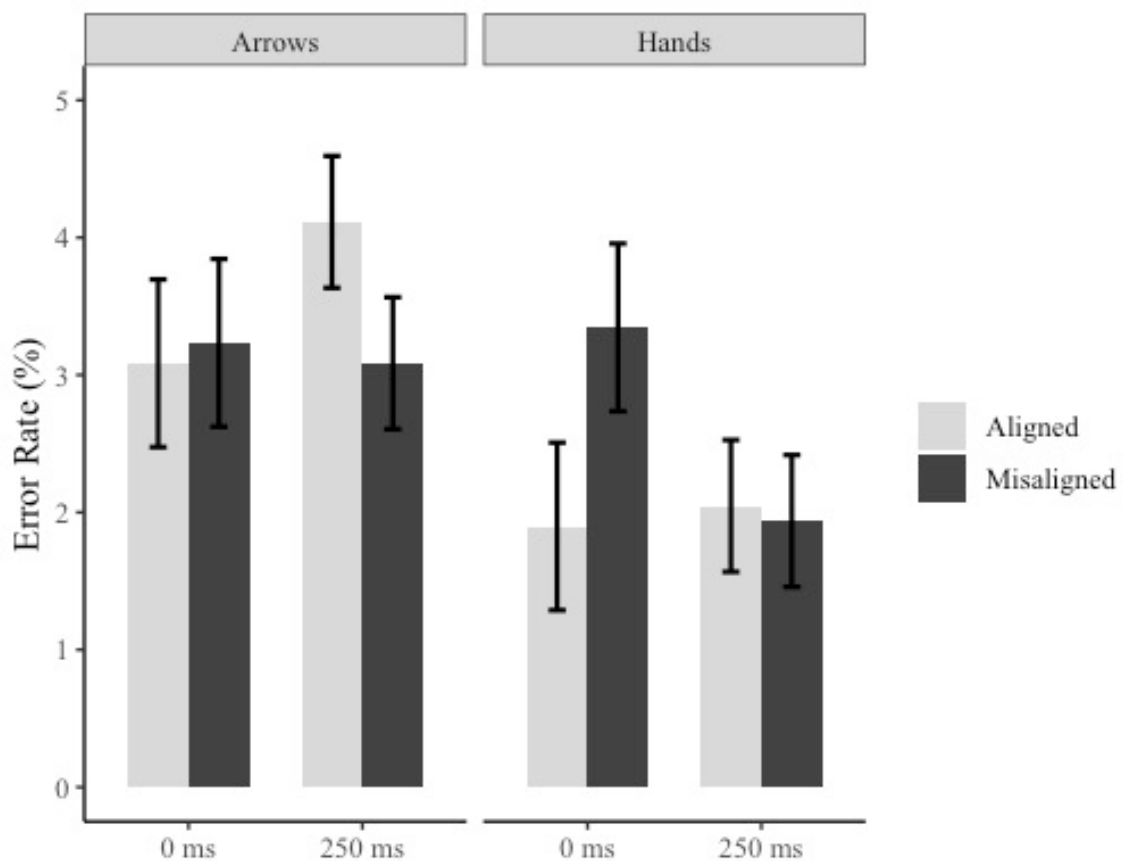
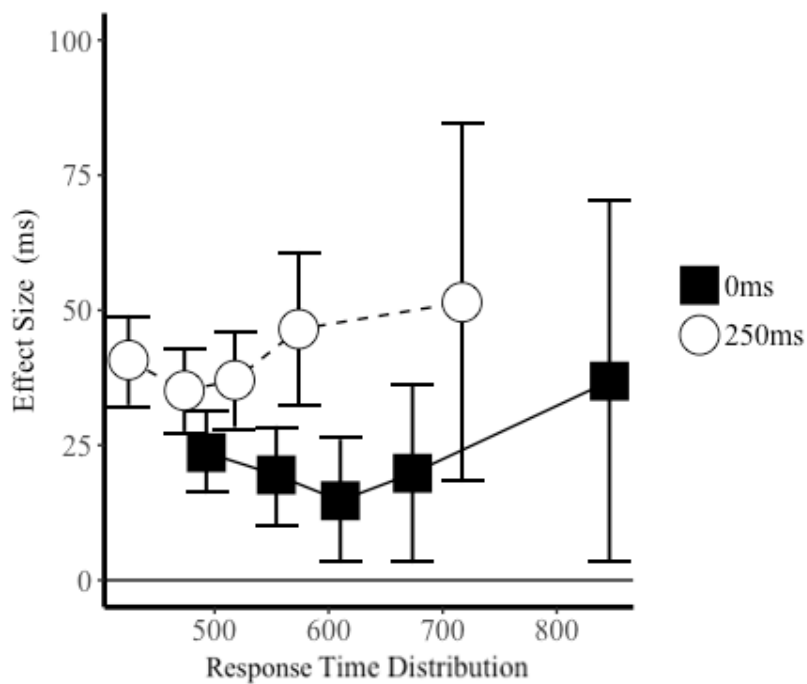
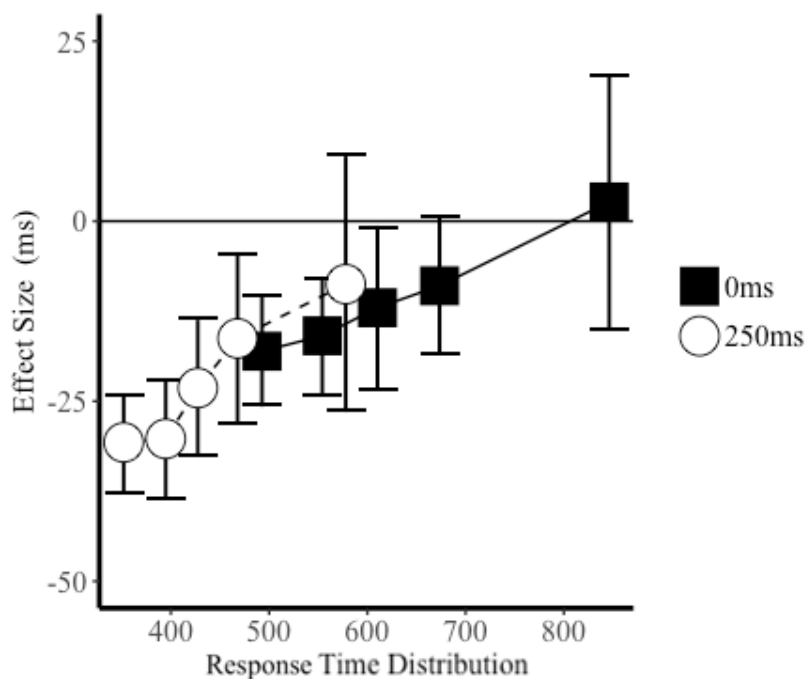


Figure 2.3.3. Mean percent error in Experiment III as a function of alignment, SOA, and imperative stimulus. Error bars represent 95% confidence intervals.

The effect of alignment was evaluated for the arrow and hand block separately over the response time distribution (see Figures 2.3.4 and 2.3.5). In the hand block, there was no effect of quintile on alignment effect size. This indicates that the effect of alignment was flat across the distribution of responses.



*Figure 2.3.4.* Delta plot of alignment effect size across the response time distribution for hand trials in Experiment III separated by the 0-ms and 250-ms SOAs. Error bars represent 95% confidence intervals.



*Figure 2.3.5.* Delta plot of alignment effect size across the response time distribution for arrow trials in Experiment III separated by the 0-ms and 250-ms SOAs. Error bars represent 95% confidence intervals.

For the arrow block, there was a significant alignment by quintile interaction ( $F[4, 128] = 7.83$ ,  $MSE = 636.88$ ,  $p[GG] = .0014$ ). The magnitude of the alignment effect size decreased across the response distribution. An initial effect size of -24.4 ms decreased to -3 ms in the last quintile.

Results from the hand block of this experiment replicate the first two experiments. The results from the arrow block of this experiment directly confirm the results found by van Noordenne (2017) in her second experiment. The reversal of the alignment effect in the arrow block supports the idea that the presence of a hand alters how attention is directed to the object. Classifying the laterality of a grasp posture directs attention to the handle of a depicted object. Classifying the direction of an arrow directs attention to spatially prominent feature of the object, in this case the spout of a teapot or the base of a

frying pan.

In our previous experiments, the response distribution of the alignment effect induced by laterality judgments to hands was flat. For the arrow block, we see a decreasing effect size across quintiles. The alignment effect across the distribution of reaction times for arrows revealed the same trend seen by van Noordenne (2017). These outcomes provide further evidence that judging the laterality of a hand superimposed on the image of a graspable object triggers qualitatively different correspondence effects on keypress responses when compared to judging the direction of an arrow.

## 2.4 Experiment IV

All of the experiments we have already discussed have had an object probe on 20% of trials. In other words, on a subset of trials we asked participants to explicitly identify the object that in other respects was task-irrelevant. Participants were never asked to judge the relationship between the object and the hand. Nevertheless, it is important to establish the impact of requesting observers to attend and identify a depicted object on the effects that we have seen in our previous experiments. Here, we have removed the additional requirement of responding to an object probe. The question of interest is whether the omission of this requirement alters the profile of the effects induced by the object.

### 2.4.1 Method

**Subjects.** Thirty-six subjects (eight males and two left-handed) completed this experiment to receive extra credit in their undergraduate psychology courses. Subjects had an average age of 21.00 years (standard deviation  $\pm$  3.75 years).

**Materials.** The materials used in this experiment were identical to those in Experiment I.

**Design.** The design of Experiment IV was identical to the design of Experiment I. The factors were alignment (comparing handle side and hand laterality), orientation (comparing handle position and hand position), block order, response mode (straight or crossed hands) and SOA (0 ms and 250 ms).

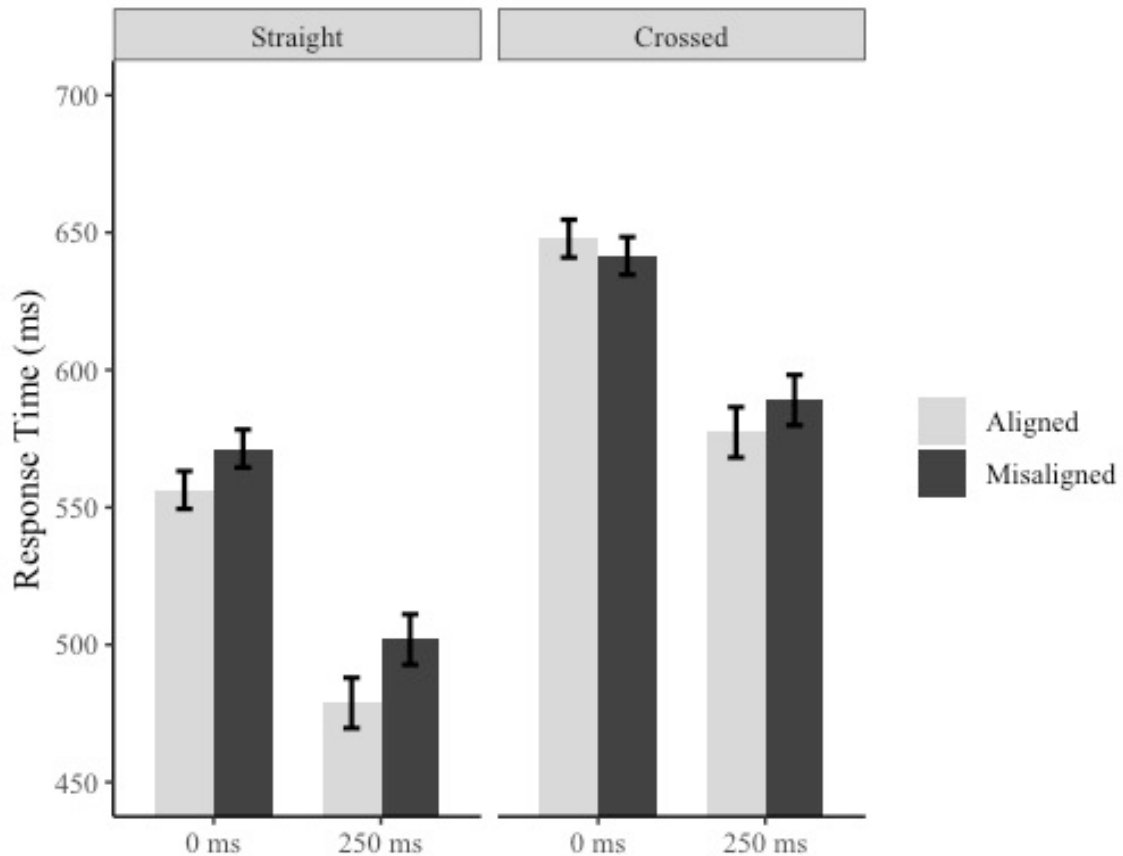
**Procedure.** The procedure for the fourth experiment was identical to Experiment I, but participants were never probed for the identity of the object. In Experiment I, they were probed for the object 20% of the time. One set of instructions was also removed (key-based). Participants were simply told to respond with the hand that matched the laterality of the hand on the screen, not the key.

#### 2.4.2 Results and Discussion

The mean percent accuracy for keypress classification of the hands was approximately 97.9% for straight hands and 96.9% for crossed hands. Two subjects were removed from the analysis, as one had an error rate of 100% for keypress classification of the hands. We removed the other subject so we had an equal number of subjects in our two counterbalanced conditions. Data from the remaining 34 subjects were analyzed.

Like the exclusion criteria from Experiment I, we excluded response times shorter than 100 ms and longer than 2,100 ms from the data.

We computed an analysis of variance (ANOVA) for the factors of alignment, SOA, and response mode as repeated-measures (see Figure 2.4.1 for response time means). Block order and orientation effects can be found in Appendix A.



*Figure 2.4.1.* Mean response times in Experiment IV as a function of alignment, SOA, and response mode. Error bars represent 95% confidence intervals.

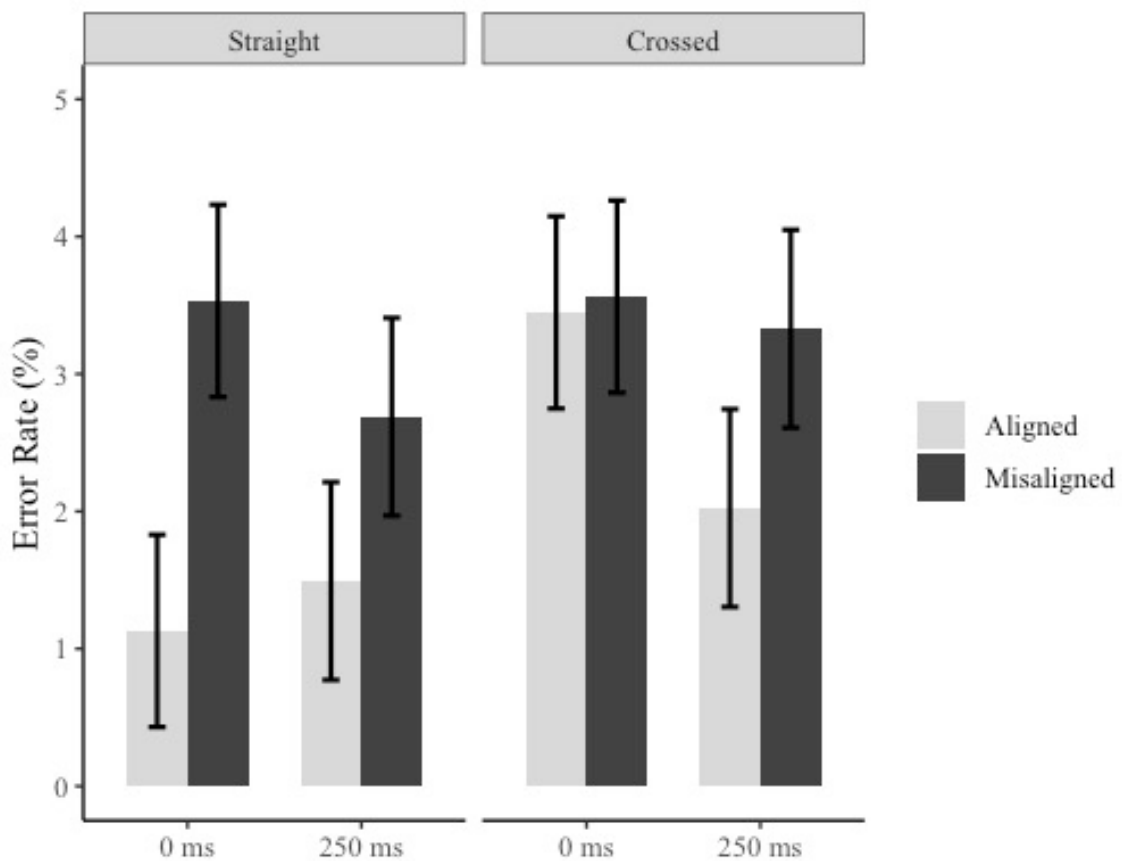
There was a main effect of alignment ( $F[1, 34] = 5.10$ ,  $MSE = 6,518$ ,  $p < .03$ ), SOA ( $F[1, 34] = 200.50$ ,  $MSE = 6,364$ ,  $p < .001$ ), and response mode ( $F[1, 34] = 42.75$ ,  $MSE = 49,353$ ,  $p < .001$ ). There were two significant interactions; one between alignment and SOA ( $F[1, 34] = 4.953$ ,  $MSE = 2,392$ ,  $p < .033$ ) and one between alignment and response mode ( $F[1, 34] = 5.109$ ,  $MSE = 3,684$ ,  $p < .03$ ).

For straight hands, response times showed a significant main effect of alignment ( $F[1, 32] = 18.13$ ,  $MSE = 1,393$ ,  $p < .001$ ). Participants made faster responses on aligned trials. There was also a significant effect of SOA ( $F[1, 32] = 160.38$ ,  $MSE = 2,348$ ,  $p <$

.001). We saw the same trend as in the previous three experiments; faster responses were made on trials with the 250-ms SOA.

For crossed hands, there was only a significant effect of SOA ( $F[1, 32] = 109.20$ ,  $MSE = 2,329$ ,  $p < .001$ ). Response times showed the same trends as previously found. The main effect of alignment was not significant.

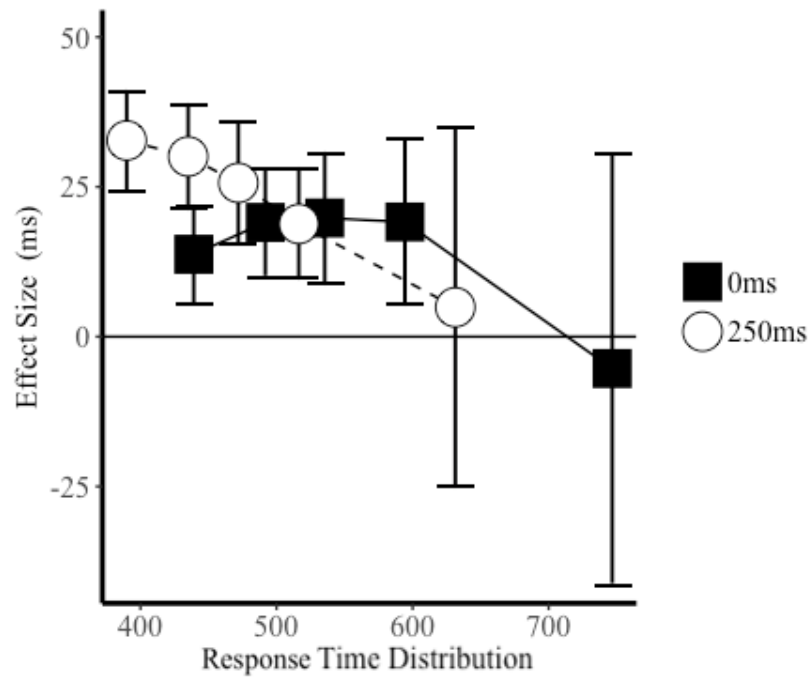
Error rates for straight hands showed only an effect of alignment (see Figure 2.4.2) ( $F[1, 32] = 9.28$ ,  $MSE = 23.46$ ,  $p = .0046$ ). Slightly more errors were made on misaligned trials.



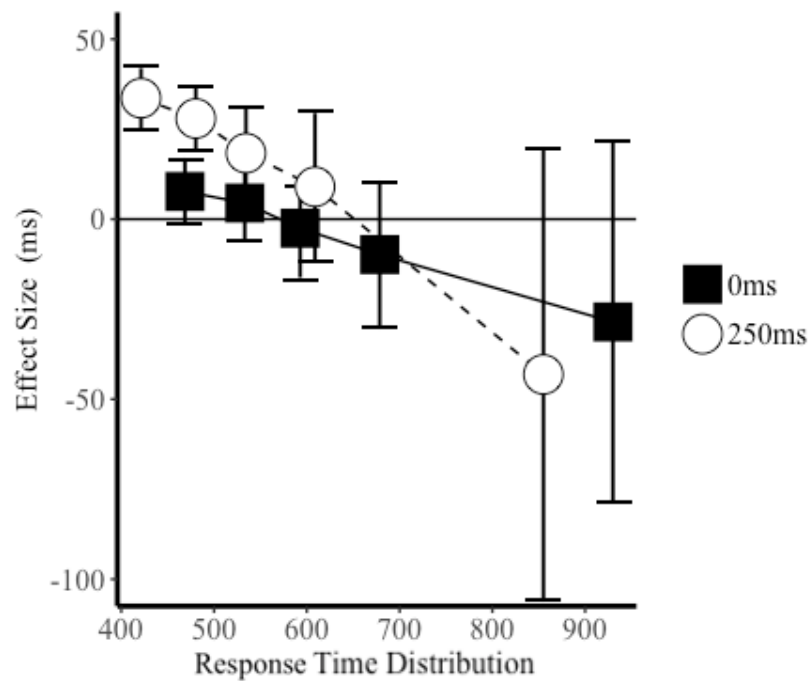
*Figure 2.4.2.* Mean percent error in Experiment IV as a function of alignment, SOA, and response mode. Error bars represent 95% confidence intervals.

There were no effects of alignment or SOA on the error rates in the crossed hand responding block.

We evaluated the effect of alignment for the straight hands responding and crossed hands responding blocks separately over the response time distribution (see Figures 2.4.3 and 2.4.4). With the straight hands block, there was an interaction between quintile and alignment effect size ( $F[4, 136] = 3.98$ ,  $MSE = 1,864.23$ ,  $p[GG] = .043$ ). Effect size of alignment decreased across the distribution of responses. For crossed hands responding, there was also a significant alignment by quintile interaction ( $F[4, 136] = 7.73$ ,  $MSE = 5,181.17$ ,  $p[GG] = .005$ ). The alignment effect size decreased across the response distribution, with no effect in the fourth quintile and a reversal of the alignment effect in the fifth quintile.



*Figure 2.4.3.* Delta plot of alignment effect size across the response time distribution for straight hands trials in Experiment IV separated by the 0-ms and 250-ms SOAs. Error bars represent 95% confidence intervals.



*Figure 2.4.4.* Delta plot of alignment effect size across the response time distribution for crossed hands trials in Experiment IV separated by the 0-ms and 250-ms SOAs. Error bars represent 95% confidence intervals.

The evidence indicates that requiring participants to attend to and identify the object on 20% of trials boosted the alignment effect, especially for longer response times. By removing this requirement, we could see an alignment effect in the faster responses of the response time distribution in the crossed hands block, along with a diminution of this effect for slower responses. The net outcome was an overall null effect of alignment on responses made with crossed hands. The presence of an alignment effect confined to faster responses is of great theoretical interest. We looked to replicate this result and determine what happens to the reversal when we add more power by only using one response mode. Our follow-up experiment allowed us to determine whether the object probe simply helped to enhance the limb-based effects and decrease the influence of spatial effects in the second half of the response time distribution.

## 2.5 Experiment V

The fifth experiment is an attempt to confirm the results of Experiment IV.

When the object probe was removed, the alignment effect in the crossed hands condition was no longer significant. However, there was a statistically significant decrease in the alignment effect across the response time distribution; positive effects were seen for faster responses while more negative effects were seen for slower responses, although this reversal was not statistically significant. In the next experiment we wish to confirm this outcome by adding more power to our statistical analysis and only using crossed hand responses.

### 2.5.1 Method

**Subjects.** Thirty-six subjects (eight males and three left-handed) completed this experiment to receive extra credit in their undergraduate psychology courses. Subjects had an average age of 21.31 years (standard deviation  $\pm$  3.40 years).

**Materials.** The materials used in this experiment were identical to those in the fourth experiment.

**Design.** The design of this experiment was similar to Experiment IV, except we required only one response mode for this experiment, crossed hands. The factors were alignment (comparing handle side and hand laterality), orientation (comparing handle position and hand position), block order, and SOA (0 ms and 250 ms).

**Procedure.** The procedure for Experiment V was very similar to that of Experiment IV. Participants were instructed to cross their hands and respond with the hand that matched the hand shown in the image. Like Experiment IV, participants were

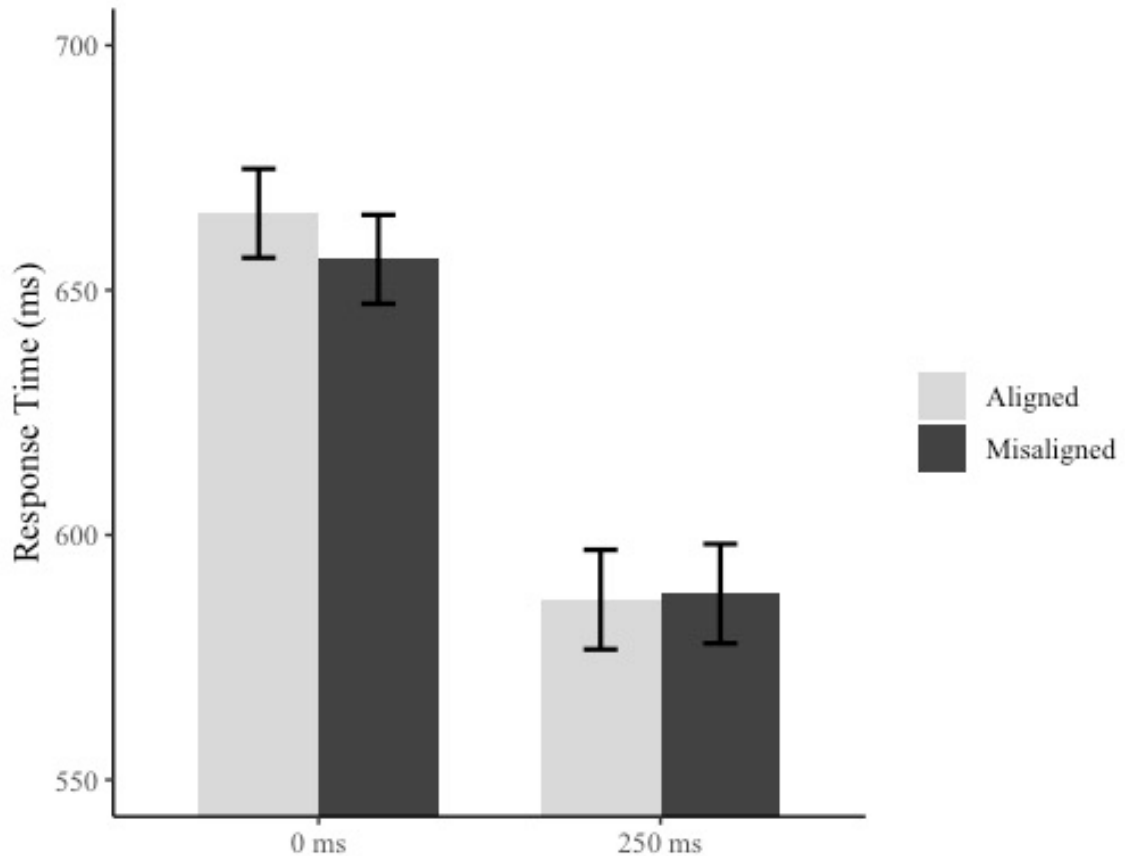
not asked which object was just shown in 20% of trials.

### **2.5.2 Results and Discussion**

The mean percent accuracy for keypress classification of the hands was approximately 97.4%. We analyzed data from all 36 subjects.

Like the exclusion criteria from Experiment I, we excluded response times shorter than 100 ms and longer than 2,300 ms from the data.

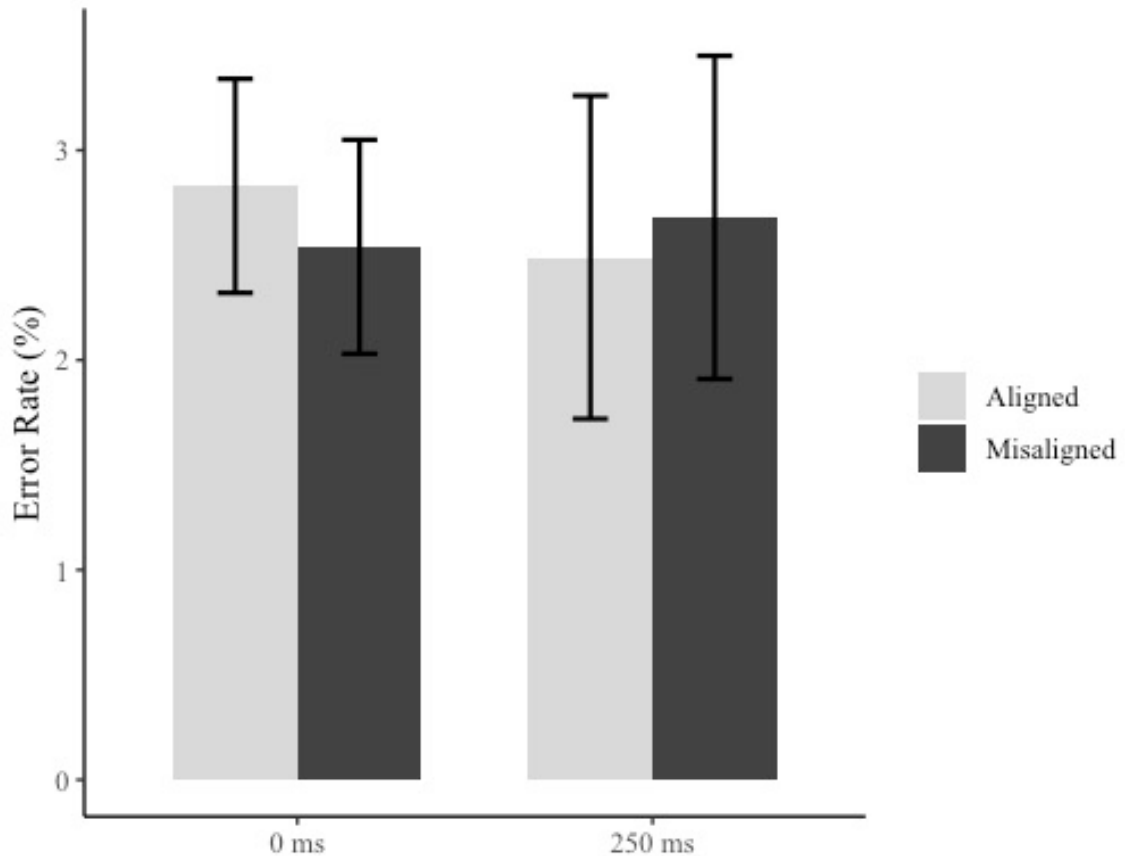
We computed an analysis of variance (ANOVA) for the factors of alignment and SOA as repeated-measures (see Figure 2.5.1 for response time means). As with previous experiments, the factor of orientation was included in the initial analysis; but was not a main effect of interest, so any orientation effects can be found in Appendix A.



*Figure 2.5.1.* Mean response times in Experiment V as a function of alignment and SOA. Error bars represent 95% confidence intervals.

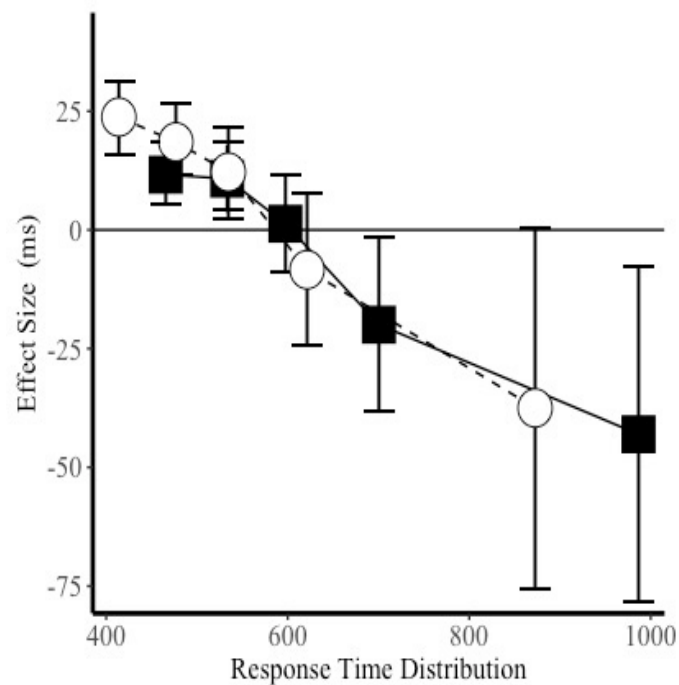
The main effect of alignment was not significant. There was a significant main effect of SOA ( $F[1, 35] = 220.80$ ,  $MSE = 1,762$ ,  $p < .001$ ) results showed faster responses in the 250-ms SOA. There were no significant interactions.

There were no significant main effects of SOA or alignment on error rates (see Figure 2.5.2). Interactions between alignment, orientation, and SOA can be found in Appendix A.



*Figure 2.5.2.* Mean percent error in Experiment V as a function of alignment and SOA. Error bars represent 95% confidence intervals.

We evaluated the effect of alignment over the response time distribution. There was an interaction between quintile and alignment effect size ( $F[4, 140] = 17.82$ ,  $MSE = 2,371$ ,  $p[GG] < .001$ ). Effect size of alignment decreased across the distribution of responses. The alignment effect size was initially positive and decreased to become negative in the final quintiles (see Figure 2.5.3).



*Figure 2.5.3.* Delta plot of alignment effect size across the response time distribution for crossed hand trials in Experiment V separated by the 0-ms and 250-ms SOAs. Error bars represent 95% confidence intervals.

These results fully replicate the results from the crossed hands condition in Experiment IV. At the longer SOA, there was a positive effect of alignment on faster responses, but this effect became negative for longer response times. In the quintiles, we can see for the 250-ms SOA the initial alignment effect was about 20 ms, but this reversed to about -32 ms at the longest response times. A similar trend was seen with the 0-ms SOA. The alignment effect was initially about 10 ms, but at the longest response times it was about -40 ms.

This pattern indicates that effects of the handle on keypress responses to the laterality of a grasp posture include two distinct representations. One is limb-specific and is initially dominant. Thus, the object depicted with the handle on the right affected a

right-handed response, which in the crossed hand condition, is made on the left key. This representation was followed quickly by spatial codes now generating correspondence effects determined by the relationship between the side of the handle and the location of the keypress. The handle appearing on the right yields faster responses made with the spatially corresponding key, which, in the crossed hands condition, are made with the left hand. The result is that slower responses yield a reverse alignment effect, given that positive alignment is defined in terms of the relationship between the handle and the left/right status of the depicted hand rather than position of the spatially corresponding key.

## 2.6 Experiment VI

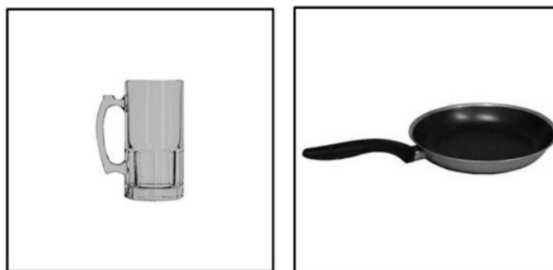
The main motivation for this experiment is to evaluate the claim that a methodologically valid way of determining that limb-specific codes are generated by the image of a graspable object is to compare the effect of the object on keypresses involving a choice between the left/right hand versus a choice involving the index/middle finger of a single hand. This assumption has been widely endorsed but we will establish here that it is invalid. We have already seen that the laterality judgments to a grasp posture superimposed on the image of an object are affected by spatial as well as limb-specific codes. An object depicted with a left-facing handle activates both the left key and the left hand, though the temporal dynamics of these effects are different. Based on this prior evidence, we would expect that alignment effects are present when laterality judgments require responses made with the index/middle fingers of one hand. Alignment effects on within-hand keypress responses cannot be due to limb-specific effects. Yet we have shown beyond doubt that such effects are present, though they vary depending on task

demands, when keypress responses depend on a choice between the left and right hand. It follows that alignment effects on within-hand keypress responses provide no relevant evidence for the claim that only spatial and not limb-specific codes are generated by the image of a graspable object.

### 2.6.1 Method

**Subjects.** Thirty-six subjects (four males and one left-handed) completed this experiment to receive extra credit in their undergraduate psychology courses. Subjects had an average age of 19.50 years (standard deviation  $\pm 1.79$  years).

**Materials.** The materials used in this experiment were identical to those used in the first experiment, with the addition of two more objects (see Figure 2.6.1). The two additional objects were a saucepan with a handle that afforded a horizontal grasp and a beer mug with a handle that afforded a vertical grasp.



*Figure 2.6.1.* Additional objects used as stimuli in Experiment VI.

**Design.** The design of this experiment was similar to Experiment I, except instead of crossing their hands in one block, participants responded with the index and middle fingers on their dominant hand. The order of these blocks was counterbalanced between

participants. In this experiment, there were 32 unique images created using the images of the hands superimposed over images of the objects (4 hands x 4 objects x 2 handle locations). The 0-ms and 250-ms SOAs were used, as in the previous experiments. This gave 64 unique trials. Each trial was presented three times for each response type, 192 trials for two hands and 192 trials for one-hand. Participants completed a total of 384 critical trials.

The factors were alignment (comparing handle side and hand or finger laterality), block order, response mode (one or two hand) and SOA (0 ms and 250 ms).

**Procedure.** The procedure for Experiment VI was similar to that of Experiment I, but the crossed hands manipulation was changed to a one-hand response. If their right hand was dominant, participants were instructed to respond with the index finger to a left hand and the middle finger to a right hand. If their left hand was dominant, participants were told to respond with their index finger to a right hand and their middle finger to a left hand. In both cases, the finger on the right responds to a right hand and the finger on the left responds to a left hand. The two-hand response block had hands straight on the button box on the two outermost buttons, as in previous experiments. On 20% of trials, participants were probed for which object was just shown.

### 2.6.2 Results and Discussion

The mean percent accuracy for keypress classification of the hands was approximately 98.6%. The accuracy for the object probe was 98.6%. Data from all 36 subjects were included in the analysis.

Like the exclusion criteria from all previous experiments, we excluded response times shorter than 100 ms and longer than 2,000 ms from the data.

We computed an analysis of variance (ANOVA) for the factors of alignment, SOA, response mode, and block order as repeated-measures (see Figure 2.6.2 for response time means). Like in Experiment III, there was no main effect of block order and were no interactions of interest; this factor was not included in the following results, but can be found in Appendix A.

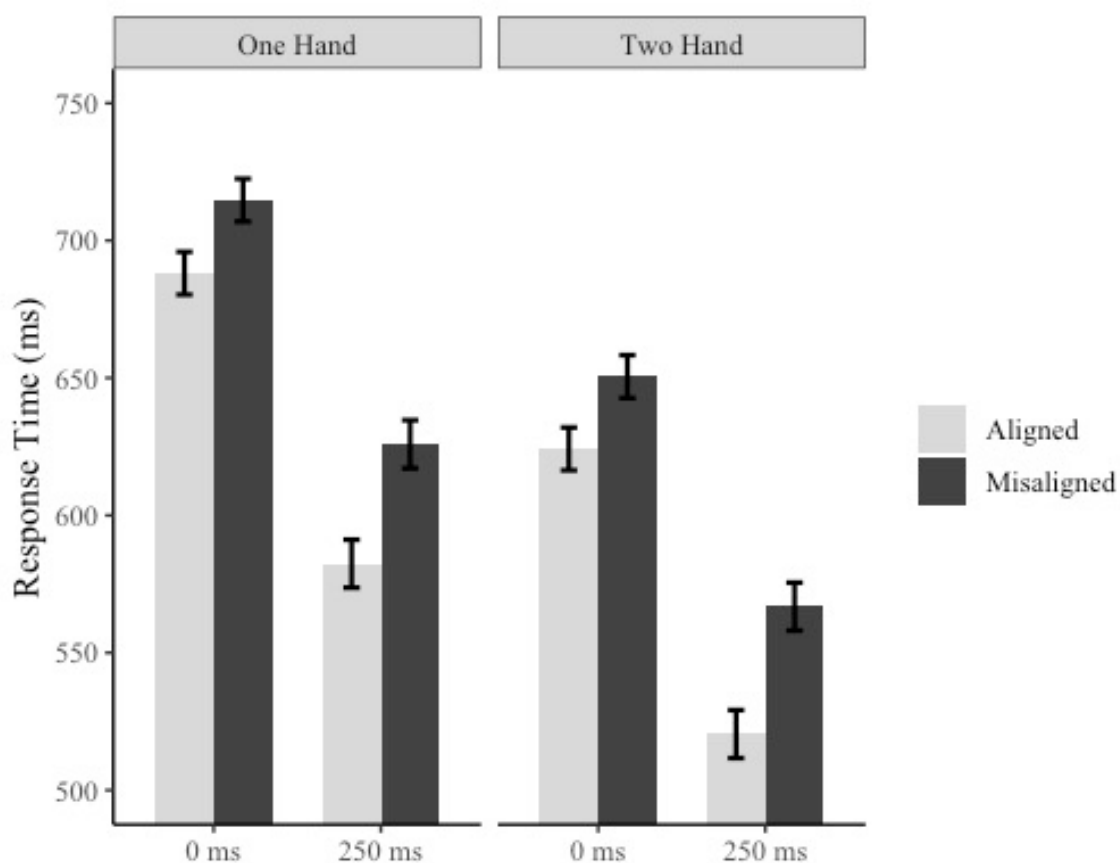


Figure 2.6.2. Mean response times in Experiment VI as a function of alignment, SOA, and response mode. Error bars represent 95% confidence intervals.

There was a significant main effect of alignment ( $F[1, 34] = 52.83$ ,  $MSE = 3,445$ ,  $p < .001$ ) and a significant main effect of SOA ( $F[1, 34] = 328.24$ ,  $MSE = 4,005$ ,  $p <$

.001) with the same trends as previous experiments. There was also a significant main effect of response mode ( $F[1, 34] = 18.30$ ,  $MSE = 30,394$ ,  $p < .001$ ); participants made slower responses with the two fingers on one hand than using the two hand response.

A significant interaction was seen between alignment and SOA ( $F[1, 34] = 8.59$ ,  $MSE = 1,388$ ,  $p = .006$ ) with a larger alignment effect at the 250-ms SOA.

There was only one main effect in error rates, a significant main effect of alignment (see Figure 2.6.3) ( $F[1, 34] = 20.41$ ,  $MSE = 7.67$ ,  $p < .001$ ). Slightly more errors were made on misaligned trials.

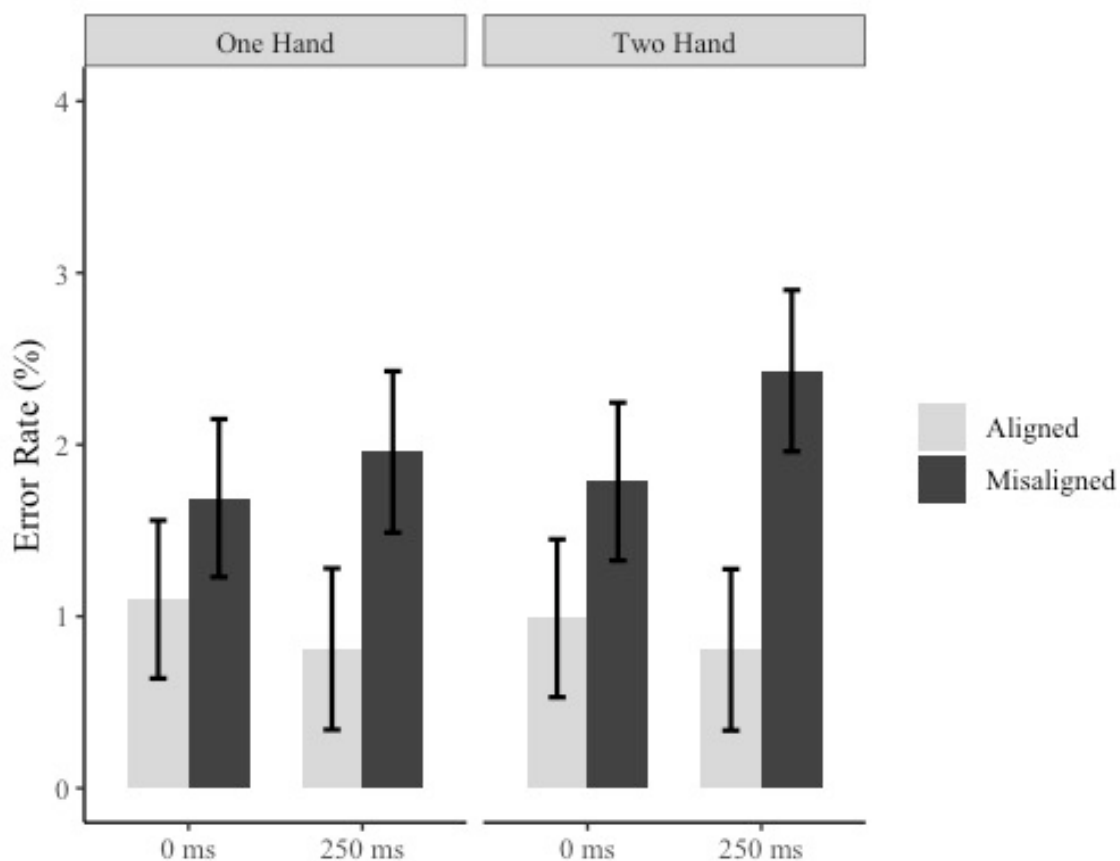
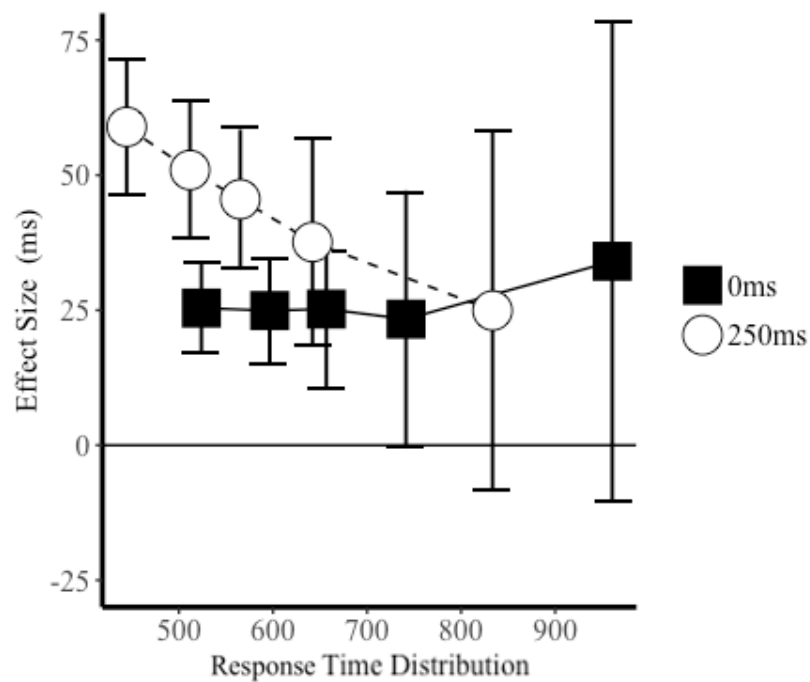
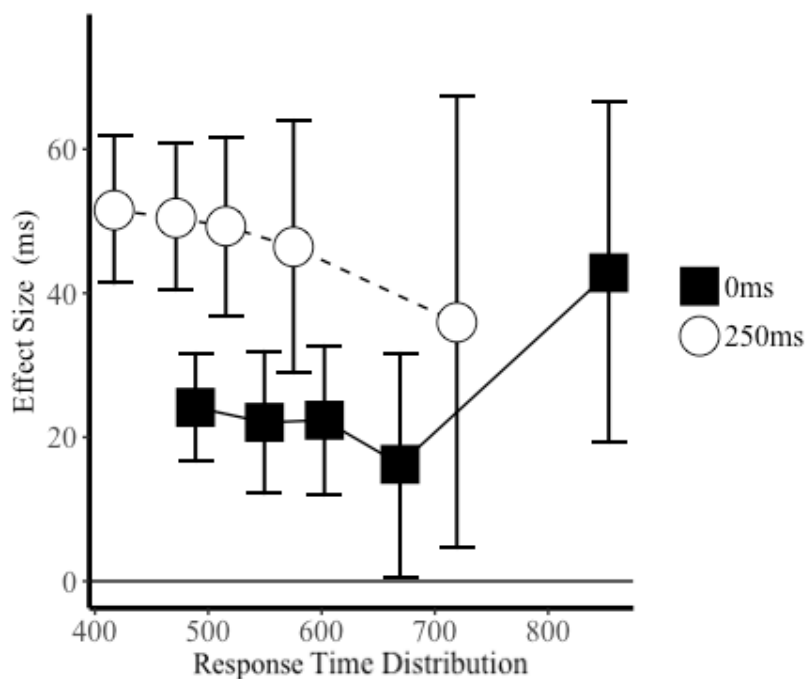


Figure 2.6.3. Mean percent error in Experiment VI as a function of alignment, SOA, and response mode. Error bars represent 95% confidence intervals.

We evaluated the effect of alignment for the both response modes separately over the response time distribution (see Figures 2.6.4 and 2.6.5). For one-hand responses, there was no interaction between quintile and alignment effect size. The effect size of alignment did not change significantly over the distribution of responses.



*Figure 2.6.4.* Delta plot of alignment effect size across the response time distribution for one-hand trials in Experiment VI separated by the 0-ms and 250-ms SOAs. Error bars represent 95% confidence intervals.



*Figure 2.6.5.* Delta plot of alignment effect size across the response time distribution for two-hand trials in Experiment VI separated by the 0-ms and 250-ms SOAs. Error bars represent 95% confidence intervals.

With two hands responding, there was also no significant alignment by quintile interaction. The alignment effect size remained flat across the response distribution, as in previous experiments.

Main effects for the two hands responding portion of this experiment replicated our first, second, third, and fourth experiments. As we anticipated, one hand responding also produced an alignment effect. In this mode of responding, the finger assigned to a left-sided keypress corresponds to the side of the handle on the left, and vice versa for a right-sided keypress. The effects induced by the depicted object on within-hand keypress responses are robust and are spatial in nature. For the one-hand response block of this

experiment, we see compatibility effects that are purely spatial in nature, as there are no competing limb-specific effects. It does not follow however, that this evidence precludes any role for limb-specific codes in the effect of the object on between-hand responses.

## General Discussion

In this thesis, we garnered evidence that under suitable conditions, task-irrelevant images of graspable objects can evoke limb-specific effects on keypress responses. Our results confirm the presence of a handle alignment effect when participants made speeded laterality judgments to the depiction of a grasp posture superimposed on the object. Keypress responses were faster when the depicted hand was aligned with the handle of the graspable object. This confirmed the results obtained previously by van Noordenne (2017). Our results highlight the subtlety of these effects. Limb-specific effects are evident throughout our results given the changes in temporal dynamics of the alignment effect.

The results from our experiments establish that keypress responses made with crossed hands can generate compatibility effects determined by the relationship between the handle and the laterality of the depicted hand. From the temporal dynamics, we can see effects that are beyond the possible influence of SS compatibility; our results reveal the influence of limb-specific and spatial SR compatibility effects. In this respect, the evidence is discrepant from two previous reports on compatibility effects induced by the picture of a graspable object on crossed hands assigned to left-right keypress responses. When responses were cued by an arbitrary symbol, alignment effects depended on only the spatial correspondence between the location of the key and the side of the handle, regardless of whether keypress responses were made with straight or crossed hands (Janyan & Slavcheva, 2012; Phillips & Ward, 2002).

Further insight into the nature of the codes affecting laterality judgments, triggered by the task-irrelevant handle of the depicted object, was gained by evaluating

the temporal dynamics of correspondence effects on left/right keypress responses. The alignment effect of the handle on crossed hands responding was apparent if participants were required to report the identity of the object on a subset of trials. When we removed the requirement of reporting the object (Experiment IV), the alignment effect was no longer seen in the overall reaction time. The delta plot showed a rapid decay of a limb-specific alignment effect across the response time distribution. We considered the possibility that including the object probe may have enhanced the activation of limb-specific codes, so that without the object probe we see a greater influence of spatial codes on response selection later in the response time distribution. The dynamics of limb-specific versus spatial codes influencing performance at different time points was confirmed in a subsequent experiment (Experiment V) by having participants complete the same experiment only responding with hands crossed on the response apparatus, again without any requirement to report the identity of the object.

Results provided confirmation that limb-specific codes do indeed affect shorter response times followed by space-based effects of the handle on longer response times. More specifically, for crossed hand responses, an object with the handle on the right, say, yielded faster responses for *right-handed* keypresses (made on the left key) in the earlier part of response time distribution. For slower responses (the later part of the response time distribution), the same image (handle on the right) yielded faster responses for *right-sided* keypresses (made with the left hand). This reversal in the nature of the codes affecting keypress responses at different time points, from an earlier limb-specific to a later spatially-based representation, is consistent with evidence from a quite different domain, involving the cross-modal integration of somatosensory and visual events. Thus,

Azanõn and Soto-Faraco (2008) required participants to respond by lifting their toes or heel off a foot pedal to the corresponding vertical location of a visual target occurring in peri-personal space, appearing to the left or right of central fixation. Just before this visual event, a tactile prime was applied to the left or right hand in the contralateral hemispace (left hand on the right side of fixation, and vice versa for the right hand). Correspondence effects were based on the relationship between the tactile and visual events. At shorter SOAs, these effects were driven by anatomically-based codes; tactile stimulation of the left hand (positioned in the right hemispace) yielded faster responses to a visual target on the left. At longer SOAs, this priming effect was determined by spatial rather than anatomical codes; responses to a visual target on the right, for example, were faster when the location of the tactile prime was also on the right.

The temporal dynamics of correspondence effects that occur when somatosensory input is combined with proprioceptive and visual cues about body posture are convergent with the effects induced by the structural properties of a task-irrelevant object on left/right-handed keypress responses to the laterality of a grasp posture. This convergence, we propose, is more than a coincidence. The image of a closed grasp posture automatically triggers limb-specific codes. In a Simon-like task, when participants respond with a left or right-handed keypress response to the colour of a dot superimposed on the depiction of a left/right-handed grasp posture, results show correspondence effects. Responses are faster when the hand assigned to a keypress response matches the laterality of the depicted grasp, regardless of whether the keypress responses are made with hands in a straight or crossed position (Teskey, 2019). These

limb-specific effects accrue rapidly and tend to decay with a longer SOA between the task-irrelevant image of the hand and the colour cue.

The visual ensemble of a grasp posture in combination with the image of graspable object also triggers limb-specific codes, but their effect on response selection rapidly gives way to spatial effects determined by the correspondence between the side of the handle and the left/right position of the keypress responses. This rapid transition makes sense; a grasp action applied to an object like a teapot requires both the selection of a limb and the spatial coding of the object and its parts in an extrinsic frame of reference.

Additional evidence to demonstrate the robustness of our alignment effects was obtained when the hands were assigned to keypress locations that emphasized the spatial coding of response options as up/down rather than left/right. Laterality judgments continued to be influenced by the relationship between the depicted hand and the position of the handle. Thus, alignment effects remained despite the assignment of responses to keys placed in a manner to discourage the spatial coding of their position in terms of left versus right.

As expected, Experiment III showed a reversal of the alignment effect when using an arrow as the imperative stimulus, replicating van Noordenne's (2017) result. This reversal is attributed to a change in the nature of the imperative cue. The arrow draws attention to the most spatially salient features of the depicted object, which for many whole-object centred images, are located away from the handle.

In our final experiment, we investigated the assumption that using a one-hand response manipulation can appropriately test for limb-specificity or motor-based effects

(Tucker & Ellis, 1998). If the alignment effect we have documented is only determined by the formation of limb-specific representations, then we should no longer have observed any effect of the object on within-hand responses. We have already seen that correspondence effects induced by handled objects are much too complex and dynamic to justify this assumption. In our final experiment, we found that alignment effects occur robustly when laterality judgments depend on responses made with the index/middle finger of one hand. The presence of the alignment effect for within-hand responding is based on the spatial compatibility between the handle and left/right responses. This outcome does not negate the evidence we have obtained that limb-specific codes are also induced when laterality judgment depend on keypress responses made with the left/right hand, but it confirms that there can also be robust spatial effects within our experiments.

A recent argument by Thomas and colleagues (2019) provides an example of a flawed inference directly attributable to the mistaken assumption that comparing alignment effects on between- versus within-hand keypress responding is relevant evidence for or against limb-specific representations. These authors instructed participants to imagine picking up a depicted object like a teapot with the handle on the left or right. Without this added instruction, no alignment effects occurred. When the upright/inverted decisions included the imagery task, alignment effects occurred that were no bigger for between- than within-hand keypress responses. The authors inferred on the basis of this evidence that “motor-imagery instructions do not elicit the activation of specific actions associated with the objects but rather generate an abstract spatial code for the left-right location of the graspable part of an object” (p. 7). As we have argued, a proper test of this claim would entail a comparison between keypress responses made

with straight versus crossed hands. We have recently established that when participants are asked to imagine picking up the depicted object while carrying out upright/inverted judgments, alignment effects on keypress responses made with crossed hands are limb-specific (responses are faster when the keypress depends on the hand aligned with the handle, regardless of whether the hand is positioned in the contralateral or ipsilateral hemispace).

Our results provide indirect evidence for the evocation of limb-specific representations with keypress responses, but these occur only under specific task demands and in a spatio-anatomical frame of reference. Contrary to the widely accepted claim of Tucker and Ellis (1998), an image of a graspable object will not automatically produce action representations due to the graspability of the handle. Images of objects can produce object-based Simon effects that arise due to the location of the handle and its spatial compatibility with the responding key (Cho & Proctor, 2010). These spatial effects depend on the location of the response key, not the location of the responding hand. The spatial compatibility of the handle with the location of a keypress, however, cannot explain all of the results from the present set of experiments. We demonstrate some subtle limb-specific effects that withstand different response configurations and cannot be attributed to spatial compatibility. Further, the temporal dynamics of our alignment effects revealed the nuances of the effects and the contribution of spatial effects. This thesis also provides evidence that within-hand responses cannot be used to test for limb-specific codes. A proper manipulation needs to eliminate any effects due to spatial compatibility; the effect of the object on keypress responses made with crossed hands can satisfy this requirement. This set of experiments presents evidence that limb-

specific representations can be triggered by task-irrelevant images of graspable objects under specific task conditions. The present work highlights the importance these effects and captures some of their subtleties.

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## Appendices

### 5.1 Appendix A

#### Experiment I – Block Order and Orientation Effects

With the hand instructions, there was a significant interaction between block order, SOA, and response mode ( $F[1, 28] = 5.10$ ,  $MSE = 2,696$ ,  $p = .032$ ). There was a larger effect of SOA for crossed hands when the crossed hand block came first. When the hands were straight, there was a larger effect of SOA when the straight hand block was first.

For the key instructions, there was a significant orientation by alignment interaction, as well as a significant block order, alignment and orientation interaction ( $F[1, 28] = 5.87$ ,  $MSE = 799$ ,  $p = .022$ ). On aligned trials, faster responses were seen on congruent trials (orientation of handle and hand match), but only when the crossed hands block was first. There was a reverse congruency effect (eg. faster responses when the hand was in a vertical position, but the handle afforded a horizontal grasp) on misaligned trials, but only when the crossed hand block was first. A significant interaction between block order and response mode was present ( $F[1, 28] = 8.58$ ,  $MSE = 61,727$ ,  $p = .007$ ). There was little difference in the response times for straight hands between the block orders. For crossed hands, response times were longer when the crossed hand block was first. A significant interaction between orientation, alignment, and response mode was also present ( $F[1, 28] = 6.06$ ,  $MSE = 941$ ,  $p = .020$ ). When hands were straight, the alignment effect was a similar magnitude on congruent and incongruent trials. With respect to the congruency effect, there was a reverse congruency effect on misaligned trials. For hands crossed, the alignment effect was smaller on incongruent trials. There

was congruency effect on aligned trials and a reverse congruency effect on misaligned trials.

For error rates with hand instructions, there was a significant block order by response mode interaction ( $F[1, 28] = 4.85$ ,  $MSE = 35.61$ ,  $p = .036$ ). Participants made more errors in the crossed hand and straight hand trials when they were in the second block. Another significant interaction was present between block order, response mode, and orientation ( $F[1, 28] = 4.74$ ,  $MSE = 13.38$ ,  $p = .038$ ). With hands straight, there was a congruency effect on error rate, but only when the straight hand block was first. When hands were crossed, there was a congruency effect when the crossed hand block was first and a reverse congruency effect when the straight hand block was first. There were more errors on crossed hand trials when the straight hand block was first.

### **Experiment II – Orientation Effects**

There was a significant orientation by SOA interaction ( $F[1, 40] = 4.41$ ,  $MSE = 196.60$ ,  $p = .042$ ). A small reverse congruency effect was present at the 0-ms SOA and no effect was seen at the 250-ms SOA.

### **Experiment III – Block Order Effects**

A significant interaction between block order and SOA was present ( $F[1, 32] = 5.30$ ,  $MSE = 1,821$ ,  $p = .028$ ). There was a 24.8 ms effect of block order at the 0-ms SOA, but a 1 ms effect at the 250-ms SOA.

For error rate, a significant three-way interaction between SOA, imperative stimulus, and block order was present ( $F[1, 32] = 5.16$ ,  $MSE = 2.85$ ,  $p = .03$ ). On arrow

trials, more errors were made when the arrow block came first. When the arrow block was second, more errors were made on 250-ms SOA trials. For hand trials, more errors were made when the hand trials came first and more errors were made in the 0-ms SOA rather than the 250-ms SOA condition. Another significant interaction between block order, alignment, and imperative stimulus was also present ( $F[1, 32] = 5.60$ ,  $MSE = 8.73$ ,  $p = .024$ ). On arrow trials, more errors were made when the arrow block came first. When the arrow block was second, more errors were made on aligned trials. For hand trials, slightly more errors were made when the hand trials came first and more errors were made when these trials were also misaligned.

#### **Experiment IV – Orientation Effects**

When hands were straight, there was a significant interaction between orientation, SOA, and alignment ( $F[1, 32] = 4.77$ ,  $MSE = 590.40$ ,  $p = .036$ ). For aligned trials, there was a reverse congruency effect at the 0-ms SOA and a congruency effect at 250-ms SOA. On misaligned trials, there was a congruency effect at the 0-ms SOA and no effect at the 250-ms SOA.

In the error rates, with hands crossed, there was a significant interaction between orientation and alignment ( $F[1, 32] = 15.65$ ,  $MSE = 95.30$ ,  $p = .019$ ). On congruent trials, there was an alignment effect, but on incongruent trials, there was no effect of alignment.

### **Experiment V – Orientation Effects**

A significant interaction was found between alignment, orientation, and SOA ( $F[1, 35] = 4.93$ ,  $MSE = 6.05$ ,  $p = .033$ ). At the 250-ms SOA, there was an alignment effect in the error rate for congruent trials and no alignment effect for incongruent trials. At the 0-ms SOA, there was a reverse alignment effect on congruent trials and no effect for incongruent trials.

### **Experiment VI – Block Order and Orientation Effects**

There was a significant interaction between response mode and block order ( $F[1, 34] = 15.49$ ,  $MSE = 30,394$ ,  $p < .001$ ); participants made faster responses in the two hand response block when the one hand response block was first. When the two-hand response block was first, there was no difference in response times between the two response modes. An interaction was also seen between SOA, response mode, and block order ( $F[1, 34] = 6.72$ ,  $MSE = 1,974$ ,  $p = .014$ ). For one hand responding, participants had shorter response times when the two-hand response block was first, but the magnitude of the SOA effect was the same between the two block orders. For two hands responding, the effect size of SOA was greater when participants had the two-hand responding first. A final interaction was present between alignment, SOA, response mode and block order ( $F[1, 34] = 4.37$ ,  $MSE = 1,020$ ,  $p = .044$ ). For one hand responding, there was a smaller alignment effect when participants had the two-hand response block first for the 0-ms SOA; there was no difference at the 250-ms SOA. For two hands responding, there was no difference in the alignment effect between the two

block orders at the 0-ms SOA. In the 250-ms SOA, if the two-hand response block was first, the alignment effect was smaller.

For error rates, there was only one interaction between block order, orientation, alignment, and SOA ( $F[1, 34] = 13.01$ ,  $MSE = 7.70$ ,  $p < .001$ ). At the 0-ms SOA on aligned trials, there was a congruency effect when the one hand responding block was first and a reverse congruency effect when the two hand responding block was first. On misaligned trials, there was a reverse congruency effect when the one-hand response block was first and a congruency effect when the two-hand response block was first. At the 250-ms SOA on aligned trials, there was a reverse congruency effect when the one-hand response block was first and a small congruency effect when the two-hand response block was first. On misaligned trials, there was a congruency effect when the one-hand response block was first and a small reverse congruency effect when the two-hand response block was first.

## 5.2 Appendix B

Table 1

*Mean response times (RT) in ms for Experiment II as a function of handle location, responding hand, and response location.*

| <i>Response Location</i> |           | <i>Right Hand</i>      |             | <i>Left Hand</i>       |             |
|--------------------------|-----------|------------------------|-------------|------------------------|-------------|
|                          |           | <i>Handle Location</i> |             | <i>Handle Location</i> |             |
|                          |           | <i>Right</i>           | <i>Left</i> | <i>Right</i>           | <i>Left</i> |
| <i>Right Top</i>         | <i>RT</i> | 553.9                  | 586.3       | 584.9                  | 562.0       |
| <i>Left Top</i>          | <i>RT</i> | 552.7                  | 574.1       | 575.9                  | 556.2       |

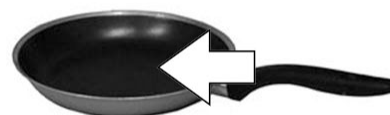
### 5.3 Appendix C

#### 5.3.1. Stimuli Used in Experiments 1, 2, 3, 4, and 5





## 5.3.2. Stimuli Used in Experiment 3



5.3.3. Stimuli Used in Experiment 6



