Distribution Agreement

Signature:

______________________________ _______________
Samuel Bennett Hunley Date

Approval Sheet

The Effect of Specific Tool Actions on Distance Estimation

By

Samuel Bennett Hunley

Master of Arts

Psychology

____

Stella F. Lourenco, Ph.D.
Advisor

____

Laura L. Namy, Ph.D.
Committee Member

____

Scott O. Lilienfeld, Ph.D.
Committee Member

Accepted:

____

Lisa A. Tedesco, Ph.D.
Dean of the James T. Laney School of Graduate Studies

______________ Date

The Effect of Specific Tool Actions on Distance Estimation

By

Samuel B. Hunley
B.S., Furman University, 2012

Advisor: Dr. Stella F. Lourenco, PhD

An abstract of

a thesis submitted to the Faculty of the

James T. Laney School of Graduate Studies at Emory University

In partial fulfillment of the requirements for the degree of

Master of Arts

In Psychology

2014

Abstract

The Effect of Specific Tool Actions on Distance Estimation

By Samuel B. Hunley

Using a tool that extends one's reach leads participants to estimate stimuli as closer than when pointing without a tool. According to the action-specific account of perception, such effects are the result of the perceptual system incorporating the specific affordances and consequences of a tool. Alternatively, such effects may result from an expanded representation of near space. Accumulating behavioral and neurological research has demonstrated that an individual's representation of near space expands with the introduction of a tool that extends reach. Thus, as one's representation of near space expands, objects may appear closer. The current study examined the effects of tool actions with varying consequences (tapping vs. pushing vs. pulling) and magnitude, on distance estimations in order to begin dissociating these accounts. Adult participants were asked to act on a target object by pointing with their finger (no tool condition) or using a baton to tap it, push it a short or long distance, or pull it a short or long distance (tool conditions). Afterwards, they performed distance estimations using a visual matching task. Our results revealed that participants significantly underestimated the target distance when using a tool to tap the object as compared to the pointing condition. However, we found no such underestimation when participants pushed or pulled the object and no effect of action magnitude. We interpret our results in regards to the competing accounts described above and discuss future studies.

The Effect of Specific Tool Actions on Distance Estimation

By

Samuel B. Hunley
B.S., Furman University, 2012

Advisor: Dr. Stella F. Lourenco, PhD

A thesis submitted to the Faculty of the

James T. Laney School of Graduate Studies at Emory University

In partial fulfillment of the requirements for the degree of

Master of Arts

In Psychology

2014

Table of Contents

Introduction

Humans wield tools with a precision and frequency rarely seen in the animal kingdom (Johnson-Frey, 2004). To be sure, there are a multitude of verified accounts of tool use in other species (Schumaker, Walkup, & Beck, 2011), and this tool behavior is impressive in its own right. However, humans have reached a unique level of competence. As a species, we have mastered tools as simple as stone hand axes and as complex as spaceships and particle colliders, and it is this proficiency that has enabled our species to succeed in even the harshest of environments. Despite the importance of tool use in human culture, the cognitive and perceptual consequences of this complex behavior remain poorly understood.

Accumulating evidence regarding the distinction between “near” and “far” space, also known as peripersonal and extrapersonal space respectively, offers potential insight into such consequences. Near space is typically described as the space within an organism’s reach or range of action (e.g., Berti & Frassinetti, 2000; Previc, 1998; Rizzolatti, Scandolara, Matelli, & Gentilucci, 1981). In contrast, far space is considered the space that is beyond an organism’s reach or range of action. Though the concepts of near and far space are not new to neurology or psychology (see Brain, 1941), Rizzolatti and colleagues provided the first direct neurological evidence of such a system through single-cell recording in macaque monkeys. In this study, the researchers identified neurons that activated specifically to objects within the monkey’s reach. Additionally, they found other neurons that fired only to objects outside of the monkey’s reach. These findings suggested that the brain codes for objects in near space differently than for objects in far space.

If near space is truly defined by one's actionable range, then it seems reasonable that anything that augments one's range of action could feasibly expand one's sense of near space (for review, see Maravita & Iriki, 2004). Iriki, Tanaka, and Iwamura (1996) found evidence for such expansion in their study utilizing single-cell recording with macaque monkeys. The researchers report that neurons, which previously responded only to objects near the hand, subsequently responded to objects placed near the end of a handheld rake after that rake had been used by the monkey. The authors took this finding to suggest that the rake was incorporated into the monkey's "body schema," or neural representation of their body (but see, Holmes, 2012).

Such findings have been extended to humans through studies of double dissociations between near and far space in the attentional deficits of neurological patients (e.g., Berti & Frassinetti, 2000; Cowey, Small, & Ellis, 1994; Halligan & Marshall, 1991). For instance, Berti and Frassinetti examined a patient with right parietal damage, who bisected lines far to the right of center (due to hemispatial neglect) in near space but not far space. However, the patient showed this neglect in far space as well when a baton extended her reach. This finding appears to indicate that the baton had extended the patient's representation of near space. Likewise, Ackroyd, Riddoch, Humphreys, Nightingale, and Townsend (2002) later substantiated this finding by demonstrating the opposite effect—a patient who demonstrated neglect in only far space no longer demonstrated neglect when using a tool to extend his reach. Thus, both of these cases, as well as others, present evidence for the near/far space distinction in humans as well as evidence that tool-use alters representations of near space (e.g., Farnè & Làdavas, 2000).

Studies of neurologically healthy participants also provide evidence for a distinction between near and far space. For example, lateral attentional biases have been found to differ as a function of viewing distance. When bisecting lines in near space, healthy participants demonstrate a slight, leftward bias, known as pseudoneglect (for review, see Jewell & McCourt, 2000). Longo and Lourenco (2006) demonstrated that participants extend this bias into far space when given a stick that extends their reach. Other studies demonstrate that one's representation of near space is directly related to one's ability to act; for instance, having longer arms is associated with larger near space representations (Longo & Lourenco, 2007), and wearing wrist weights results in contraction of near space (Lourenco & & Longo, 2009). All of these studies demonstrate that one's actionable range directly impacts near space representations.

Given the above conclusion, it could also be that one's range of action actually influences the way he or she *perceives* a given environment. In other words, a person's actionable range may serve as a scale by which an environment is measured. This argument is based on the ecological approach proposed by Gibson (1979), who claimed that perception is tightly connected to action. In short, Gibson argued that perception is inherently *for* action. Rather than viewing the environment purely as visual angles, he claimed that the visual system perceives the world in terms of affordances, that is, what actions can be achieved by a given organism in a given environment. Multiple studies have presented evidence in favor of this claim. For example, in a seminal study, Bhalla and Proffitt (1999) demonstrated that participants estimated a hill as steeper if they were wearing a heavy backpack as compared to when they did not wear a backpack. Likewise, in a task where participants were asked to block an oncoming target (similar to Pong), they reported it as slower when using a larger paddle that made their task easier (Witt & Sugovic, 2012). In yet another example, older adults, for whom walking can be difficult, reported walkable extents as farther than younger adults (Sugovic & Witt, 2013). Proffitt and his colleagues suggest that these cases imply that we scale our perception according to our actionable range (Proffitt & Linkenauger, 2013; Witt & Proffitt, 2008; Witt, Proffitt, & Epstein, 2010).

Based on this argument, Witt, Proffitt, and Epstein (2005) had participants point at with their finger or tap with a baton and estimate the distance to a stimulus that was presented for 500 ms at the beginning of the trial. Participants underestimated the target distance after using a baton to tap the stimulus location as compared to when they pointed with their hand. Interestingly, this effect was only apparent at distances that were out of arm's reach, at which point the baton extended participants' range of action beyond what was provided by their arm alone. Similar to Iriki and colleagues (1996), the experimenters also reported that participants did not underestimate relative to the pointing condition when they held the baton but did not use it, implying that intent to use a tool affected perception of distance (Experiment 3).

Follow-up studies utilizing indirect measures of distance found similar effects (Witt, 2011b). Specifically, after either pointing at a stimulus with their hand or tapping it with a baton, participants judged, using visual match, the shape of a triangle or the parallelism of a pair of lines, of which the stimulus was a part. In both cases, participants' underestimated the distance to target stimuli when using the baton relative to pointing with the hand. Furthermore, participants showed similar effects in studies utilizing greater distances (Davoli, Brockmole, & Witt, 2012) and even when watching someone else use a tool (Bloesch, Davoli, Roth, Brockmole, & Abrams, 2012). Importantly, research has shown the opposite effect as well, with participants providing greater distance estimates in conditions where obstacles hinder reaching (Morgado, Gentaz, Guinet, Osiurak, & Palluel-Germain, 2013).

Proffitt, Witt, and colleagues (Witt, 2011a; Witt & Proffitt, 2008; Witt, Proffitt, & Epstein, 2010) have argued that such findings provide strong support for what is known as ‘action-specific perception’. On this view, visual perception is scaled according to the action one intends to perform and his or her ability to complete that action in a given environment and situation. Witt and Proffitt (2008) have further suggested that this adaptation is driven by the mechanism of simulation such that, as an individual prepares to commit an action, the brain simulates completing that action, and this simulation, including the anticipated difficulty and consequences of the action, are incorporated into visual perception. In this way, the effects of a specific action should be incorporated into visual perception (cf. Barsalou, 2008).

An alternative account suggests that the perceptual system incorporates how a tool expands one's representation of near space without simulating the actions completed with that tool (Davoli et al., 2012). Thus, in the case of Witt and colleagues (2005), Davoli and colleagues argue that participants underestimate the target distance in the tool condition because the tool expands participants’ representation of near space and not because participants simulate the consequences of that tool. Per this account then, the consequences of specific actions should not matter. To evaluate this account, Davoli and colleagues had participants point the nozzle of an industrial vacuum cleaner towards a target while the vacuum was set to either suction or blower, or the nozzle was detached from the vacuum. Participants estimated the target as closer in both the suction and blower conditions relative to the detached nozzle condition, indicating that the specific consequences of the action did not affect estimates of distances. Davoli and colleagues argue that this finding implies that the perceptual system incorporates the extended range provided by tools rather than the action-specific affordances of a given tool. However, participants in this experiment were relatively far from the target stimulus, meaning that the vacuum cleaner would not have different consequences depending on its setting. Thus, this experiment may not have been a strong test of the action-specific account that would predict differences based on different consequences.

Present Study

The present study sought to examine the effects of specific tool actions, varying in consequence, on distance estimations. Specifically, participants were asked to either point at an object with their hand (Point condition) or use a baton to tap (Tap condition), push (Push conditions) or pull (Pull conditions) the object. In the Push and Pull conditions, we also varied the magnitude of the action such that participants pushed or pulled the object a short (i.e., Short Push condition, Short Pull condition) or long distance (i.e., Long Push condition, Long Pull condition). After performing the assigned action, participants would then estimate the distance to the target using a visual matching task. This study expanded upon previous work by examining the effect of varying actions with very different consequences on distance estimations. In so doing, we hoped to begin disassociating between the above accounts.

Based on Witt (2011a) and Davoli and colleagues (2012), we developed two competing hypotheses. If the action-specific account of perception holds true, then we would expect the different tool actions to have different effects. For example, if participants simulate actions and their consequences, then participants would overestimate when pushing the object away relative to when they pointed at, tapped, or pulled the object. Inversely, participants would underestimate when pulling the object towards themselves relative to when they committed the other actions. Furthermore, if participants are simulating action consequences, then the magnitude of a given action should also affect estimates. Thus, participants should over or underestimate most when pushing or pulling the object a long distance, respectively, and least when moving the object a short distance. However, it could also be that participants do not simulate actions and their consequences and instead simply incorporate the tool into their body schema, resulting in an expanded representation of near space, regardless of the action performed (Davoli et al., 2012). Thus, participants should underestimate equally in all tool conditions, relative to the tap condition.

Methods

Participants

Forty-two students (31 female, mean ± SE age = 19.50 ± 1.5) from Emory University participated for research credit. All but two participants were right-handed, as determined by the Edinburgh Handedness Inventory (Oldfield, 1971; *M* = 84.03; range = -52.38 to 100). All provided written informed consent, and all procedures were approved by the Institutional Review Board (IRB) at Emory University.

Apparatus and Stimuli

Participants sat on a drafting stool, set at 64 cm high, in front of a 121.92 × 182.88 x 77 cm table covered in a white cloth (see Figure 1). A metal disk rested in front of the participant, serving as a reference point during the visual matching task. We utilized a visual matching task given that previous work has shown it to be more reliable than verbal report (Witt et al., 2005). A second disk, placed directly in front of the first disk, created the target distance on each trial. Twenty different target distances were used, ranging from 17.49 to 76.67 cm. Distances were selected based on the criteria that, at all locations, the distal disk was out of reach of participants' hands and within reach of a baton. The target distance was randomly determined on each trial.

A ceiling-mounted projector (Epson PowerLite S5) projected two white circles onto the table throughout the trial. These circles were used for the visual matching task (Visual Basic 2012 on a Dell Optiplex 760, Intel Core 2 Duo, Windows 7) and appeared halfway between the target stimuli, forming a perpendicular line, 9.80 cm in length (see Figure 2; task based on Loomis, da Silva, Fujita, & Fukusima, 1992). Participants used the arrow keys on a keyboard placed in their lap to adjust the distance between these two circles until they were sure the distance between them matched the target distance. Throughout trials, participants were asked not to lean forward, preventing changes in viewing perspective.

On trials when participants used a tool, they were given a yellow, red, or blue baton, 91 cm in length. For each participant, functions were randomly assigned to batons at the beginning of the experimental session such that a given participant would only use a baton of a certain color to achieve a given task. For instance, a participant might use only the blue baton for tapping, only the yellow baton for pushing, and only the red baton for pulling. This manipulation was added to ensure that each baton had a decidedly different appearance as well as function, potentially reducing any carry over effects between blocks.

Procedure

Participants participated in 6 blocks, one for each condition (i.e., Point, Tap, Short Push, Long Push, Short Pull, Long Pull), of 20 trials each, for a total of 120 trials. In the Point and Tap conditions, participants simply pointed at the target disk or used a stick to lightly tap it. In the Short Push and Short Pull conditions participants moved the disk approximately 10 cm either away from or towards themselves. To ensure consistency, participants were shown this distance on a ruler before the relevant blocks; the experimenter also demonstrated the specific action before participants began the block and reminded participants as needed throughout the block. In the Long Push and Long Pull conditions, participants were asked to move the disk as far as possible without leaning forward. For instance, in the Far Push condition, participants pushed the target disk as far as they could by simply extending their arm and then nudged the disk so that it was slightly out of reach. In the Far Pull condition, participants pulled the distal disk all the way to the proximal disk.

Prior to beginning the study, we collected arm length (measured from the right acromion to tip of right middle finger) and height measurements (without shoes) for each participant. This addition was motivated by research showing a relationship between arm length and near space (Longo & Lourenco, 2007). If participants' distance estimates are related to their representation of near space as argued by Davoli and colleagues (2012), then arm length and height, both predictors of one's range of action, should also be related to participants' distance estimates. After taking these measurements, participants entered the study room where they were asked to take a seat on the drafting stool and adjust its location so that their knees rested comfortable against the table. This allowed us to scale participants' distance from the table to their heights.

At the beginning of each block, participants were instructed on how to perform the target action and reminded about the visual matching task. Participants would begin each trial by performing the target action. If the target disk was moved during the trial, participants were asked to close their eyes while the experimenter moved the disk back to its original location on that trial. This manipulation was included to prevent participants from watching the experimenter perform an action, which has been shown to lead to underestimation (Bloesch et al., 2012). Participants then completed the visual matching task, pressing the space bar to start the next trial when they were satisfied with their response. After completing a trial, participants were asked to close their eyes while the experimenter placed the distal metal disk at its new location. Instructions throughout the task emphasized accuracy.

Results

Out of all trials, 21 (< 1%) were removed due to participant error (e.g., missed trial due to wrong key press). On average, participants completed 119.5 out of 120 (99.6%) possible trials. Outliers, identified as 2.5 standard deviations from individual means, were excluded from analyses. We identified a total of 116 outliers (2.4%) with an average of 2.83 outliers per participant.

To examine whether participants scaled their estimates to the true distance values, we first ran a one-way repeated-measures analysis of variance (ANOVA) with distance as a factor (20 distances) and participants' estimates as the dependent variable, collapsing across condition. As expected, this analysis yielded a significant effect of distance, *F*(19, 41) = 1917.84, $p < 0.05$, $\eta_p^2 = 0.98$, such that participants produced larger estimates when viewing larger distances [see Figure 3; see also linear contrast analysis, *F*(19, 779) = 2712.61, $p < 0.05$, $\eta_p^2 = 0.99$].

A preliminary analysis utilizing paired samples *t*-tests revealed no significant difference in participants' difference scores (estimated distance minus true distance) between either the Short Push (*M* = 0.63, *SE* = 0.83) and Long Push (*M* = 0.29, *SE* = 0.85) conditions, *t*(41) = 1.05, *p* = 0.30, or between the Short Pull (*M* = 0.37, *SE* = 0.87) and Long Pull (*M* = 0.22, *SE* = 0.86) conditions, *t*(41) = 0.56, *p* = 0.58. Consequently, all subsequent analyses were conducted collapsing across magnitude of action (i.e., Push vs. Pull conditions). Additionally, an independent samples *t*-test with gender as the independent variable and difference scores the dependent variable collapsed across conditions revealed no significant effect of gender, *t*(40) = -0.51, *p* = .61. Therefore, we did not include gender in later analyses.

To investigate the effect condition, we conducted a repeated measures ANOVA with condition (Point, Tap, Push, Pull) as a factor and participants' difference scores as the dependent measure. This analysis revealed a significant main effect of condition, *F*(3, 39) = 3.59, $p < .05$, $\eta p^2 = 0.22$. Post-hoc comparisons (with Bonferoni correction for multiple comparisons) revealed that participants estimated the target distance as significantly shorter in the Tap condition (*M* = -0.52, *SE* = 0.68) versus the Pointing condition (*M* = 0.30, *SE* = 0.77), $p < 0.05$ (see Figure 4). No comparisons involving the Push condition (*M* = 0.47, *SE* = 0.83) or the Pull condition (*M* = 0.35, *SE* = 0.88) reached statistical significance (all *p*'s > 0.70). In addition, we utilized one-sample *t*-tests to examine whether biases differed from zero. These tests revealed no significant differences in any of the conditions, indicating that participants' estimates did not differ significantly from the veridical distances (all *p*'s > 0.40). Importantly, the standard deviations of the four conditions did not differ significantly, indicating that our results cannot be explained as due to greater variance in any given condition, *F*(3, 39) = 1.10, *p* = 0.36

In the study of Witt and colleagues (2005), statistical comparisons were only made for the farthest distances; that is, participants underestimated the target distance when holding a tool as compared to when they simply pointed, but this was only shown for distances outside of reach (> 70 cm). Because all of our distances were out of reach, we thus included all distances in our original analyses. However, one could ask whether the difference between Tap and Pointing could be stronger or whether other conditions would differ if we focused only on the farthest distances. To ensure that the effects of different tool actions were not limited to more distal distances, we performed a one-way repeated measures ANOVA using the difference between participants' estimates and the true distances for only the 10 farthest distances. However, this ANOVA revealed no significant effect of condition, *F*(3, 39) = 2.46, *p* = 0.077. Thus, unlike Witt and colleagues, our results are not driven by estimates made at the farthest distances.

Finally, we investigated the relationship between height and arm length and participants' difference scores. Pearson product-moment correlations revealed no significant correlations between height and the Point (*r* = -0.21), Tap (*r* = -0.16), Push (*r* = -0.16), or Pull (*r* = -0.22) conditions (all *p*'s > 0.10). Pearson product-moment correlations revealed a marginally significant relationship between arm length and difference in the Tap condition ($r = -0.30$), $p = 0.051$, but no other significant correlations between arm length and difference scores were found in the Point ($r = -0.17$), Push ($r = -0.16$), or Pull ($r = -0.20$) conditions (all p's > 0.15). Thus, although all correlations were in the same direction, there was no significant relationship between participants' distance estimations and their heights and arm lengths.

Discussion

Importantly, we replicate the effect shown by multiple studies that having a tool that allows one to tap a target leads participants to underestimate the distance to that target relative to when they point at it with their finger (e.g., Bloesch et al., 2012; Witt & Proffitt, 2008; Witt et al., 2005). However, our remaining analyses hinder attempts to identify the underlying mechanism or mechanisms that produce this effect. For instance, one possibility as put forth by Witt, Proffitt, and colleagues is that participants' simulate the specific actions and consequences of a given tool, and this simulation is incorporated into perception (e.g., Witt, 2011a; Witt et al., 2005). Thus, in our study, participants should have underestimated when pulling the object toward themselves and overestimated when using the tool to push the disk away. However, we found no such effect of pushing or pulling. Furthermore, if specific action consequences affect distance estimations, then the effects should also be modulated by the magnitude of action consequences, but again, we found no such effect.

Another possibility as argued by Davoli and colleagues (2012) is that these effects are due to the expanded representation of near space as provide by a tool. Per this account, participants should have underestimated the distance in all conditions when they used a tool, regardless of its consequences, given that, in all tool conditions, the baton extended their reach equally. However, we found no evidence of underestimation when participants were pushing or pulling relative to when they were simply pointing with their finger or tapping with the baton. Given that our results do not support either of the above mechanisms, then there must be other factors at work.

Role of effort

There are a couple of potential explanations for our data. One explanation relates to the effect of effort (Proffitt, 2013; Proffitt & Linkenauger, 2013). Per this account, the effort to complete a given task could serve as a metric by which visual perception is scaled. As described in the Introduction, a hill is judged as steeper when a person is wearing a heavy backpack versus a light backpack, presumably because a heavier backpack increases the effort necessary to scale the hill (Bhalla & Proffitt, 1999). Likewise, an oncoming target appears to move more quickly when it takes greater effort to block (Witt & Sugovic, 2012), and a distance seems farther when it takes greater effort to walk due to age (Sugovic & Witt, 2013). If one were to interpret the original study by Witt and colleagues (2005) in this way, one could explain the results in terms of effort as well: reaching with the baton takes less effort than reaching with one's hand, ergo objects appear closer in the tool condition. Based on this logic, it could be that the relatively greater effort of pushing or pulling an object versus simply tapping it masked any potential effect of the tool. If this were case, however, then one might have expected an effect of magnitude (i.e., long vs. short manipulation in each of the pull and push conditions) given that manipulating magnitude directly affects effort. Because we did not find any effect of magnitude, it would seem to argue against this possibility; however, it could be that the two competing effects of tool usage and effort negate each other. We thus suggest that it is critical to control effort across conditions in future research so as to ensure that all conditions require the same amount of effort and any potential tool effects are not masked.

Methodological Differences

A second possibility is that our data result from minor methodological differences between conditions. In the Point and Tap conditions, participants were able to immediately perform the visual matching task. In the Push and Pull conditions, though, there was a brief delay during which participants were asked to close their eyes so as to prevent any effects due to watching the experimenter interact with the disk. It could thus have been the case that the brief delay with eyes closed in the Push and Pull conditions negated any perceptual effects of tool use.

This possibility suggests an intriguing scenario. On the one hand, this finding could underscore the necessary plasticity of the perceptual system (Holmes, Calvert, & Spence, 2007; Longo & Lourenco, 2006; Lourenco & Longo, 2009). If the perceptual system is affected by changes in tool or action capabilities, then this system would need to be capable of rapid change in order to be adaptive in the dynamic environments in which humans exist. For instance, it would not be adaptive to carry-over perceptual adjustments due to tool use into a situation in which one no longer had access to the tool. However, it could also support arguments that these effects are simply artifacts of other processes and not useful for visually guided action (Firestone, 2013). This latter argument is supported by the small magnitude of the differences between conditions in our study. Though previous studies such as the one by Witt and colleagues (2005) found that participants underestimated by an average of 7 cm (7.25%) in the tapping condition relative to when they simply pointed (Experiment 2), we found a difference of only 0.826 cm (1.76%). Furthermore, participants' estimates did not differ significantly from the veridical distance. Given these findings, it implies that such effects on distance judgments may be so small as to be meaningless in the scope of action planning.

Future Research

To test these two hypotheses, we are designing two follow-up experiments. In the first experiment, we will utilize the same paradigm as the current study with four different conditions: Point, Tap, Point with Delayed Estimate, Tap with Delayed Estimate. In the delayed estimate conditions, we will ask participants to perform the target action and then close their eyes for approximately 5 sec before completing the visual matching task. If the delay with eyes closed eliminates the effects of tool-use, then we should see no difference between the delayed estimate conditions or between the delayed estimate and replication conditions.

If the delay has no significant effect on participants' estimates, we will proceed with our second follow-up study examining the effect of effort. In this study, participants will participate in four separate conditions: Point, Tap, Push, and Pull. The Push and Pull conditions will differ from the current study in that we will utilize only the long conditions where participants move the target stimulus as far as possible. In addition, we will modify the tools such that pulling and pushing take just as much effort as tapping. For instance, one possibility is to use magnets with different polarities. Thus, the participant can push the object away or pull it towards themselves with as little effort as tapping. Another option would be to modify the affordances of the batons used for pushing or pulling such that they are specifically designed for one action but not any other. In this way, if the perceptual system is incorporating the specific affordances of a tool, then it will take these affordances into account even when tapping.

Conclusion

The current study combined with the findings of the follow-up studies will shed important insight into the connection between perception and action. By highlighting the role of specific tool action, effort, and minor methodological differences, these studies will demonstrate the specificity, sensitivity, and robustness of these effects. In so doing, we will then have a clearer grasp on the role these effects play in action planning and coordination. Furthermore, these data may lead to new questions regarding the purported examples of the perception-action connection, opening new, informative lines of research.

Following from studies showing that the canes of blind individuals serve to expand their peripersonal spaces (Serino, Bassolino, Farné, & Làdavas, 2007) and that prosthetic limbs dramatically alter the sensorimotor representations of amputees (Ramachandran & Blakeslee, 1998), the current study and follow-up studies have the potential to inform the development of technologies designed for individuals with visual and physical impairments. Furthermore, this work has the potential to yield crucial data to burgeoning fields of augmented and virtual realities, where developers are constantly seeking to integrate physical and virtual tools in psychologically realistic ways.

References

Ackroyd, K., Riddoch, M. J., Humphreys, G. W., Nightingale, S., & Townsend, S. (2002). Widening the sphere of influence: Using a tool to extend extrapersonal visual space in a patient with severe neglect. *Neurocase, 8*(1-2), 1-12. doi: 10.1093/neucas/8.1.1

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59,* 617-645. doi: 10.1146/annurev.psych.59.103006.093639

Berti, A., & Frassinetti, F. (2000). When far becomes near: Remapping of space by tool use. *Journal of Cognitive Neuroscience, 12*(3), 415-420. doi: 10.1162/089892900562237

Bhalla, M., & Proffitt, D. R. (1999). Visual–motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception and Performance, 25*(4), 1076-1096. doi: 10.1037/0096-1523.25.4.1076

Bloesch, E. K., Davoli, C. C., Roth, N., Brockmole, J. R., & Abrams, R. A. (2012). Watch this! Observed tool use affects perceived distance. *Psychonomic Bulletin & Review, 19*(2), 177-183. doi: 10.3758/s13423-011-0200-z

Brain, W. R. (1941). Visual orientation with special reference to lesions of the right cerebral hemisphere. *Brain: A Journal of Neurology, 64,* 244-272. doi: 10.1093/brain/64.4.244

Cowey, A., Small, M., & Ellis, S. (1994). Left visuo-spatial neglect can be worse in far than in near space. *Neuropsychologia, 32*(9), 1059-1066. doi: 10.1016/0028-3932(94)90152-X

Davoli, C. C., Brockmole, J. R., & Witt, J. K. (2012). Compressing perceived distance with remote tool-use: Real, imagined, and remembered. *Journal of Experimental*

Psychology: Human Perception and Performance, 38(1), 80-89. doi: 10.1037/a0024981

Farnè, A., Serino, A., & Làdavas, E. (2007). Dynamic size-change of peri-hand space following tool-use: Determinants and spatial characteristics revealed through cross-modal extinction. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior, 43*(3), 436-443. doi: 10.1016/S0010-9452(08)70468-4

Firestone, C. (2013). How “paternalistic” is spatial perception? Why wearing a heavy backpack doesn’t—and couldn’t—make hills look steeper. *Perspectives on Psychological Science, 8*(4), 455-473. doi: 10.1177/1745691613489835

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston, MA US: Houghton, Mifflin and Company.

Halligan, P. W., & Marshall, J. C. (1991). Left neglect for near but not far space in man. *Nature, 350*(6318), 498-500. doi: 10.1038/350498a0

Holmes, N. P. (2012). Does tool use extend peripersonal space? A review and re-analysis. *Experimental Brain Research, 218*(2), 273-282. doi: 10.1007/s00221-012-3042-7

Holmes, N. P., Calvert, G. A., & Spence, C. (2007). Tool use changes multisensory interactions in seconds: Evidence from the crossmodal congruency task. *Experimental Brain Research, 183*(4), 465-476. doi: 10.1007/s00221-007-1060-7

Iriki, A., Tanaka, M., & Iwamura, Y. (1996). Coding of modified body schema during tool use by macaque postcentral neurones. *Neuroreport*, *7*(14), 2325-2330.

Jewell, G., & McCourt, M. E. (2000). Pseudoneglect: A review and meta-analysis of performance factors in line bisection tasks. *Neuropsychologia, 38*(1), 93-110. doi: 10.1016/S0028-3932(99)00045-7

Johnson-Frey, S. H. (2004). The neural bases of complex tool use in humans. *Trends in Cognitive Sciences, 8*(2), 71-78. doi: 10.1016/j.tics.2003.12.002

Longo, M. R., & Lourenco, S. F. (2006). On the nature of near space: Effects of tool use and the transition to far space. *Neuropsychologia, 44*(6), 977-981. doi: 10.1016/j.neuropsychologia.2005.09.003

Longo, M. R., & Lourenco, S. F. (2007). Spatial attention and the mental number line: Evidence for characteristic biases and compression. *Neuropsychologia, 45*(7), 1400-1407. doi: 10.1016/j.neuropsychologia.2006.11.002

Loomis, J. M., da Silva, J. A., Fujita, N., & Fukusima, S. S. (1992). Visual space perception and visually directed action. *Journal of Experimental Psychology: Human Perception and Performance, 18*(4), 906-921. doi: 10.1037/0096-1523.18.4.906

Lourenco, S. F., & Longo, M. R. (2009). The plasticity of near space: Evidence for contraction. *Cognition, 112*(3), 451-456. doi: 10.1016/j.cognition.2009.05.011

Maravita, A., & Iriki, A. (2004). Tools for the body (schema). *Trends in Cognitive Sciences, 8*(2), 79-86. doi: 10.1016/j.tics.2003.12.008

Morgado, N., Gentaz, É., Guinet, É., Osiurak, F., & Palluel-Germain, R. (2013). Within reach but not so reachable: Obstacles matter in visual perception of distances. *Psychonomic Bulletin & Review, 20*(3), 462-467. doi: 10.3758/s13423-012-0358-z

Previc, F. H. (1998). The neuropsychology of 3-D space. *Psychological Bulletin, 124*(2), 123-164. doi: 10.1037/0033-2909.124.2.123

Proffitt, D. R. (2013). An embodied approach to perception: By what units are visual perceptions scaled? *Perspectives on Psychological Science, 8*(4), 474-483.

Proffitt, D. R., & Linkenauger, S. A. (2013). Perception viewed as a phenotypic expression. *Action science: Foundations of an emerging discipline*, 171-198.

Ramachandran, V., & Blakeslee, S. *Phantoms in the Brain: Probing the Mysteries of the Human Mind*.

Rizzolatti, G., Scandolara, C., Matelli, M., & Gentilucci, M. (1981). Afferent properties of periarcuate neurons in macaque monkeys: II. Visual responses. *Behavioural Brain Research*, *2*(2), 147-163. doi: 10.1016/0166-4328(81)90053-X

Serino, A., Bassolino, M., Farnè, A., & Làdavas, E. (2007). Extended multisensory space in blind cane users. *Psychological Science, 18*(7), 642-648. doi: 10.1111/j.1467-9280.2007.01952.x

Shumaker, R. W., Walkup, K. R., & Beck, B. B. (2011). *Animal tool behavior: The use and manufacture of tools by animals (rev. and updated ed.)*. Baltimore, MD US: Johns Hopkins University Press.

Sugovic, M., & Witt, J. K. (2013). An older view on distance perception: Older adults perceive walkable extents as farther. *Experimental Brain Research, 226*(3), 383-391. doi: 10.1007/s00221-013-3447-y

Witt, J. K. (2011a). Action's effect on perception. *Current Directions in Psychological Science, 20*(3), 201-206. doi: 10.1177/0963721411408770

Witt, J. K. (2011b). Tool use influences perceived shape and perceived parallelism, which serve as indirect measures of perceived distance. *Journal of Experimental*

Psychology: Human Perception and Performance, 37(4), 1148-1156. doi: 10.1037/a0021933

Witt, J. K., & Proffitt, D. R. (2008). Action-specific influences on distance perception: A role for motor simulation. *Journal of Experimental Psychology: Human Perception and Performance, 34*(6), 1479-1492. doi: 10.1037/a0010781

Witt, J. K., Proffitt, D. R., & Epstein, W. (2005). Tool Use Affects Perceived Distance, But Only When You Intend to Use It. *Journal of Experimental Psychology: Human Perception and Performance, 31*(5), 880-888. doi: 10.1037/0096-1523.31.5.880

Witt, J. K., Proffitt, D. R., & Epstein, W. (2010). When and how are spatial perceptions scaled? *Journal of Experimental Psychology: Human Perception and Performance, 36*(5), 1153-1160. doi: 10.1037/a0019947

Witt, J. K., & Sugovic, M. (2012). Does ease to block a ball affect perceived ball speed? Examination of alternative hypotheses. *Journal of Experimental Psychology: Human Perception and Performance, 38*(5), 1202-1214. doi: 10.1037/a0026512

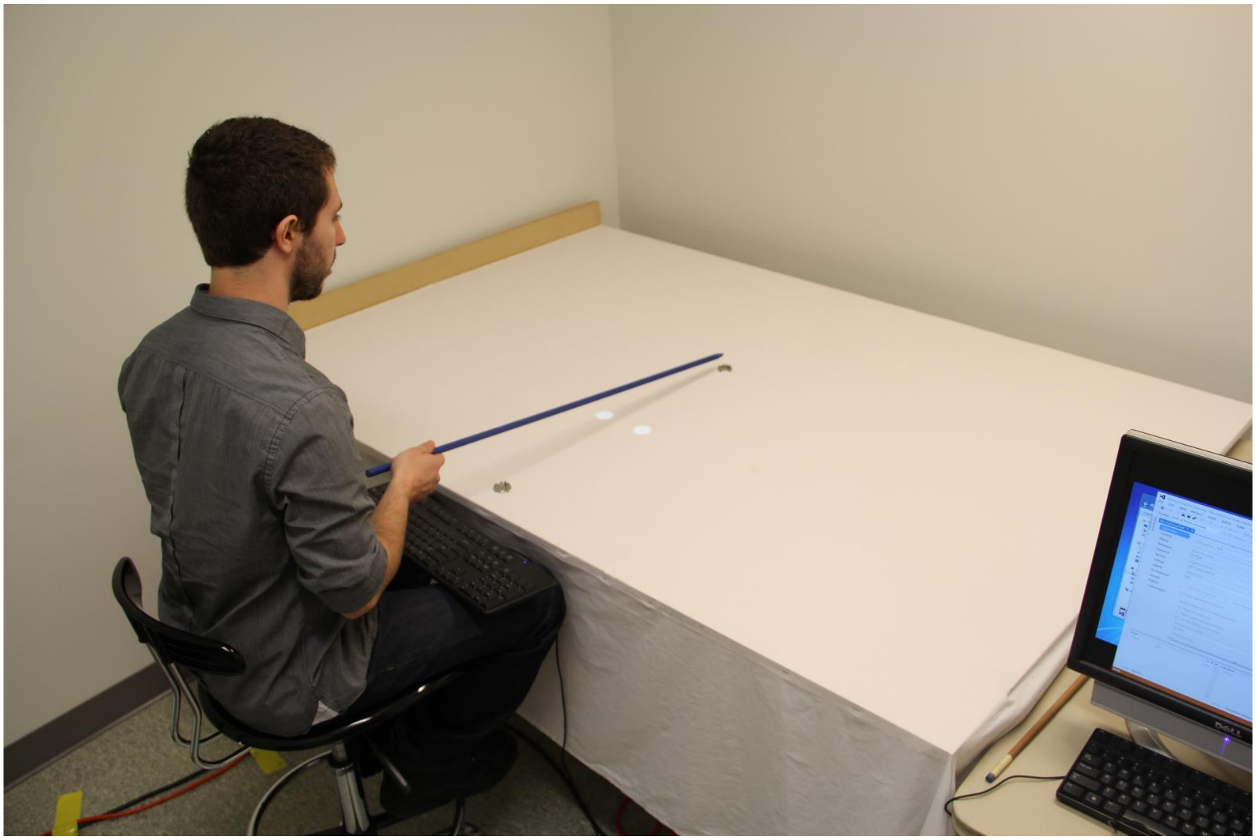

Figure 1. Photograph of testing room with participant. Experimenter stood to the right of the participant.

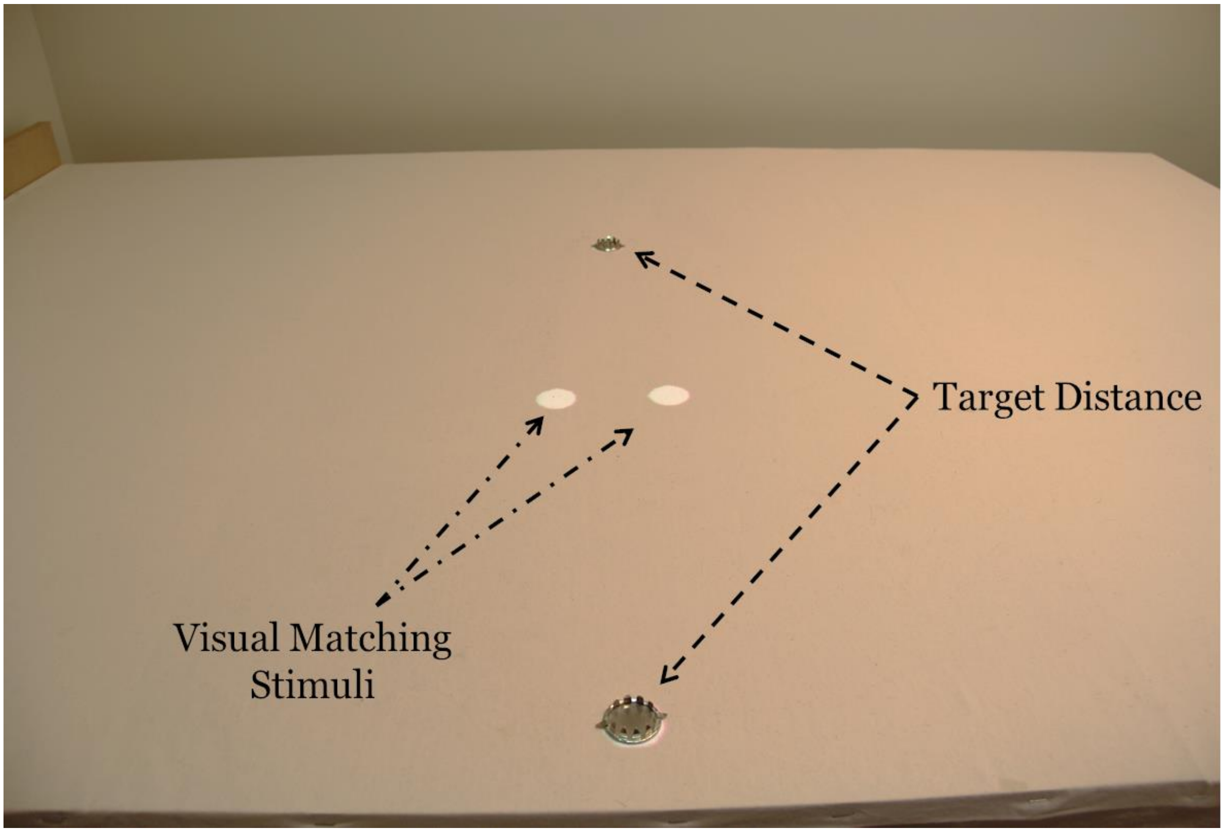

Figure 2. The participant's point of view during the task. Target distance was randomly determined on each trial.

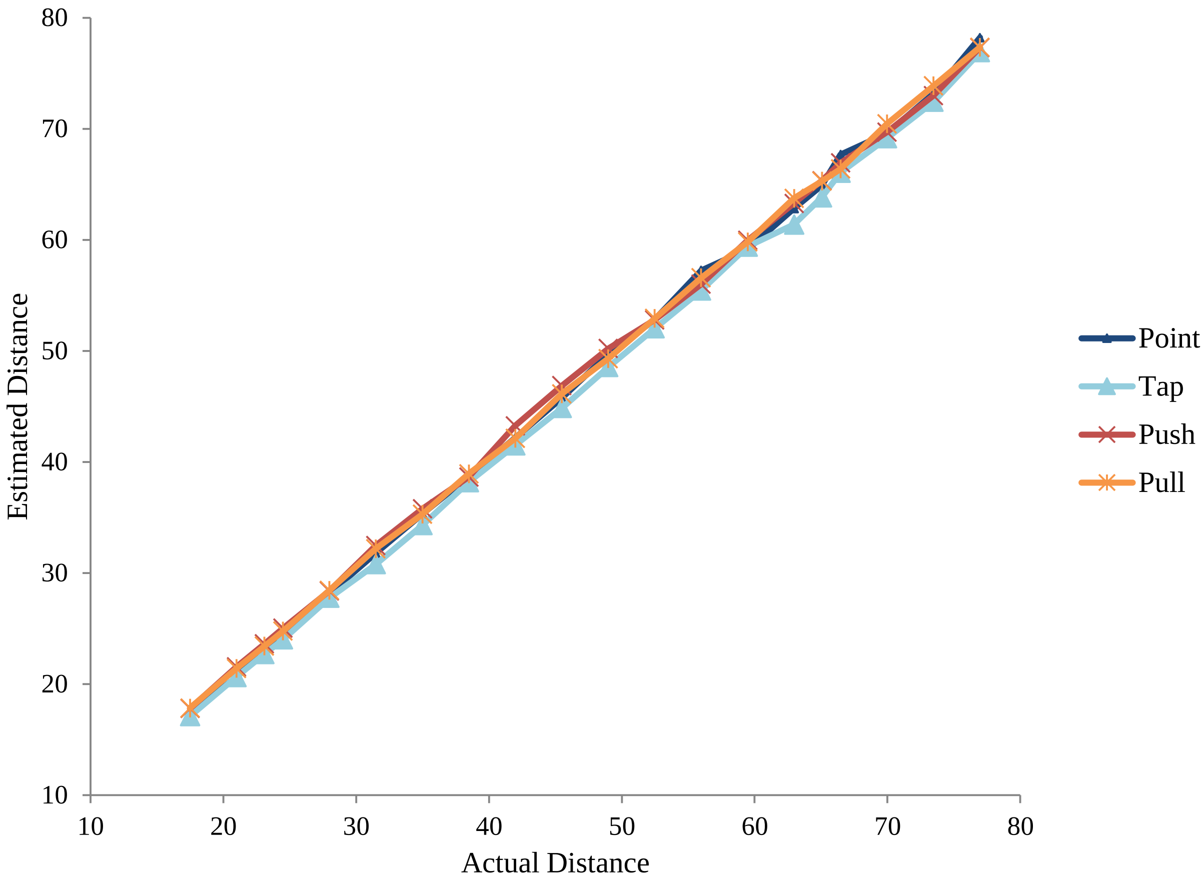

Figure 3. Mean estimates of distance in each condition. Participants scaled their estimates according to the veridical distance in all conditions.

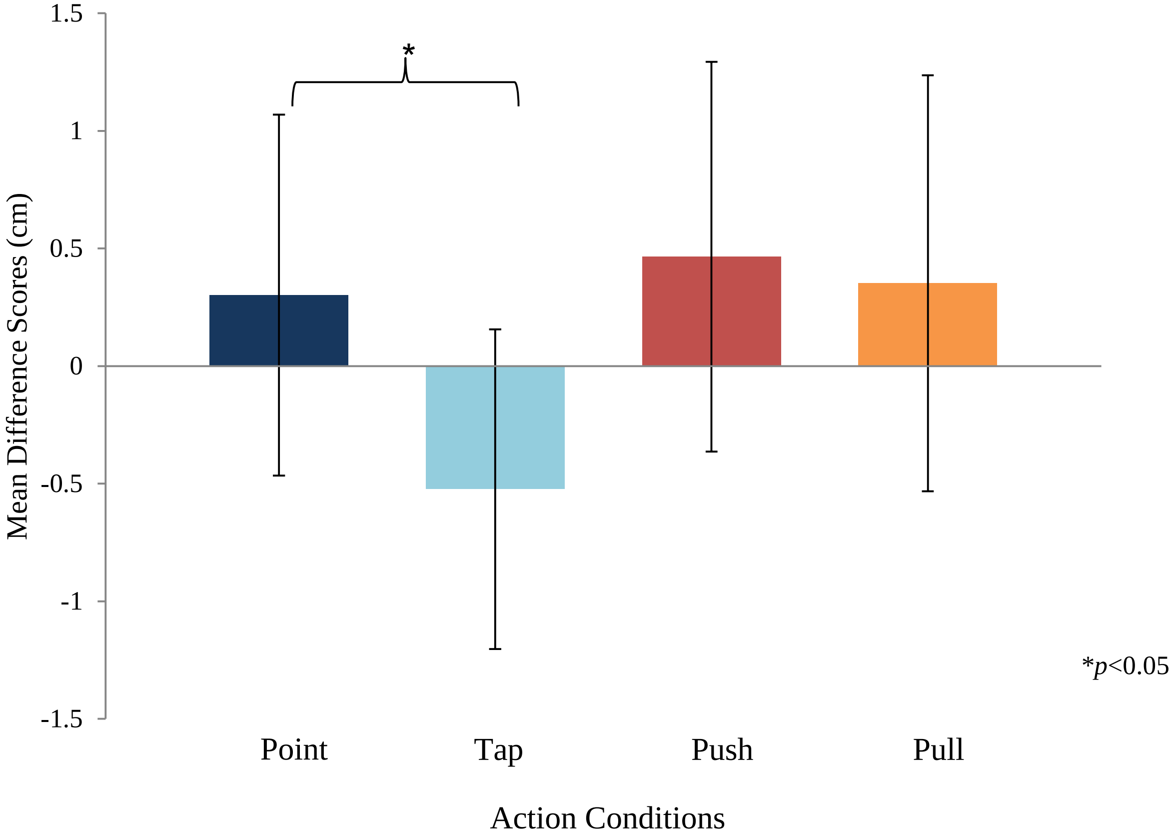

Figure 4. This graph depicts the mean differences between participants' estimates and the actual distance (difference scores) across condition. Error bars represent one standard error of the mean. Participants significantly underestimated the target distance in the Tap condition relative to the Point condition. No other significant relationships were found.