INVESTIGATING THE MECHANISM DRIVING NEAR-TOOL VISUAL BIASES

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

Previous research has shown that when observers hold a tool, they experience action-oriented visual biases in the area around this tool that are similar to visual biases that exist around the hands. Some researchers have theorized this effect is due to the tool being incorporated into the body schema following active tool use, while others argue that this effect may simply be due to the tool's visual salience. The goal of the present study was to test these competing explanations of near-tool visual biases. In the first experiment, participants completed a target detection task under one of three conditions: 1) while holding a small rake next to one side of a monitor, preceded by an active object retrieval task; 2) while holding a rake next to a monitor, preceded by a passive looking task; or 3) with the rake placed next to a monitor by a researcher, preceded by a passive looking task. Participants detected targets near the rake faster than targets far from the rake in the first two conditions, but no target detection facilitation was seen in the third condition. Participants in Experiment 2 held a small rake next to a monitor after an active object retrieval task, but a paper shield blocked the tool from view, eliminating its visual salience. While the pattern of near-tool target detection facilitation did not significantly differ between shielded and unshielded conditions, the shield did reduce the magnitude of the near-tool effect. Taken together, these results suggest that near-tool effects cannot be driven by the visual presence of a tool alone, but they also indicate that a period of active use may not be necessary to introduce visual biases near tools.

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INTRODUCTION

The term "functional action area" is defined as the region within which a person can reach and interact. A great deal of research has shown that our brains have evolved a number of mechanisms that prioritize this space to guide and improve our movements (e.g., Graziano & Cooke, 2006; Reed, Grubb, & Steele, 2006; Thomas, 2013; Tseng & Bridgeman, 2011). These mechanisms automatically prepare us to interact with any objects that fall within this region, also known as peripersonal space, giving rise to several visual biases which can be measured experimentally, such as improved object recognition (Graziano & Cooke, 2006), change detection (Tseng & Bridgeman, 2011), and target detection (Reed et al., 2006) for stimuli presented within reach of the hands. Additionally, hand-held tools that extend our reach and thereby our action area have also been shown to extend the distance at which these visual biases in peripersonal space—referred to here as *near-tool effects*—are found (Maravita, Spence, Kennett, & Driver, 2002; Reed, Betz, Garza, & Roberts, 2010).

Some researchers argue that active use of hand-held tools expands the representation of the body (i.e., the body schema) and updates our representation of peripersonal space to include the space around the tool (Berlucchi & Aglioti, 1997; Canzoneri, Ubaldi, Rastelli, Finisguerra, Bassolino, & Serino, 2013; Graziano & Cooke, 2006). Other researchers have countered that these visual biases associated with the space surrounding a hand-held tool may be due to the tool's visual salience—visual attention and gaze are drawn towards a tool simply because it is a novel object (Holmes, 2012; Holmes, Sanabria, Calvert, & Spence, 2007; Humphreys, Riddoch, Forti, & Ackroyd, 2004). Researchers on both sides of this debate have produced evidence in support of their arguments, but several confounds and inconsistent definitions make accurate evaluation of this evidence difficult. The purpose of the current study is to address many of these inconsistencies and confounds in order to determine whether near-tool visual biases result from hand-held tools extending the boundaries of peripersonal space through active use, or are simply a product of attentional effects driven by a tool's visual salience.

In this study, I will utilize a target detection task to examine the explanatory power of the active use and attentional accounts of near-tool effects. Improvements in detection for targets presented near a tool have been studied using the Posner Cuing task (Posner, Walker, Friedrich, & Rafal, 1987). Researchers first found that when participants hold a hand next to one side of a computer monitor, they respond significantly faster to targets presented near that hand than targets presented far from that hand (Reed et al., 2006). This effect seemed to be dependent on an observer's ability to interact with the stimulus; improved target detection only occurs for targets presented within the hand's grasping space (Reed et al., 2010). Critically, researchers also found improvements in target detection for targets presented near a hand-held tool using this paradigm. When participants held a small rake next to one side of the monitor, researchers found that targets presented near the rake were detected faster than targets presented far from the rake, the same results observed when a hand was held next to the monitor. These results seemed to be dependent on action as well; this effect was seen after participants spent a minute using the tool to rake a tray full of sand (Reed et al., 2010). This practice period was theorized to give participants time to develop an active relationship with the tool, and to allow participants to redefine the boundaries of peripersonal space to include the tool.

Another paradigm which has provided a great deal of insight into the characteristics of near-tool effects involves the interaction between visual and tactile stimulus perception, a paradigm known as crossmodal competition. Single cell recordings of macaque monkeys have shown that peripersonal space is represented by bimodal neurons, which respond to both tactile and visual information (Iriki, Tanaka, & Iwamura, 1996). These cells fire at the greatest rate when responding to both visual and tactile stimulation, which facilitates perception if the stimuli are coming from the same location. If, however, the visual and tactile information are presented at incongruent locations, perceptual resources will be split, creating interference. In an experimental setting, crossmodal competition manifests as faster reaction times to detect tactile targets presented—typically on the hand—concurrently with a visual stimulus on the same side of space and slower reaction times to detect a tactile target presented in tandem with an incongruent visual stimulus on the opposite side of space relative to a tactile stimulus presented alone (Brozzoli, Pavani, Urquizar, Cardinali, & Farnè, 2009; Maravita et al., 2002). This effect is specific to stimuli in peripersonal space; stimuli in extrapersonal space are processed in parallel through unimodal neurons, and so visual information coming from outside peripersonal space has no effect on the firing rate and perception of tactile stimuli. Notably, this effect can also be extended by implementing hand-held tools. Visual stimuli presented 75 cm from the hand will not normally influence perception of tactile stimuli through the hands, but when holding a 75 cm club-like tool, visual stimuli presented near the end of the club will elicit crossmodal competition (Maravita et al., 2002). Relative to tactile stimuli alone, congruent visual stimuli will facilitate responses to tactile targets and incongruent visual stimuli will interfere with tactile target perception when the visual stimuli are presented at the end of a 75 cm tool (Maravita et al., 2002).

The facilitation of target detection near tools and the crossmodal competition effect may be explained by the idea that using a hand-held tool expands an observer's effective action area, leading to an update of the body schema and expansion of peripersonal space to include the tool. This theory, which I will refer to as the *active use account*, holds that tools are incorporated into the body schema as extensions of the limb, evidenced by increases in perceived limb length after using a tool (Canzoneri, Ubaldi, Rastelli, Finisguerra, Bassolino, & Serino, 2013). The critical feature of this theory is that active, goal directed use of the tool is necessary to generate any near-tool effect. The participant must have a sense that a tool can actually be used to act on their environment, which comes from experience using the tool. For this hypothesis to be supported, it would need to be true that near-tool effects are only present after active practice using a tool, and that passively holding a tool without using it to complete a task does not elicit any visual biases near the tool. Many studies have found this to be the case: participants holding a 60 cm rake without using it for any task do not exhibit crossmodal competition when visual stimuli are presented near the end of the rake, but after participants use the rake to retrieve distant objects, researchers found that visual stimuli at the end of the rake began to significantly influence the detection of tactile targets (Farnè, Iriki & Ladavas, 2005; Farnè & Làdavas, 2000; Maravita, Husain, Clarke, & Driver, 2001; Rossetti et al., 2015).

Much of the theory behind the active use account stems from single cell recordings of macaque monkeys, which showed that the receptive fields of the neurons responsible for representing peripersonal space only expand after the monkeys go through extended periods of practice using a rake to grab food pellets (Iriki et al., 1996). The neurons representing peripersonal space were bimodal, responding to both visual and tactile stimuli. Bimodal neurons are specific to peripersonal space representation: the neurons responsible for representing extrapersonal space are unimodal, responding to only one modality. Neural measures in humans have also shown that objects in peripersonal space are represented in terms of the potential actions they elicit, as opposed to just their location in space (Murata, Fadiga, Fogassi, Gallese, Raos, & Rizzolatti, 1997; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997). These features of peripersonal space gave rise to the crossmodal competition and target detection paradigms discussed above, which measure behavioral changes presumably stemming from these neural mechanisms. The bimodal nature of peripersonal space representations creates competition for perceptual resources between visual, tactile, and possibly auditory stimuli if those stimuli appear close to the body (Brozzoli et al., 2009; Canzoneri, Magosso, & Serino, 2012; Canzoneri et al., 2013; Maravita et al., 2002). Participants will be slower to detect a visual stimulus on the left side of space if there is a competing tactile stimulus on the right side of space. As for target detection, when targets appear within grasping distance of a hand, they become candidates for action, and are thought to receive additional action-oriented processing (Murata et al., 1997; Rizzolati et al., 1997).

However, there is a competing explanation for these effects, which I will refer to as the *attentional account*. This theory holds that perceptual alterations around tools are a result of attentional prioritization of a novel, visually salient object. Holding a tool up to one side of a monitor creates asymmetry, where one side of the display has greater visual salience than the other. This asymmetry may naturally draw attention to the side with the tool, which may account for any near-tool visual biases (Holmes, 2012). In crossmodal competition paradigms, attention may be drawn towards the visual stimulus and away from the tactile stimulus because a tool is more visually salient than an empty hand (Holmes, 2012). Experimental support for this hypothesis would need to show that active use is not necessary to elicit near-tool effects, and that passively holding a tool can elicit these visual biases. While there are many studies that found near-tool effects only after a period of active use (Maravita et al., 2002; Rossetti, Romano, Bolognini, & Maravita, 2015), there are others that do in fact find near-tool effects around tools that participants held without any requirement for active use. Holding a stick without performing any sort of active task has been found to elicit crossmodal competition between tactile targets and visual distractors presented at the end of the stick (Holmes, Sanabria, Calvert, & Spence, 2007; Maravita et al., 2001; Humphreys et al., 2004; Yue, Bischof, Zhou, Spence, & Röder 2009). Proponents of the attentional account have also noted inconsistencies between the predictions of the active use account and experimental results, such as the fact that near-tool visual biases seem to exist only at the end of the tool, as opposed to along the entire shaft. They argue that if peripersonal space was expanding along the tool, near-tool effects should be seen along the entire tool, which research has shown is not the case (Holmes, 2012). The attentional account proposes that near-tool effects are not a result of alterations to the body schema or peripersonal space but are instead a result of attentional biases due to the visual salience of a tool.

Unfortunately, there are many obstacles preventing accurate comparisons of the evidence supporting each of these two explanations for near-tool visual effects. One such obstacle is the varied, often contradictory definitions of active use employed by these studies. Active use can be operationally defined as retrieving objects (Farnè et al., 2005) or raking sand (Reed et al., 2010), two tasks which involve physically acting on the environment and accomplishing some sort of goal. Active use has also been operationally defined as simply picking up a tool (Maravita et al., 2001). Studies using both of these definitions found evidence that the "active use" task was necessary to generate near-tool effects, and were all taken as support of the active use account (Farnè et al., 2005; Maravita et al., 2001). Other studies, however, have defined passive use as simply picking up a tool, and found merely holding a tool frequently fails to generate any near-tool effects (Maravita et al., 2002; Rossetti et al., 2015). This inconsistency makes it very difficult to judge whether a study defining holding a tool as active use provides support for the active use or the attentional account.

Another issue clouding interpretation of the current literature is the idea of simulation or expertise effects. Proponents of the active use account argue that any near-tool effects associated with tools that participants hold but do not use to act on the environment are not due to the tool's visual salience alone, but instead rely on the participants' mentally simulating active use of the tool—that is, drawing on past experience using a tool to complete another task (Maravita et al., 2001). If a tool is simple enough or familiar enough, a participant can create an active, functional relationship with the tool even without a period of active use. According to this idea, the participant will still update their body schema and peripersonal space to incorporate the tool, which is consistent with the active use account (Baccarini, Martel, Cardinali, Sillan, Farnè, & Roy, 2014; Maravita et al., 2001). This is a difficult issue to address, as the types of tools used in the literature are nearly always simple and familiar. While concurrent motor tasks could be implemented while the participant holds the familiar tool in order to occupy the motor cortex and inhibit motor simulation (Wexler, Kosslyn, & Berthoz, 1998), it is difficult to determine whether adding distractor tasks into an experiment might create other potentially problematic confounds. While these tasks might inhibit motor simulations under a condition in which participants passively hold a tool, they may also eliminate the functional relationship arising from an active use task.

The attentional account has also developed modifications to explain common findings in the literature, which have the same effect of making falsification very difficult. Researchers have generally found that there are differences between active use and passive hold tool conditions when it comes to near-tool effects in cross-modal competition paradigms (Maravita et al., 2002;

Rossetti et al., 2015) and that target detection facilitation only occurs near a used tool's functional end (Reed et al., 2010). This is not consistent with the idea that the sight of a tool alone can elicit attentional biases. However, proponents of the attentional account argue that actively using a tool will increase its visual salience. A tool that is picked up and moved around a table to complete some task or to interact with objects is more salient than a stationary tool (Holmes, 2012). This offers a visual explanation as to why active conditions elicit greater near-tool effects than passive conditions in some studies. This also makes the attentional account more difficult to falsify, as visual salience must be entirely controlled and accounted for.

The goal of the present study is to resolve these obstacles in an attempt to falsify either the attentional or active use account of near-tool effects. Experiment 1 incorporated a rigorous, goal-directed definition of active use, as well as multiple tool conditions, including active use, passive holding, and a control condition with the tool placed in front of a participant by a researcher. There were two goals for Experiment 1, the first of which was to demonstrate that the tool task and target detection paradigm used in this study could successfully elicit a near-tool effect, replicating previous findings (e.g., McManus & Thomas, under review; Reed et al., 2010). The ability to find evidence of a near-tool effect can be determined by the outcome of the active use condition: finding faster target detection near the end of the tool than on the opposite side of space would indicate that the experimental setup could elicit a near-tool effect, while a failure to see target detection differences near and far from the tool in the active use condition would indicate that the paradigm could not elicit a near-tool effect.

The second goal of Experiment 1 was to use three experimental tool conditions to provide a more fine-grained analysis of near-tool effects. The vast majority of previous studies have run two conditions, with one defined as active and one defined as passive (e.g., Maravita et al., 2002;

Rossetti et al., 2015). Including three experimental conditions allowed me to further tease apart potential differences between outcomes supporting either the active use or attentional accounts. In Experiment 1, based on the findings of previous studies (e.g., Reed et al., 2010), I predicted that I would find evidence of target detection facilitation near the tool in the active condition. In the passive hold condition—where participants hold a tool but never use it to act on the environment—the strictest interpretation of the active use account would lead us to the prediction that there should be no near-tool target detection facilitation without active practice. However, appeals to mental simulation could potentially explain a near-tool effect in the passive hold condition without completely falsifying a more expansive version of the active use account. In fact, based on previous studies (Holmes et al., 2007; Maravita et al., 2001; Serino, Ubaldi, & Làdavas, 2010) I considered this outcome fairly likely. Yet no version of the active use account would predict near-tool facilitation in a passive place condition in which a participant sees a tool near the display but never touches it, as there is no opportunity for the tool to expand representations of peripersonal space. However, if I find evidence of near-tool facilitation even when participants do not use or hold the tool, it may be that an active relationship with a tool is not driving near-tool effects. Such an outcome would strongly support the attentional account, and would indicate that a tool's visual salience draws attention towards one side of space.

Although Experiment 1 may produce a pattern of results that is more consistent with either the active use or attentional accounts of near-tool effects, this experiment alone cannot necessarily falsify either account. In Experiment 2, I implemented a paper shield to block participants' view of a tool during target detection while still allowing them to actively use the tool, creating a functional relationship between the tool and the participant in the absence of the tool's visual salience. The active use account predicts that target detection facilitation should still occur. Participants in the shielded condition should still form an active relationship with the tool and therefore should incorporate that tool into their body schema. While the body schema does utilize visual information, it is also constructed from tactile and proprioceptive input (Berlucchi & Aglioti, 1997; Graziano & Cooke, 2006), which should not be affected by a paper shield. Under this account, target detection facilitation should be relatively unaffected by the addition of a paper shield between the participant and the tool. Such a result would pose a significant challenge for the attentional account, as it would indicate that near-tool effects can be present even in the absence of any visual signal from the tool. If, on the other hand, near-tool effects are eliminated in the shielded condition, it would indicate that near-tool effects are dependent on visual information, bolstering the attentional account. This result would suggest that the body schema alone is not responsible for near-tool effects, which would provide compelling evidence against the active use account.

Although both the active use and attentional accounts of near-tool effects have received support in the literature (e.g., Farnè & Làdavas, 2000; Holmes 2012: Humphreys et al., 2004; Maravita et al., 2001; Rossetti et al., 2015), I predicted that this study would lend support to the active use account, and that any near-tool effects observed would be contingent on a participant's active, functional relationship with that tool. Based on the current state of the literature, I found the evidence in support of the active use account stronger and more compelling than the evidence in support of the attentional account. The definitions of active use, tool tasks, peripersonal space, and the body schema tend to be more consistent in the active use literature than the attentional literature, suggesting greater validity (Farnè & Làdavas, 2000; Maravita et al., 2001; Rossetti et al., 2015). Several studies have found evidence of visual biases around tools that are passively held, which seems to support the attentional account (Holmes et al., 2007; Maravita et al., 2001), but studies which include additional comparisons between an active condition and a passive condition (although the definitions may vary study to study) do tend to find significant differences between these groups, suggesting that tool presence alone cannot explain these findings (Canzoneri et al., 2013; Farnè et al., 2005). Based on the weight of evidence for the active use account, I expected to find improvements in target detection for targets near an actively used tool, but not near a passively held or a placed tool. This would indicate that the tool is incorporated into the participants' body schema, and that their peripersonal space representation had expanded to include the tool as a result of active use. I also expected that introducing a paper shield between the participant and the tool would not eliminate near-tool effects, as the shield would not interfere with the active relationship between the tool and the participant. If, however, I find evidence that passively holding a tool or that placing a tool in front of a participant also generates near tool effects, or that the paper shield does eliminate near-tool target detection facilitation, then it may be that the visual salience of a tool alone is responsible for near-tool effects.

OVERVIEW OF TASK

The task used in this study was the Posner Cueing Task (Posner et al., 1987). Stimuli were presented on a monitor with a resolution of 1024 x 768 pixels and a refresh rate of 60 Hz, with viewing distance approximately 36 cm from the monitor. Stimuli consisted of a black central fixation cross and two empty black squares measuring 3.25^0 positioned 14.63^0 to the left and to the right of fixation. The target stimulus was a black dot (2.44^0), which appeared inside one of the black squares.

During the task, the outline of one of the boxes was darkened after a random delay between 1,500 to 3,000 ms, representing the cue. Two hundred milliseconds after cue onset, a dot either appeared in the darkened box (representing a valid cue trial), the opposite box (invalid cue trial), or did not appear (catch trial). Participants pressed a button on a keyboard as soon as a dot appeared in either the cued or uncued location. Each block contained 56 valid trials, 16 invalid trials, and 8 catch trials for a total of 80 trials per block. Trial type was randomized within blocks.

EXPERIMENT 1

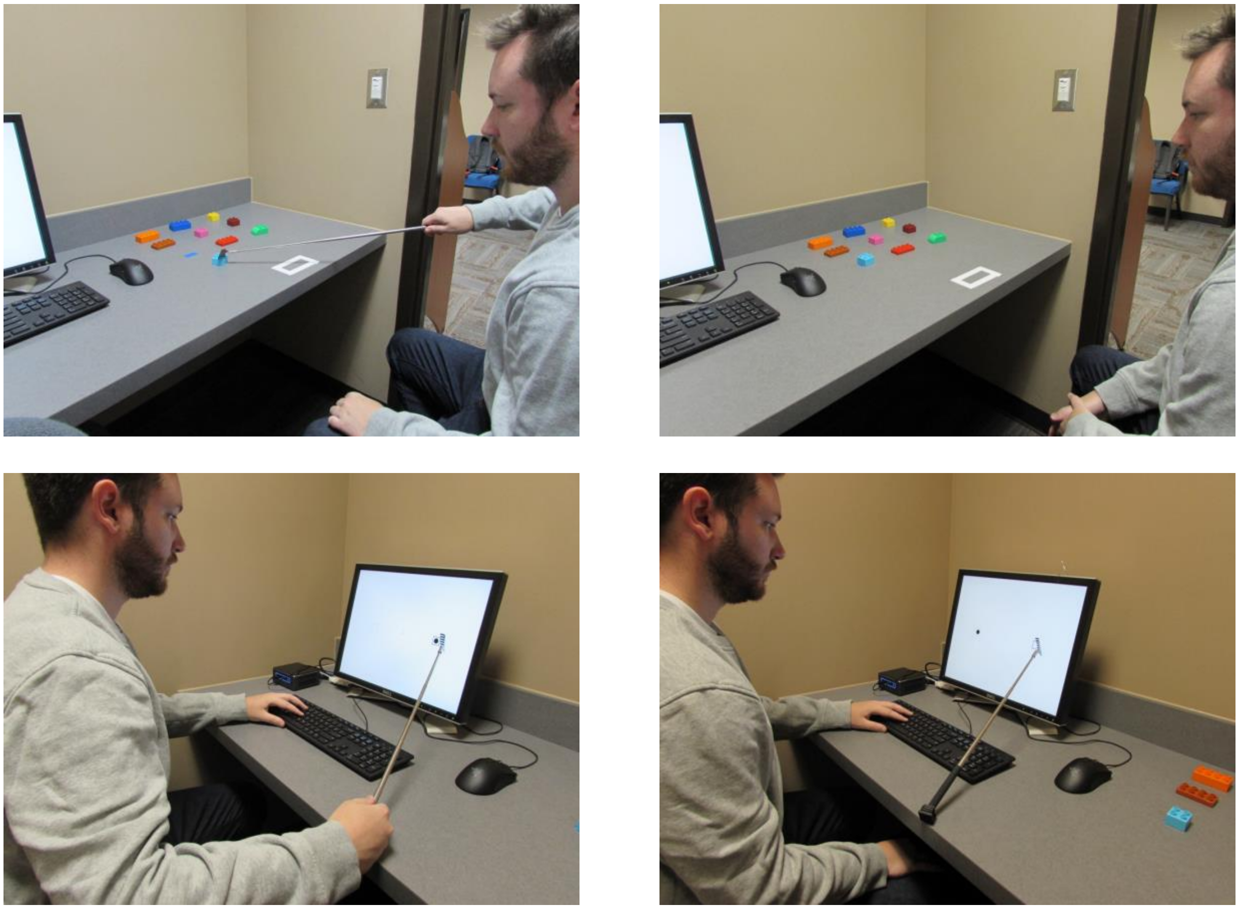
Methods

The purpose of Experiment 1 was to serve as a typical near-tool study but with more controls employed to address certain confounds often found with these types of studies, namely the lack of consensus around definitions of tools and of active use. This experiment utilized a rigorous definition of a tool task, which was that the tool was used to elicit a change in the participant's environment by moving objects that would otherwise be out of reach. This experiment also included a passive place condition in addition to the more common active use and passive holding conditions, where participants never pick up the tool themselves but instead have the tool placed in front of them. Theoretically, this will prevent participants from drawing on past knowledge of tool use by simply picking up the tool. Some researchers have theorized that just holding a tool is enough to create an active tool relationship through mental simulations of actions.

156 Participants were recruited through SONA for course credit. The number of participants was determined based on subject numbers of past experiments of this nature (McManus & Thomas, under review; Reed et al., 2010). All participants were right-handed and had normal or corrected-to-normal vision. Participants were assigned to one of three groups: an active use group, a passive hold group, and a passive place group.

Figure 1

Experimental setup for Experiment 1



The top left panel depicts the task performed in the active use condition, where participants used a rake to retrieve Legos as they were named by a researcher. The top right panel depicts the directed looking task performed in the passive hold and passive place condition, where participants looked at the Legos as they were named by a researcher without holding the rake. The bottom left panel shows the target detection phase of the experiment for the active use and passive hold groups. The rake was held so that the prongs of the rake were next to one of the two possible target locations. The bottom right panel shows the target detection phase of the passive place condition. The rake was suspended in front of the participant using wire hooks and fishing line, so that the prongs of the rake were next to one of the target locations.

Participants in the active use group began the experiment by using a 60 cm rake to retrieve several Legos of different shapes and colors spread around a table using their dominant hand. Researchers named each object to be retrieved by the participant. Participants performed the retrieval task for two minutes and thirty seconds. Participants in the passive hold and passive place condition performed a passive looking task using the same Legos, where the researcher named a Lego and the participant simply looked at the named object. Participants in the passive hold and passive place conditions did not hold the rake during this task.

These tasks were then followed by the Posner cuing task. Participants in each condition ran through 20 practice trials of the task in which they responded to targets using their right hand while keeping their empty left hand on the desk to familiarize themselves with the task. Participants then completed eight blocks of the Posner task, under four conditions. The four conditions for participants in the active use and passive hold conditions were as follows: 1) hold the rake next to the right target box, and respond to targets with the left hand, 2) hold the rake next to the left target box, and respond with the right hand, 3) place the rake aside and respond to the targets with the left hand with the right hand on the desk, and 4) place the rake aside and respond to the targets with the right hand with the left hand on the desk. Each condition was performed twice. Participants in the active use condition performed an additional minute of the retrieval task before blocks with the rake held next to the monitor. During the minute-long retrieval tasks, participants raked using the hand indicated in the instructions: if the rake was to be held on the left side of the screen, participants raked Legos using the left hand. Participants in the passive hold condition performed an additional minute of the directed looking task. Participants in the passive place condition had slightly different block conditions, which were as follows: 1) Researchers placed the rake next to the right target box (the participant did not hold the rake) and participants used the left hand to respond to the targets, 2) the rake was placed next to the left target box, and participants used the right hand to respond, 3) the rake was moved aside, and participants used the left hand to respond, and 4) the rake was moved aside, and participants used the right hand to respond. The end of the rake was hung by a fishing line (used to reduce visibility of the support) which was attached to a hook at the top of the monitor, so the prongs of the rake were suspended next to the appropriate target box. The handle rested on the table in front of the participant. This kept the rake in approximately the same location as in the conditions where the rake was held. Again, each condition was run twice, and as in the passive hold condition participants performed an additional minute of the directed looking task before blocks with the rake present. Block order was randomized for all groups.

Results and Discussion

Based on inclusion criteria from previous studies (e.g., Reed et al., 2006), four participants were excluded from analysis for responding to over 50% of the catch trials presented during the experiment. These participants were likely not fully paying attention to instructions or not waiting for the target dot to appear before responding to a trial. Another two participants were excluded from analysis as they were determined not to have been fully following instructions by the researcher administering the study. Excluded participants were replaced. This left 150 participants to be analyzed, with 50 in each group. Furthermore, any trials shorter than 200 ms or longer than 1000 ms were omitted from analysis, as these likely indicate anticipation or inattention errors. This excluded 7.09% of trials.

The time to detect each target (measured in ms) was submitted to a 3 x 2 x 2 x 2 mixed-factors ANOVA, with a between-subjects factor of group (active, passive hold, or passive place) and within-subjects factors of validity (valid or invalid trials), rake presence (present or absent) and target distance (whether the target appeared on the side of the non-responding hand). It should be noted that target distance is only meaningful when the rake is held or placed next to the monitor, as the target will appear near the rake or on the opposite side of the monitor. If the researcher removed the rake, the target distance factor served as a control/comparison condition. All results from this ANOVA are reported in Table 1, and mean reaction times from each condition are displayed in Figure 1. This discussion will focus on the significant results of this ANOVA that are most theoretically relevant.

Table 1

Results from 3 x 2 x 2 x 2 Mixed-Factors ANOVA for Experiment 1

Factor	F Value	Significance	η_p^2
Validity	F(1, 147) = 568.302	<.001*	.794
Validity * group	F(1, 147) = .021	.979	.000
Rake presence	F(1, 147) = .198	.657	.001
Rake presence * group	F(1, 147) = 1.453	.237	.019
Target distance	F(1, 147) = 6.376	.013*	.042
Target distance * group	F(1, 147) = 4.384	.014*	.056
Validity * rake presence	F(1, 147) = 1.618	.205	.011
Validity * rake presence * group	F(1, 147) = .056	.946	.001
Validity * target distance	F(1, 147) = 2.157	.144	.014
Validity * target distance * group	F(1, 147) = 2.848	.061	.037
Rake presence * target distance	F(1, 147) = 13.035	<.001*	.081
Rake presence * target distance * group	F(1, 147) = 3.399	.036*	.044
Validity * rake presence * target distance	F(1, 147) = 5.504	.020*	.036
Validity * rake presence * target distance * group	F(1, 147) = .788	.457	.011

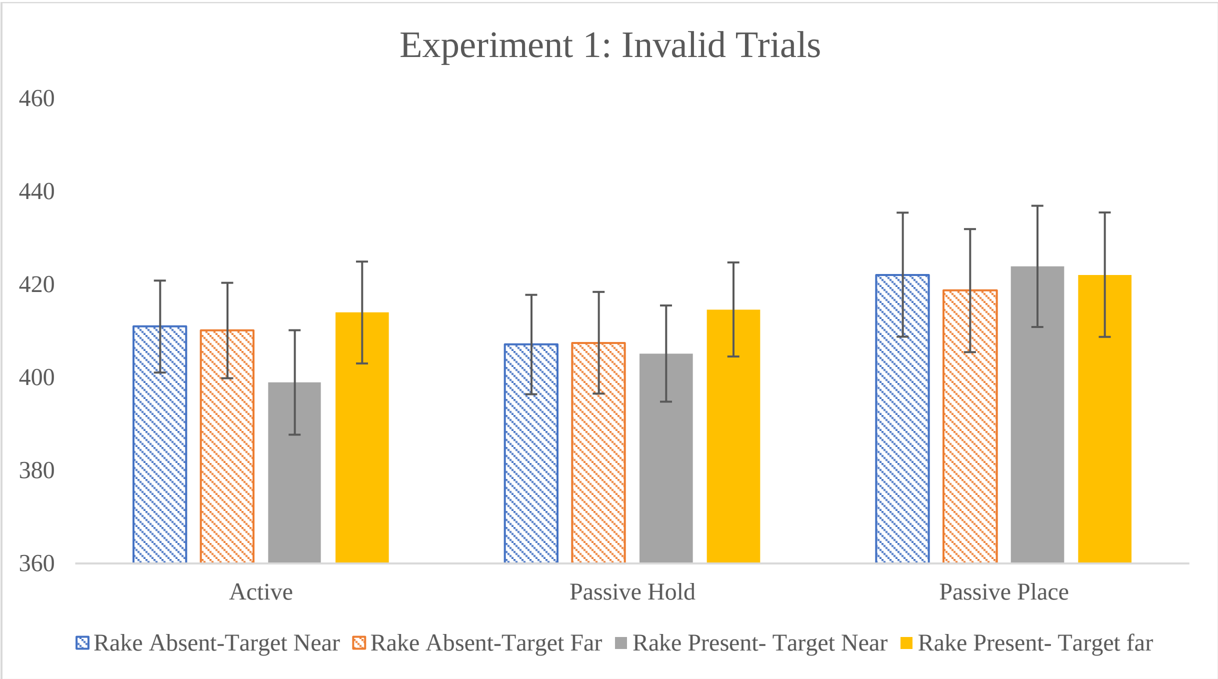
Note: Factors included group assignment (active, passive hold, or passive place), validity, rake presence (whether the rake was present or absent), and target distance (whether the target appeared either near the rake or on the side of the non-responding hand).

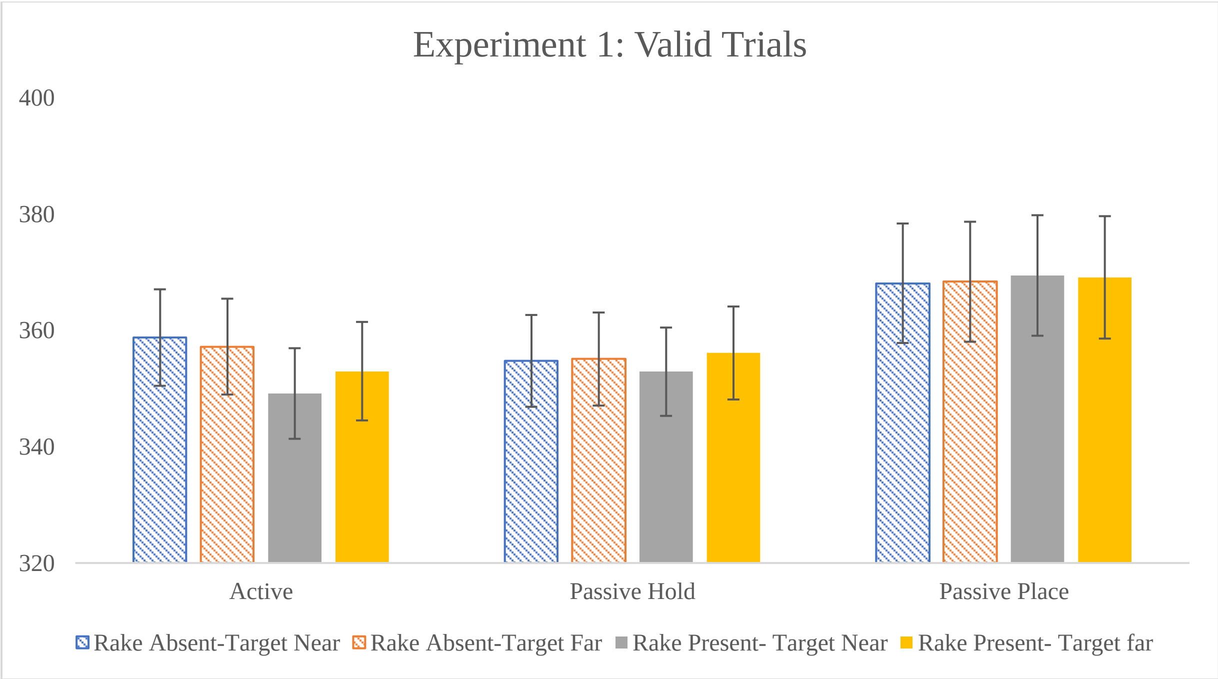
The ANOVA yielded a large main effect of validity (F (1, 147) = 568.302, $p < .01$, η_p^2 = .794) which was expected based on the paradigm used. The ANOVA also yielded a main effect of target distance (F (1, 147) = 6.376, p = .013, η_p^2 = .042). There were also significant interactions between target distance and group assignment, (F (1, 147) = 4.384, p = .014, η_p^2 = .056) and between rake presence (present or absent) and target distance (F (1, 147) = 13.035, p < .01, η_p^2 = .081). The latter interaction indicates that participants tended to respond faster to targets presented near the rake than targets far from the rake when that rake was next to the monitor. This is the critical interaction that indicates near-tool effects are present in this paradigm and means that this experiment was successful in replicating past results (e.g., Reed et al., 2010). Importantly, these interactions were qualified by a significant interaction between rake presence, target distance, and group assignment (F (1, 147) = 3.999, p = .036, η_p^2 = .044), which indicates that the key interaction between rake presence and target distance signaling the presence of near-tool effects differed across groups. The ANOVA also yielded an interaction between validity, rake presence, and target distance (*F* (1, 147) = 5.504, *p* = .020, η_p^2 = .011). This is likely due to the fact that there are significantly greater reaction times for invalid trials than valid trials, and therefore a greater magnitude of the near-tool effect for invalid trials than valid trials, as seen in the graphs in Figure 1. For invalid trials when the rake was up near the monitor, targets near the rake were detected (on average) 15 ms faster than targets far from the rake in the active condition, 14 ms faster in the passive condition, and 2 ms slower in the place condition. On valid trials however, targets near the rake were detected 4 ms faster than targets far from the rake in the active condition, 3 ms faster in the passive condition, and showed no difference in the place condition.

We ran three separate mixed 2 x 2 x 2 x 2 ANOVAs to directly compare the extent to which the key rake presence x target distance interaction itself differed across groups (see Appendices A-C). Running ANOVAs directly comparing the active and passive hold groups and the passive hold and passive place groups did not yield significant interactions between group, rake presence, and target distance (*p* = .125 or greater in both comparisons), but this key interaction was significant between the active and passive place groups (*F* (1, 98) = 5.993, *p* = .016, η_p^2 = .058). These results indicate that the active and passive place conditions were significantly different in the extent to which they yielded a near-tool effect, whereas the near-tool effect did not differ significantly across the active and passive hold conditions, nor between the passive hold and passive place conditions. Planned pairwise comparisons for reaction time data collapsed across validity also show significantly faster target detection near a tool than far from a tool for the active condition (*t* (49) = -3.031, *p* = .004) and the passive hold condition (*t* (49) = -2.606, *p* = .012), but not in the passive place condition (*t* (49) = .354, *p* = .725). These pairwise comparisons suggest that target detection was faster near the rake than far from the rake in both the active condition and in the passive hold condition, but not in the passive place condition.

Figure 2

Results from Experiment 1





Average reaction times for Experiment 1 are depicted above. Data was split by valid and invalid trials. The patterned columns are comparisons between trials where the rake was absent, while the solid columns indicate trials where the rake was present and held next to the screen. Error bars indicate ±1 SEM.

These results fit the larger pattern of near-tool effects found in the literature: actively using a tool or holding a tool elicits near-tool effects, which in this case meant faster target detection near the end of the rake. I successfully replicated previous findings of faster target detection near the end of a tool in the active use condition (e.g., Reed et al., 2010), suggesting that the task and the tool I used were appropriate for more deeply investigating near-tool effects. Based on the results of the 3 x 2 x 2 x 2 ANOVA, the near-tool effect I found did differ across groups, as group assignment itself interacted with the critical rake presence x target distance interaction. The 2 x 2 x 2 x 2 comparison ANOVAs and pairwise comparisons indicated that the active condition, which did show faster target detection for targets near the held rake than targets far from the held rake, was significantly different from the passive place condition, where the presence of the rake did not influence target detection times. These results, taken alone, are strongly supportive of the active use account, as they show that developing an active relationship with the tool led to near-tool target detection facilitation. This is inconsistent with the strictest interpretation of the attentional account, as it was clear that simply seeing a tool—presumably a visually salient object—on one side of a monitor did not elicit near-tool effects. The difference in target detection times between the active use and passive place groups cannot be explained on the basis of visual salience alone.

The outcome in the passive hold condition, however, complicates the interpretation of these results. The near-tool effect in the passive hold condition was not significantly different from this effect in the active use condition based on the results of a 2 x 2 x 2 x 2 comparison ANOVA, and indeed pairwise comparisons showed significant facilitation of target detection in both conditions. Participants were faster to detect targets appearing near a tool they held than targets far from this tool, regardless of whether they had recently used that tool to retrieve objects or not. The lack of a clear significant difference between the near-tool effect observed in the active use and passive hold groups is not consistent with a strict interpretation of the active use account, as it suggests that active use is not necessary to elicit near tool effects: simply holding a tool without any active task beforehand is enough to change target detection speeds. According to the most basic version of the active use account, holding a tool should not induce any update to the body schema. These results are instead more in line with the attentional account, as it seems that attentional prioritization is no different when actively using or passively holding a tool.

Proponents of the active use account do have a counterargument to the lack of significant difference between a passively held tool and an actively used one, which is a pattern of results often seen in the literature (Farnè & Làdavas, 2000; Rossetti et al., 2015). They have argued that passively holding a tool, given that it is simple enough to use, can activate prior motor knowledge of using the tool (or similar ones). The participant can mentally simulate how they might use the tool, which actually has the same end result as if they had physically used the tool. They are then able to develop an active relationship with the tool, which induces an update to the body schema (Serino et al., 2015). Intuitively, this does make sense: the goal of actively using the tool in this experiment is to give the participant a sense of agency with the tool, or a sense that they can use the tool to interact with the items around them that were previously out of reach. If a tool is simple or familiar enough, however, that sense of agency may come as soon as a participant picks up the tool, eliminating the need for any practice beforehand. The results of this experiment are consistent with this modified version of the active use account: in the active use and passive hold conditions, where I would expect participants to develop a sense of agency with the tool, I do see evidence of targets presented near the end of that tool being detected faster than targets far from that tool. In the passive place condition, however, where I would not expect participants to have a sense of agency with the tool (since they never held it), there is no difference in target detection near and far from the tool.

Further complicating interpretation of the results was the fact that the critical rake presence x target distance interaction in the passive hold condition was also not significantly different from this interaction in the passive place condition based on the results of the 2 x 2 x 2 x 2 comparison ANOVA. Although pairwise comparisons showed significant facilitation of target detection near the rake in the passive hold condition, but not in the passive place condition, this difference in facilitation between groups did not reach statistical significance in the ANOVA. This is consistent with the active use account, which would not predict any difference between conditions without an active use task. Neither condition involved practicing with the tool, so based on the arguments of the active use account one would not predict that either condition would successfully elicit near-tool effects. However, this is consistent with the attentional account as well. Visually, there was no difference between the tools used in the passive hold and passive place conditions, so there should be no difference in performance on a target detection task.

A modified version of the attentional account may also explain the difference between the active use and passive place conditions seen in this experiment. While an actively used tool and a passively placed tool are visually identical to the participant, proponents of the attentional account have argued that performing an active use task actually increases the visual salience of a tool (Holmes et al, 2007). This is driven by the mechanical connection between the participant and the tool, as well as a shift in the depth of attention paid to the end of an actively used tool. A tool that has been moving around a table, interacting with objects, may be more visually interesting and demand more attention than a stationary tool that has been placed in front of the participant (Holmes et al, 2007). This does offer an attention-based explanation for why I found a difference between the active use and passive place conditions that need not appeal to alterations to the body schema and peripersonal space. However, this is a very difficult explanation to falsify, as visual salience is a highly complex construct. One goal of the next experiment will be to address this possibility, by entirely eliminating the visual salience of a tool by placing it behind a paper shield.

There were several goals of this first experiment, the first of which was to serve as a controlled version of a typical near-tool experiment with clear definitions of active use and passive hold conditions. This goal was met: I implemented a rigorous definition of a tool task, in which participants used a tool to physically interact with their environment and found participants were faster to detect targets near the end of an actively used tool. The paradigm I used therefore successfully elicited near-tool effects. However, there was great variability in the literature on how authors defined active and passive use, with "active" sometimes defined as simple holding of a tool (Maravita et al., 2001; Yue et al., 2008), to moving a tool around a table (Holmes et al., 2007), to using a tool to interact with objects (Reed et al., 2010; Rossetti et al., 2015). Similarly, "passive" use has been defined as placing a tool in front of a participant (Maravita et al., 2001) or a participant holding a tool (Rossetti et al., 2015). Along with the great variability in the type of tools used in the literature, this lack of consistent definitions has made direct comparison between different studies very difficult. Unlike a typical near-tool study, this experiment contained three conditions to more clearly examine where differences between previously labeled "active" and "passive" experimental conditions arise. I found that passive place and active use conditions were certainly different from one another in the extent to which they elicited a near-tool effect. But the results of the passive hold condition (which has been defined as active holding in other experiments (Maravita et al., 2001; Yue et al., 2008)) were not statistically different from either the clear presence of the near-tool effect in the active use condition nor the clear lack of a near-tool effect in the passive place condition. To help resolve this ambiguity and further tease apart the active use and attentional accounts of near-tool effects, Experiment 2 controlled for the tool's visual salience.

EXPERIMENT 2

Method

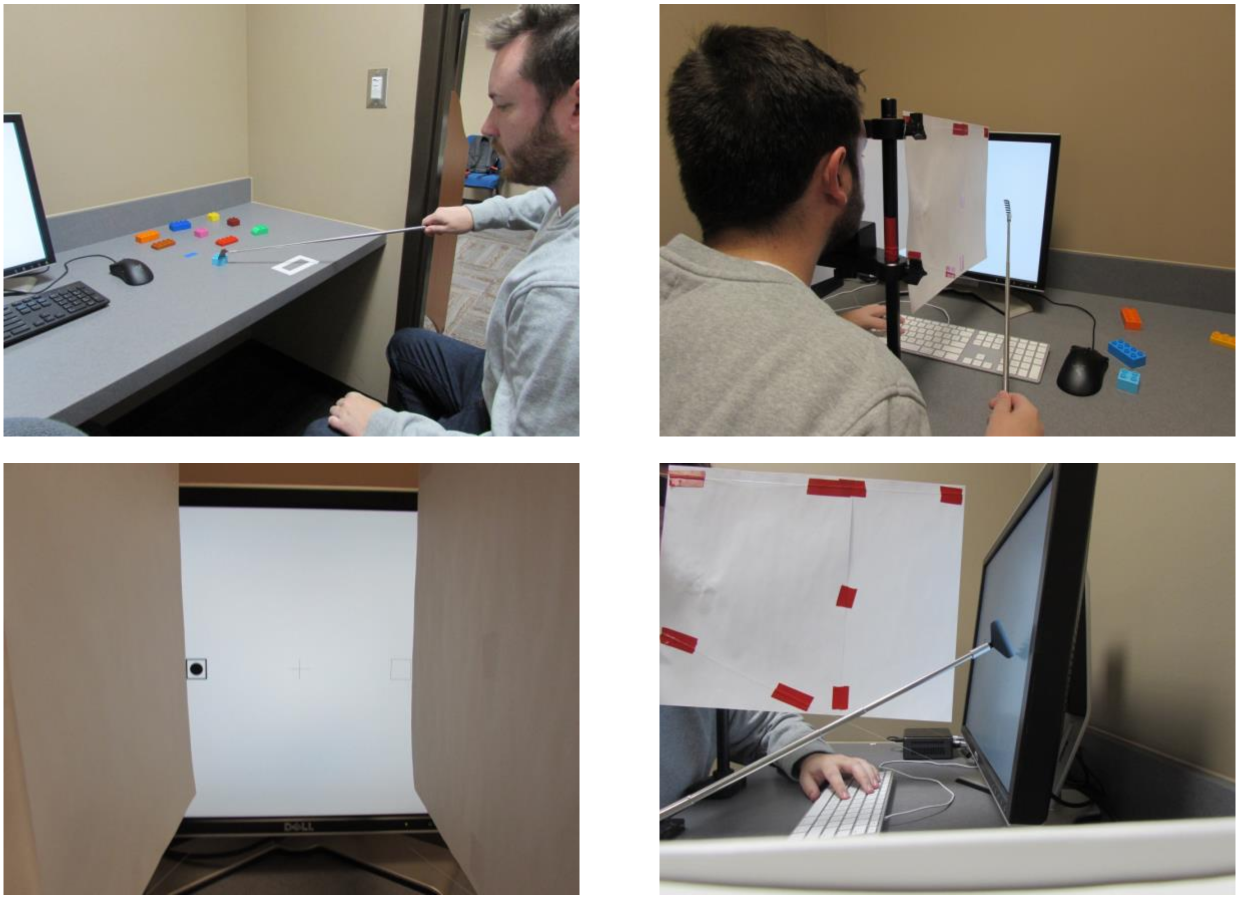
Experiment 2 followed a similar procedure to Experiment 1 but incorporated a paper shield to prevent participants from viewing the tool during the target detection task. The purpose of the shield is to differentiate between the active use and attentional accounts by eliminating the tool's visual salience while maintaining contact and control of the tool behind the shield. If participants hold a tool that they have actively embodied during a practice task near a monitor, but they cannot see the tool due to the shield, any target detection facilitation near the end of the hidden tool is unlikely to be due to visual attentional biases. In contrast, if participants show no evidence for near-tool facilitation when the tool is behind a shield, despite having an active relationship with the tool and full control over it during the target detection task, it may indicate that near-tool effects are contingent on being able to see the tool, a result more in line with the attentional account.

Fifty-four participants were recruited for Experiment 2 through SONA for course credit or for pay. Again, the number of participants was based on subject numbers for previous studies (McManus & Thomas, under review; Reed et al., 2010). All participants were right-handed and had normal or corrected to normal vision. Participants recruited for Experiment 2 were all assigned to the shielded condition. Results from this condition were then compared to the data from the active condition in Experiment 1, which has been renamed as the unshielded condition for this experiment.

To reiterate, participants in the active condition in Experiment 1 (referred to as the unshielded condition in this experiment) began by completing a retrieval task using a 60 cm rake. Participants were sat at a table with several Legos spread over it, then spent two and a half minutes retrieving Legos with the rake as the Legos were named by a researcher. After the retrieval task, participants completed eight blocks of a Posner cuing task under one of four conditions: 1) with the tool held in the right hand next to the right target box, responding to targets with the left hand; 2) with the tool held in the left hand next to the left target box, responding to targets with the right hand; 3) with the tool removed, the right hand down on the desk, and responding to targets with the left hand; and 4) with the tool removed, the left hand down on the desk, and responding to the targets with the right hand. Each condition was completed twice in a random order. Before blocks with the tool present, participants completed an additional minute of the retrieval task using the hand indicated by the instructions, to ensure they did not lose an active relationship with the tool.

Figure 3

Experimental Setup for Experiment 2



The four panels depict the experimental setup for the shielded condition. Participants in the shielded condition performed the same retrieval task as in the active use condition, as shown in the top left panel. The top right panel shows the target detection phase for the shielded condition. The bottom left panel depicts what the participant would see during the target detection phase: they could see the target boxes, but not the rake next to the target location. The bottom right panel shows that while the participants could not see the rake, the shield did not block the rake from interacting with the screen.

Participants in the shielded condition performed the same retrieval task, retrieving Legos spread around a table as they were named by a researcher. Participants used the same 60 cm rake from the previous experiment. After the retrieval task, participants ran through the Posner cuing task under the same four conditions as the shielded group, but with a paper shield attached to the monitor that hid the tool from view. The shield was positioned between the participants' eyes and the tool, but did not separate the tool from the monitor. This eliminated the visual salience of the tool without eliminating the participants' affordance for interaction with the monitor. The same four conditions were used: two conditions where the tool was present, one on the left side and one on the right side, and two conditions with the tool absent and the non-responding hand resting on the desk. Each condition was performed twice, for a total of eight blocks. Participants underwent an additional minute of the retrieval task before blocks with the tool present. These additional retrieval sessions were performed using the hand that would be holding the rake next to the screen in order to maintain an active relationship between the rake and the participant.

Results and Discussion

Data collected for the shielded condition in this experiment was subjected to the same screening process as in Experiment 1 (based on previous work, i.e. McManus & Thomas, under review; Reed et al, 2010). Three participants were dropped from analyses and replaced for responding to more than 50% of catch trials, leaving data from 51 participants to be analyzed. Any trials greater than 1000 ms or shorter than 200 ms were also excluded from analyses, dropping 8.5% of all trials.

Reaction times to detect each target were submitted to a 2 x 2 x 2 x 2 Mixed-Factors ANOVA. Factors included the between-subjects group manipulation (shielded vs unshielded), plus the within-subjects factors of validity (valid or invalid trials), rake presence (whether the tool was held up near the monitor or put aside), and target distance (whether the target was presented near or far from the tool when held up near the monitor, or whether the target was on the same or opposite side of the non-responding hand when the tool was placed aside). Results from the ANOVA are reported in Table 2, and the mean RTs for each condition are shown in

Figure 4. I will again focus the discussion on the ANOVA results that are most relevant to the theories under investigation.

Table 2

Results from 2 x 2 x 2 x 2 Mixed-Factors ANOVA for Experiment 2

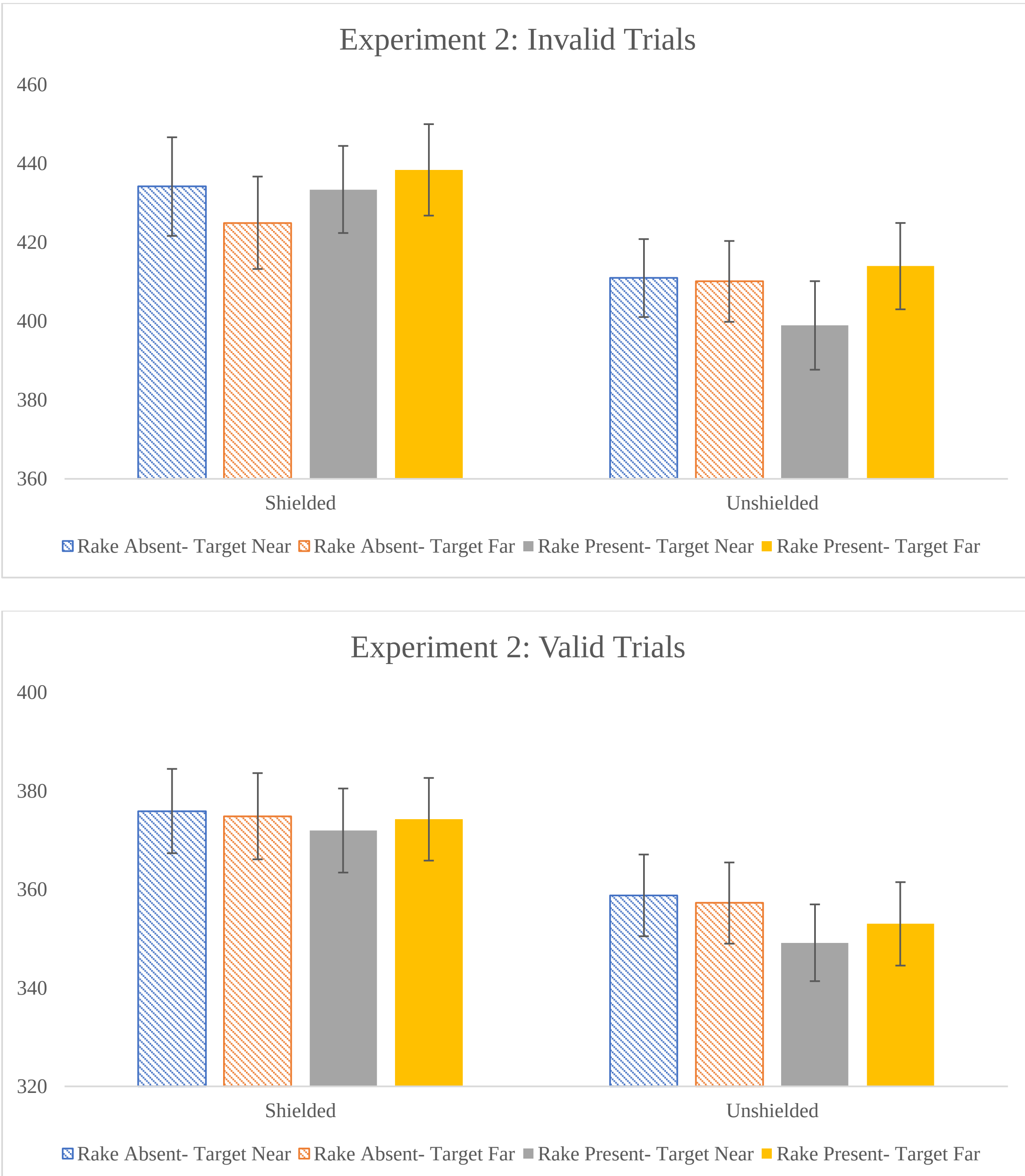
Factor	F Value	Significance	η_p^2
Validity	F(1, 99) = 460.550	<.001*	.823
Validity * group	F(1, 99) = .759	.386	.008
Rake presence	F(1, 99) = .374	.542	.004
Rake presence * group	F(1, 99) = 1.759	.188	.017
Target distance	F(1, 99) = 1.416	.237	.014
Target distance * group	F(1, 99) = 2.942	.089	.029
Validity * rake presence	F(1, 99) = 4.072	.046*	.040
Validity * rake presence * group	F(1, 99) = 1.034	.312	.010
Validity * target distance	F(1, 99) = .594	.443	.006
Validity * target distance * group	F(1, 99) = 4.290	.041*	.042
Rake presence * target distance	F(1, 99) = 12.732	.001*	.114
Rake presence * target distance * group	F(1, 99) = .123	.727	.001
Validity * rake presence * target distance	F(1, 99) = 5.234	.024*	.050
Validity * rake presence * target distance * group	F(1, 99) = .001	.972	.000

Note: Factors included group assignment (shielded or unshielded), validity, condition (whether the rake was present or absent), and target distance (whether the target appeared either near the rake or on the side of the non-responding hand).

As expected based on the cuing paradigm, the ANOVA yielded a strong main effect of validity (F (1, 99) = 460.550, $p < .001$, $\eta_p^2 = .823$). Valid trials were detected significantly faster than invalid trials. There was a significant interaction between validity and rake presence (F (1, 99) = 4.072, $p = .046$, $\eta_p^2 = .040$) as well as an interaction between validity, target distance, and group assignment (F (1, 99) = 4.290, $p = .041$, $\eta_p^2 = .042$). Importantly, I did see the critical interaction between rake presence and target distance (F (1, 99) = 12.732, $p = .001$, $\eta_p^2 = .114$), which was qualified by the interaction between validity, rake presence and target distance (F (1, 99) = 5.234, $p = .024$, $\eta_p^2 = .050$). Across the shielded and unshielded groups, targets presented near a rake were detected faster than targets presented far from that rake when that rake was held near a monitor. As can be seen in Figure 2, this effect was also much more pronounced for invalid trials than for valid trials, likely due to the greater RTs allowing for stronger near-tool effects to emerge. Importantly, the near-tool effect was not significantly different between the shielded and unshielded groups (rake presence x target distance x group $p = .727$; validity * rake presence * target distance * group $p = .972$).

Figure 4

Results from Experiment 2



Average Reaction times for experiment 2, split by valid and invalid trials. Patterned columns indicate blocks with the rake placed aside (the comparison condition), while solid blocks indicate blocks with the rake held next to the monitor. Error bars reflect standard error for each condition. Error bars indicate 1 SEM.

While caution should be exercised when interpreting a null result, the lack of a significant difference between the shielded and unshielded condition in the degree of target detection facilitation near the rake does suggest that near-tool effects are not due to visual salience alone. This may indicate that removing a tool's visual salience does not suppress target detection facilitation, which provides strong evidence against the attentional account. This pattern is consistent with a previous study which examined the relative contributions of visual and proprioceptive inputs to near-hand target detection. Instead of holding a tool up to the side of a monitor, participants held a hand up to the monitor, which was either freely within view or obscured behind a cardboard box. This study found that proprioceptive input alone was sufficient to induce faster target detection in the space near the hands (Reed et al., 2006). The results here show the same pattern of findings for the space around a tool, suggesting that updates to the body schema are driving near-tool target detection facilitation in this experiment.

With that said, however, it may be that this experiment simply does not have the power to detect a significant difference that may be present. The magnitude of target detection facilitation is certainly greater in the unshielded condition than in the shielded condition: targets near the end of an unshielded rake were detected 4 ms faster in valid trials and 15 ms faster in invalid trials than targets far from the rake, while targets near the end of the shielded rake were detected 2 ms faster in valid trials and 5 ms faster in invalid trials than targets far from the shielded rake. Planned pairwise comparisons between targets near and far from the shielded and unshielded rake, collapsed across validity, also do show a significant difference between near and far targets for the unshielded condition, (t (49) = .004 for targets near and far from a held rake) but do not show the same significant difference for the shielded condition (t (50) = .305 for targets near and far from a held rake). However, a larger near-tool effect in the unshielded condition than the shielded condition is consistent with the above-mentioned near-hand study, which also found that near-hand effects were stronger when a hand was freely visible than when it was obscured (Reed et al., 2006). The authors of this study suggested that while visual salience is not the sole driver of near-hand effects, visual information does contribute to updating of the body schema. Similarly, these findings indicate that eliminating visual inputs and relying solely on tactile and proprioceptive information may reduce the magnitude of the near-tool effect found in this experiment, but this effect in the shielded conditions was not significantly different from the near-tool effect in the unshielded condition.

While these results do provide evidence against the attentional account, they do not necessarily rise to the level of falsification. The near-tool target detection facilitation in this experiment did not depend on group assignment, and target detection was faster near the end of the shielded and unshielded tool than across the monitor. However, the lack of significant pairwise comparisons and the reduced magnitude of the effect in the shielded condition prevent falsification of the attentional explanation. These results may very well be due to the fact that the body schema does rely on visual inputs, and restricting the available information sources makes it more difficult to update and maintain the body schema. This outcome is not inconsistent with the active use account. However, caution should be exercised when attempting to trace the theoretical implications of a null result, particularly when falsifying a possible explanation for a phenomenon. More work may be needed to definitively meet this standard.

GENERAL DISCUSSION

The purpose of this study was to conduct a series of experiments to test the two competing explanations for near-tool visual biases. The first explanation, known as the active use account, holds that after a period of practice with a tool an individual can incorporate that tool into their body schema. The tool is treated as an extension of the arm, granting the area around the tool many of the same visual biases to improve action accuracy. The alternative explanation for the visual biases seen near tools is that these effects are not due to any change in the body schema, but instead are a result of the visual salience of the tool naturally capturing attention. This is referred to as the attentional account, and unlike the active use account it maintains that near-tool effects are not contingent on practice using a tool.

The first experiment of this study served as a rigorous replication and extension of previous near-tool studies (e.g., Reed et al., 2010), comparing target detection speeds between groups that actively used, passively held, or passively viewed a tool. Participants in the active use condition used a rake to retrieve a series of Legos, while participants in the passive hold and passive place condition merely looked at the same Legos. Participants then performed a target detection task, with participants in the active use and passive hold conditions holding the rake next to one of the target locations while participants in the passive place condition saw a researcher suspend the rake next to one of the target locations. Overall, I did find evidence of near-tool effects using this paradigm; collapsing across groups, participants detected targets presented near the end of a tool significantly faster than targets appearing far from the tool. This effect was also found to depend on group assignment, as direct comparison between the active use and passive place groups revealed that while there was strong target detection facilitation near tools in the active use group, there was no evidence of any change in target detection near the end of a passively placed tool. The passive hold group, however, landed in the middle ground between the two other conditions. Planned pairwise comparisons did show evidence of target detection facilitation near the end of a passively held tool, but this group was not significantly different from the passive place group based on the results of a comparison ANOVA.

While the first experiment served mainly to reproduce results from the existing literature under more controlled conditions (Maravita et al., 2001; Reed et al., 2010; Rossetti et al., 2015;), the purpose of the second experiment was to more thoroughly test the predictions of the active use and attentional accounts, with the goal of falsifying one of these competing explanations. Data from the active use group in Experiment 1 was compared to participants that completed the same procedure but with a paper shield blocking their view of the tool during the target detection task. Participants completed the same active use task of retrieving Legos using the same tool and held the tool in the same locations during a target detection task, but by implementing a paper shield I removed any visual signal of the tool. Under the shielded condition, I did find a trend of target detection facilitation; targets near the end of the shielded tool were detected faster than targets far from the tool, and this pattern of facilitation was not found to be significantly different from participants in the unshielded condition. However, some caution is advisable when interpreting null results, and it should be noted that the detection times between targets near and far from a shielded tool did not rise to the level of significance based on pairwise comparisons. While this experiment showed that blocking sight of an actively used tool did not significantly change target detection facilitation around a tool (as compared to an unshielded condition), it does suggest that eliminating visual inputs may reduce the magnitude of near-tool effects.

Unfortunately, reluctance to rely on null results to make strong theoretical claims means the outcomes of these experiments cannot falsify either explanation. Statistical analyses of the above data did not produce definitive enough results to claim that the active use or attentional account are impossibilities. However, I do find these results to favor of the active use account than the attentional account. At their most basic forms, the active use account states that near-tool effects are contingent on active practice with a tool, while the attentional account holds that practicing with a tool does not induce near-tool effects. In Experiment 1, the difference between the active use and passive place groups provides strong evidence in favor of the active use account. The tools used by both groups were visually identical. The only differences between the conditions were that participants in the active use group performed a retrieval task while participants in the passive place group performed a directed looking task, and the active use group held the tool next to the monitor during the target detection task while the passive place group had the tool set in front of them by a researcher. These results do provide evidence that an active relationship with a tool elicits near-tool effects, which is strongly in line with the active use account. Results from the passive hold condition may not support the most basic version of the active use account, as this group seemed to show evidence of faster target detection near a held tool without any previous practice. However, these results are consistent with a modified (and widely accepted) active use explanation, which states that a simple and familiar tool can activate prior motor knowledge just through holding, developing an active relationship without the need for a practice period (Baccarini et al., 2014). The tool used in this experiment was quite simple and the results from the passive hold condition are in line with this modified active use account.

Experiment 2 also offers evidence in favor of the active use account. While the magnitude of the target detection facilitation may have been reduced, there was a trend of faster target detection near tools held behind a paper shield than far from the tools—a trend that did not differ significantly from the facilitation in the unshielded condition. According to the active use account, in the absence of visual input participants should still have an intact representation of the body schema from proprioceptive and tactile inputs (Berlucchi & Aglioti, 1997; Graziano & Cooke, 2006; Reed et al., 2006), and so should still show faster target detection near the ends of shielded tools. The body schema does incorporate visual information, so restricting the visual stream may make updates to the body schema somewhat more difficult (Berlucchi & Aglioti, 1997; Graziano & Cooke, 2006), which offers an explanation for the reduction in the magnitude of near-tool effects seen in the shielded condition.

However, these results do not entirely falsify the attentional account. In Experiment 1, participants in the passive hold condition did show target detection facilitation near the end of passively held tools, offering some evidence that active use may not be necessary for near-tool effects. While there was a significant difference between the active use and passive place groups, proponents of the attentional account have raised a possible explanation. They suggest that actively using a tool, or even holding it, may increase its visual salience (Holmes et al., 2007). A tool that is moving around a table is more salient than one that is stationary, and a stationary tool physically held by a participant may be more visually salient than one that is passively placed in front of the participant. The results of Experiment 1 are therefore not entirely inconsistent with the attentional account. As for Experiment 2, the fact that pairwise comparisons failed to yield statistically significant evidence of target detection facilitation in the shielded condition is consistent with predictions of the attentional account. While there was no statistical difference between the shielded and unshielded groups, this null result may be due to low experimental power as opposed to an actual equivalence in the near-tool effect observed in these groups. These experiments, taken alone, do not necessarily disprove the arguments made in the attentional account.

To accomplish the ultimate goal of this study (falsifying either the active use or attentional account) further experiments are still needed. I do have a planned follow-up experiment[1] designed to test the active use account, or more specifically, the modification to this account that suggests simply holding familiar tools may allow them to be incorporated into the body schema. I planned to employ a novel tool that participants had no prior experience using in a similar paradigm used in these experiments (see appendix D for the experimental setup for this follow-up). By comparing performance on a target detection task between a group that has had time to practice with the novel tool and a group that only passively holds the tool during the target detection task, I hope to eliminate any prior motor knowledge or simulation effects confounding the results. If it turns out that participants in the active use group still show significant levels of target detection facilitation near the novel tool, while participants in the passive hold condition no longer show any difference in target detection speed near the tool, it would seem that the target detection facilitation seen in Experiment 1's passive hold group was in fact due to familiarity with the tool, and would provide strong support for the modified active use account. If both the active use and passive hold groups still show significant target detection facilitation near the end of the tool, it will instead indicate that target detection facilitation in the passive hold group is not due to any familiarity effects. This result would suggest that active use is not necessary to elicit near-tool effects.

Other possible future directions for this work to take include incorporating neural measures into this paradigm, or running similar experiments using a cross-modal competition

[1] Data collection for this experiment was underway when campus was shut down to prevent spread of COVID-19.

paradigm instead of the target detection paradigm. By using TMS, one could experimentally manipulate the active brain regions during the experiments carried out in this study. Proponents of the active use account have theorized that the premotor cortex and the posterior parietal region should be active if the body schema and peripersonal space expansion are driving near tool effects (Berlucchi & Aglioti, 1997; Longo & Lourenco, 2006; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997; Rizzolatti, Scandolara, Matelli, & Gentilucci, 1981). Neural activity in the premotor cortex is believed to indicate that the brain is preparing to interact with the targets as if they appeared near the hand, in line with the active use account. Offering some indirect evidence for this phenomenon, a study was carried out concerning the role of motor imagery: after researchers had participants imagine using a tool—which theoretically would activate the motor cortex—the researchers found that participants had significantly different grasp kinematics, as if they were mentally accounting for the tool they had imagined using (Baccarini et al., 2014). TMS may be a fruitful avenue here: simulating a lesion in the premotor cortex may suppress near-tool effects by deactivating that preparation for action, or may even provide a control for simulation effects.

As for the posterior parietal cortex, this area has been linked to representation of the body schema, so activity here, possibly during an active practice session, may provide evidence that the body schema is updating to include the tool (Longo & Lourenco, 2006). Adding TMS into the shielded paradigm could help to determine whether the body schema is responsible for any near-tool target detection facilitation near a shielded tool. As I discussed in Experiment 2, in the absence of visual input, any near-tool effects are likely due to the tool's incorporation into the body schema. Experimentally manipulating activity in the brain regions thought to be responsible for the body schema, could better show if that is the case. If, on the other hand, neural measures find that there is no difference between neural activity when the tool is or is not held near the monitor, or if the only differences are in visual areas of the brain, it may instead indicate that near-tool effects are a purely visual phenomenon, consistent with the attentional account.

Employing a cross-modal competition paradigm to examine some of the questions posed in this study is also a potentially fruitful future direction. Inside peripersonal space, visual and tactile information are processed together, leading to reduced detection accuracy and speed if the two modalities occur in different locations, but better speed and accuracy if the two modalities are presented in the same location (Brozzoli et al., 2009; Farnè et al., 2005; Maravita et al., 2002). This is specific to stimuli inside peripersonal space: visual and tactile stimuli in extrapersonal space will not interact (Iriki et al., 1996). Using the cross-modal competition paradigm, researchers have been able to draw conclusions about whether peripersonal space has expanded around a tool. Running the experiments described in this study using a cross-modal competition paradigm, rather than the target detection paradigm, would provide an additional source of evidence to clarify the results of this study. It would also serve to determine whether cross-modal competition and target detection paradigms are consistent with each other, or whether they may in fact be measuring different constructs. Several researchers have raised the concern that while the findings from cross-modal and target detection studies in humans are consistent with results from single-cell recordings of bimodal neurons in macaque monkeys, there is no hard evidence linking behavioral data in humans to neural activity in macaque monkeys (e.g., Holmes, Calvert, & Spence, 2004). Much of the near-tool research does stem from the assumption that the visual biases seen around tools are driven by bimodal neurons representing peripersonal space (Brozzoli et al., 2009; Maravita et al., 2002; Reed et al., 2006).

Conducting rigorous comparisons between target detection, cross-modal paradigms, and other paradigms used to study near-tool space, such as line bisection (Longo & Lourenco, 2006), and grasp kinematic paradigms (Baccarini et al., 2014), using the same underlying manipulations, would help provide evidence that they are in fact measuring the same construct. A more definitive answer on this would aid interpretation of previous results from these paradigms and allow us to properly assess the strength of the evidence for either the active use or the attentional account.

It may also be beneficial to increase the power of Experiment 2, likely by increasing the sample size. While analysis does indicate that there may be no difference between the shielded and unshielded condition, too much weight should not be placed on a null result, particularly when pairwise comparisons do not show significant levels of facilitation near the shielded tool. More participants may be needed to determine whether the null result is due to target detection facilitation in both the shielded and unshielded condition, or due to a lack of experimental power.

Finally, a result found in this experiment which deserves additional follow up is the interaction between validity and near-tool effects. In both experiments, the critical interaction between rake presence and target distance was found to interact with validity. The difference in detection speed between targets near the rake and targets far from the rake was much greater for invalid trials than valid trials in both experiments. This may be partially due to the greater overall RTs and variability present in invalid trials. However, another possibility is that near-tool visual biases play more of a role in switching costs than in a general attentional prioritization around a tool. These results showed significant interactions between validity and the critical near-tool interaction (rake presence and target distance) in Experiment 1 (F (1, 147)= 5.504, p = .020, η_p^2 = .036) and in Experiment 2 (F (1, 99) = 5.234, p = .024, η_p^2 = .050), indicating greater magnitudes of near-tool target detection facilitation on invalid trials. These findings suggest that the participants found it easier to shift attention from an invalid cue towards a target if that target was near a tool than if the target was far from a tool. In other words, it is easier to shift attention towards a tool than away from a tool if that tool is actively used. For valid trials, however, where attention is already focused on the correct location, there was not as great a difference between detection speeds for targets near and far from the tool.

While the possibility that holding a tool or a hand next to a monitor influences shifts of attention rather than general attentional prioritization has been previously raised by other researchers (Reed et al., 2006), this result has not actually been found by other studies. A near-hand target detection study found that cue validity did not interact with target detection facilitation (Reed et al., 2006). This unexpected outcome in the current study could point to a possible difference between near-hand and near-tool visual biases. Tools may induce shifts of attention, while hands may induce more general prioritization of space. This would not be entirely unexpected: hands have the benefit of many tactile and proprioceptive neurons supplying info about the hand’s position and surroundings, which are not present in the tool. Additional experimentation could more thoroughly investigate what differences may exist between near-hand and near-tool effects.

In conclusion, while this study does not definitively falsify either the active use or the attentional account, I believe these results favor the active use account. Target detection facilitation did seem to depend on participants having an active relationship with the tool, although this active relationship may have derived from prior motor knowledge in the passive hold condition. Furthermore, I did find evidence that near-tool effects are not significantly mitigated by removing all visual information. Blocking participants sight of the tool did not significantly change target detection facilitation from a tool they could see. More work will need to be done to test the predictions made by each account and to falsify one explanation, but these experiments serve as a step towards doing so.

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APPENDIX

Table A1

2 x 2 x 2 x 2 Comparison ANOVA Between Active Use and Passive Hold

Factor	F Value	Significance	η_p^2
Validity	F(1, 98) = 401.503	<.001*	.804
Validity * group	F(1, 98) = <.001	.987	.000
Rake presence	F(1, 98) = .740	.392	.007
Rake presence * group	F(1, 98) = 1.664	.200	.017
Target distance	F(1, 98) = 12.977	<.001*	.117
Target distance * group	F(1, 98) = .137	.712	.001
Validity * rake presence	F(1, 98) = 1.323	.253	.013
Validity * rake presence * group	F(1, 98) = .001	.973	.000
Validity * target distance	F(1, 98) = 5.847	.017*	.056
Validity * target distance * group	F(1, 98) = .546	.462	.006
Rake presence * target distance	F(1, 98) = 17.663	<.001*	.153
Rake presence * target distance * group	F(1, 98) = 1.372	.244	.014
Validity * rake presence * target distance	F(1, 98) = 7.070	.009*	.067
Validity * rake presence * target distance * group	F(1, 98) = .465	.497	.005

Note: Factors included group assignment (shielded or unshielded), validity, condition (whether the rake was present or absent), and target distance (whether the target appeared either near the rake or on the side of the non-responding hand).

Table A2

2 x 2 x 2 x 2 Comparison ANOVA Between Passive Hold and Passive Place

Factor	F Value	Significance	η_p^2
Validity	F(1, 98) = 377.084	<.001*	.794
Validity * group	F(1, 98) = .029	.866	.000
Rake presence	F(1, 98) = .514	.475	.005
Rake presence * group	F(1, 98) = .032	.859	.000
Target distance	F(1, 98) = 1.202	.276	.012
Target distance * group	F(1, 98) = 6.360	.013*	.061
Validity * rake presence	F(1, 98) = .964	.329	.010
Validity * rake presence * group	F(1, 98) = .098	.755	.001
Validity * target distance	F(1, 98) = .025	.874	.000
Validity * target distance * group	F(1, 98) = 2.300	.133	.023
Rake presence * target distance	F(1, 98) = 3.414	.068	.034
Rake presence * target distance * group	F(1, 98) = 2.401	.125	.024
Validity * rake presence * target distance	F(1, 98) = 1.602	.209	.016
Validity * rake presence * target distance * group	F(1, 98) = .357	.551	.004

Note: Factors included group assignment (shielded or unshielded), validity, condition (whether the rake was present or absent), and target distance (whether the target appeared either near the rake or on the side of the non-responding hand).

Table A3

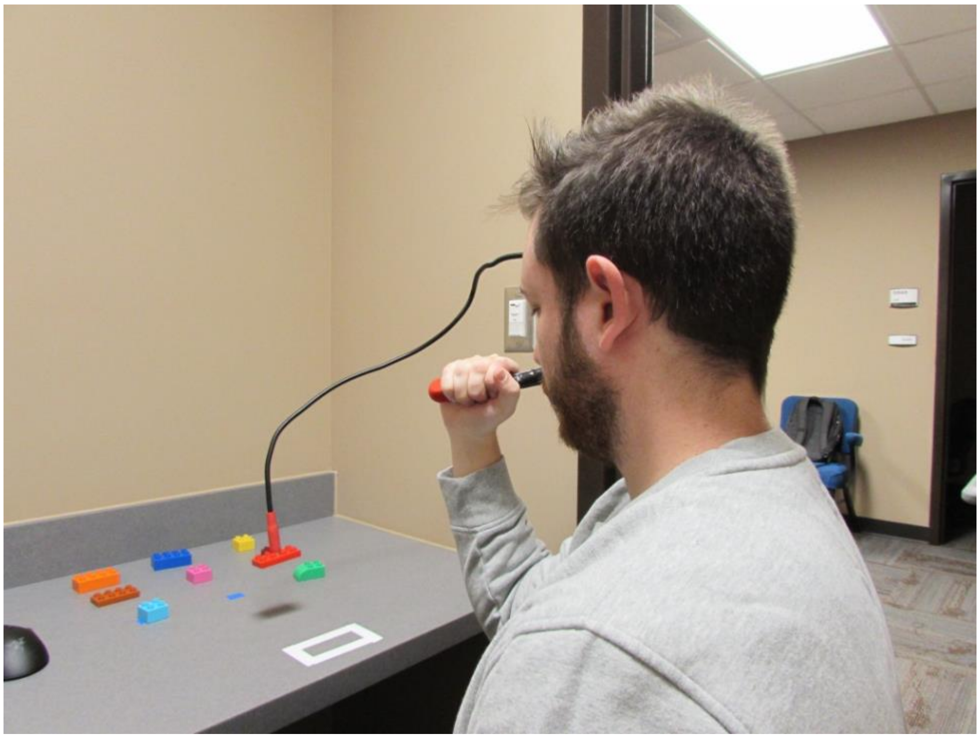
2 x 2 x 2 x 2 Comparison ANOVA Between Active Use and Passive Place

Factor	F Value	Significance	η_p^2
Validity	F(1, 98) = 359.941	<.001*	.786
Validity * group	F(1, 98) = .033	.857	.000
Rake presence	F(1, 98) = .553	.459	.006
Rake presence * group	F(1, 98) = 2.196	.142	.022
Target distance	F(1, 98) = 1.895	.172	.019
Target distance * group	F(1, 98) = 7.163	.009*	.068
Validity * rake presence	F(1, 98) = .952	.332	.010
Validity * rake presence * group	F(1, 98) = .081	.777	.001
Validity * target distance	F(1, 98) = 1.014	.316	.010
Validity * target distance * group	F(1, 98) = 6.415	.013*	.061
Rake presence * target distance	F(1, 98) = 7.308	.008*	.069
Rake presence * target distance * group	F(1, 98) = 5.993	.016*	.058
Validity * rake presence * target distance	F(1, 98) = 3.493	.065	.034
Validity * rake presence * target distance * group	F(1, 98) = 1.476	.227	.015

Note: Factors included group assignment (shielded or unshielded), validity, condition (whether the rake was present or absent), and target distance (whether the target appeared either near the rake or on the side of the non-responding hand).

Figure A1

Experimental Setup for the Planned Novel Tool Follow-up



This figure shows the practice task for the planned follow up experiment utilizing a novel tool. A flexible tool with a magnet at one end was used to complete a similar task as in Experiments 1 and 2. Magnets were attached to the Legos, allowing the participant to pick up the Legos and move them to the indicated box. The tool was bent into a more complex shape than in previous experiments, and the participant had to hold the tool using an unconventional grasp.