Reaching with Light: The Impact of Remote Tool Use on Size and Distance Perception

Sarah Grace Frary

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Reaching with Light: The Impact of Remote Tool Use on Size and Distance Perception

by

Sarah Grace Frary

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Dr. Peter M. Vishton, Advisor

Dr. Catherine A. Forestell

Dr. M. Christine Porter

Dr. Daniel A. Cristol
ABSTRACT

Actions, whether performed or mentally planned, have been demonstrated to have an effect on the way that we perceive size and distance within the space around us. Acting upon the Ebbinghaus Illusion reduces the magnitude of the illusion. The use of tools to engage in actions has been demonstrated to expand peripersonal space and compress perceived distance. Specifically, remote tools, or manual tools that indirectly interact with objects, have been demonstrated by Davoli, Brockmole, and Witt (2012) to compress perceived distance in a similar manner to manual tools. The experiment described in this thesis first tested the effect of remote tool use on size perception, using the Ebbinghaus Illusion as a measure of size perception, and second, measured the effect of remote tool use on distance judgments in a typical university classroom. Data indicate that there is not an effect of remote tool use on size perception at a distance. Trends in the distance perception data suggest that there may be an effect of remote tool use on distance perception, but that the effect may be a perceived distance expansion, contrary to predictions. Potential contextual interpretations for this effect, including differences in tool use, setting, and methodology between this study and the study of Davoli et al. are discussed. The experiment suggests that the effect of remote tool use on distance perception is contingent upon some combination of environmental and individual factors, which call for more exploration in future studies. The experiment also suggests that whatever mechanisms affect size perception are not identical to the mechanisms which affect distance perception.
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Chapter I
Size Perception Research, Action, and the Ebbinghaus Illusion

The Ebbinghaus illusion, or Titchener Circles illusion, is a visual illusion in which two circular discs of equal size are presented beside each other on the same plane. One disc is surrounded by a ring of circles (called inducers) larger than the disc inside them, and one is surrounded by smaller circle inducers than the disc inside them. The central discs, while still the same size, are perceptually different to the viewer: the disc surrounded by the annulus of smaller inducers appears larger than its equal counterpart, which is surrounded by wider inducers.

The study of the Ebbinghaus illusion is derived from the cognitive tradition of the Gestalt school of perception. This school of thought asserted that there are a series of discrete principles and rules which govern perception, and that perception can therefore be intentionally manipulated by illusory stimuli when the rules of perception are known. Coren and Miller in their 1974 exploration of the Ebbinghaus illusion’s effects cite Hermann von Helmholtz (1866), a Gestalt theorist who introduced the principle of contrast in visual perception research. Contrast in the field of Gestalt perception is the idea that our interpretation of size, length, and distance are not fixed, and that each stimulus is compared to its surroundings and to prior knowledge of the stimulus and its context to determine the perception of its size. This principle was formalized by Wilhelm Wundt in 1894 as the Law of Relativity, because objects’ characteristics relative to one another change the way that we perceive the world around us. The Ebbinghaus Illusion provides a ready example of Wundt’s law of relativity in its main effects, given that the disc
surrounded by larger circles appears smaller, and the disc surrounded by smaller circles appears larger. This assumption was supported by findings from Massaro and Anderson, who presented different sized circles in annuli around the central discs and noticed that the size difference of the central disc and surrounding circles follows a directly linear pattern, where increasing larger circles make central discs appear increasingly small (Massaro & Anderson, 1971).

![Figure 1a.][figure1a]  ![Figure 1b.][figure1b]

*Figure 1a, 1b: Plain background display versus Ebbinghaus Illusion display. Both have central discs that are equivalent in diameter; however, in Figure 1a, the central disc on the left appears smaller than the one on the right. In Figure 1b, the discs appear similar in size.*

Coren and Miller in 1974 expanded upon these results further. They recognized that the law of relativity cannot be alone in influencing size perception in the Ebbinghaus Illusion, and they created an experiment to gain specific information about the particular features of the Ebbinghaus illusion which cause it to alter size perception (Coren & Miller, 1974).
In Coren and Miller’s experiment, the inducers surrounding the discs of the Ebbinghaus illusion varied in shape and size. Inducers were circles, hexagons, triangles, and jagged asymmetrical polygons. Coren and Miller predicted that the law of relativity is only as effective as how the task allows the shape in question to be compared. If the circle in the center is difficult to compare to an unrelated polygon because it is shaped differently, they reasoned, then the effect of the illusion should decrease as a function of differing shape. A rotating wheel of circles of incrementally increasing size was used by participants to match the size of the central discs, once for the left central disc and once for the right in each group of inducer shapes. Coren and Miller found that while the illusion continued to function as expected, the illusion magnitude decreased as the inducers became more dissimilar to the central disc (Coren & Miller, 1974). Jaeger and Grasso (1993) found similar effects in an experiment during which they manipulated inducer colors, and found that the brightness of the display also affects the magnitude of the Ebbinghaus illusion, with similar colors being associated with greater magnitude; the distance between the annuli and the discs has also been shown to be an important factor in the magnitude of the effect of the illusion (Massaro & Anderson 1971; Girgus et al. 1972).

Once the mechanics of the Ebbinghaus illusion were better known, its use in neuroscience and psychophysics research became more intricate. In 1995, Aglioti, DeSouza & Goodale presented the Ebbinghaus illusion to healthy participants, who observed the illusion displayed in front of them, at the table where they sat. The researchers had designed the experiment to measure the discrepancies between the efficacy of the illusion under two conditions: when participants were making verbal judgments of the discs’ sizes, and when they were reaching for the discs. Participants were instructed to reach for one central disc (left or
right) if they saw the discs as identical in size, and the other if they saw the discs as different in size. Central discs consisted of discs 5 mm in thickness and between 27 and 33 millimeters in diameter, placed on top of an Ebbinghaus illusion display which didn’t . After each judgment, the task was reset and the participant was presented with another stimulus.

Participants tended to be affected by the illusion, seeing equivalent discs surrounded by the annulus of smaller circles as larger, and seeing different-sized discs as equivalent. However, their grip aperture was significantly less affected; when reaching for their selected disc, participants’ fingers were in nearly the correct configuration to pick up the disc regardless of its size. Thus it seemed as if there were two very disparate visual inputs: one for visual judgment, which was susceptible to the visual illusion, and one which was being used to guide the reaching and grasping action, which remained unaffected (Aglioti, DeSouza, & Goodale, 1995).

The results of this experiment led these researchers to conclude that there are two independent visual neural pathways: one pathway designed to see for the purpose of perceiving visual space, and one pathway designed to see for the purpose of acting upon an environment (Aglioti, DeSouza & Goodale, 1995). The interpretation of the results of this experiment further supported a proposition by one of the researchers, Melvyn Goodale, that there exist two distinct streams of neural processing for visual information. This hypothesis was known as the two-streams hypothesis (Goodale & Milner, 1992), and the proposal of the separate neurological streams based on function (visual judgment or action) was further detailed in the book *The Visual Mind in Action*, written to expound upon the findings presented by this and their other research (Milner & Goodale, 2006).
The paper in which Aglioti et al. described this procedure also noted that grip aperture would “of course” be affected by the shape and purpose of the object for which a person is reaching, particularly if that object is familiar (p. 682). They addressed this after finding that their participants frequently took longer in conditions where the discs were perceptually the same but actually different, and there was a slight tendency for the grip aperture to be more variable and slightly larger when judging “perceptually identical but physically different” stimuli (p. 681). Their hesitance and these tendencies were not elaborated upon. The research team stood behind their interpretation that their results demonstrated two independent neural visual streams, and began to hypothesize where in the brain these pathways for either perception or action are situated (Aglioti, DeSouza & Goodale, 1995).

The line of conclusions drawn about two independent visual systems by Aglioti et al. (1995) and Goodale and Milner (1992) was not without a great deal of debate from fellow researchers. Other perception researchers noted that the systems of visual perception are likely much more complicated and interconnected than Milner and Goodale had suggested. For instance, Franz, Gegenfurtner, Bulthoff and Fahle (2000) asserted that there is no reason to conclude that the effects that Milner and Goodale claimed were due to a dissociation between vision for perception and vision for action are truly so; the effects seem to be largely due to an additivity effect within the Ebbinghaus illusion. The additivity effect they described was an additional comparative effect of the Ebbinghaus Illusion. If the central disc surrounded by the annulus of larger circles is placed next to the central disc surrounded an annulus of smaller circles, the magnitude of the perceived difference between the two central discs is increased. When compared to the effects of presenting one half of the illusion (for instance, the central disc
surrounded by larger circles alone), the effect of the illusion on the perceived size of the disc is less than the effect of the whole illusion because of the added effects of the additional central disc and annulus. In 2000, Franz et al. published a series of three experiments. The first was a study intended to be a replication study of the Aglioti et al. study from 1995. However, the main difference between the two studies was only one of the Titchener circles was presented to participants, and the circles in the perceptual task were judged based on a comparison disc on a computer screen, which the participant adjusted to match the perceived size.

The flaw that these authors observed was that the original Aglioti et al. study allowed for comparison between the two discs during the perception task, but during the grasping task, only one judgment is being made. The other Titchener circle is not involved in the grasping task, as a participant can only reach for one object at a given time. Franz et al. (2000) created a replication of the Aglioti et al. 1995 study while accounting for this oversight, and thus prevented the additivity effect of the full Ebbinghaus illusion. In this experiment, the same effects for grasping and visual judgment were observed, but when the results were examined together, the effect that Milner and Goodale produced (that of the grasping task being less affected by the illusion) was greatly reduced.

To test their follow-up hypothesis that the results produced by Aglioti et al. (1995) were attributable to additive processes in the two-figure Ebbinghaus Illusion, the researchers conducted an experiment in which participants first compared the two inner circles in the figures in the Ebbinghaus illusion, and then compared each one to a separate third circle without any judgment circles. The results demonstrated that there was a larger effect of the Ebbinghaus illusion if it is in its entirety (with smaller and larger annuli both present and visible), and the
figures within are then compared. Experiment 3 in this study demonstrated that just conducting a
direct comparison does not create the additivity effect; it is an inherent property of the illusion
itself. Thus, Franz et al. (2000) concluded that there is no basis to conclude that there are two
independent streams for visual perception based solely on grasping tasks when there are many
other variables in the illusion itself, as I have described.

In 2007, Vishton, Stephens, Nelson, Morra, Brunick and Stevens examined the action vs.
perception hypothesis in three experiments utilizing the Ebbinghaus illusion, because despite
Milner and Goodale’s assertions, it remained unclear whether there are two streams of vision, or
one large system which changes according to whatever visually-aided task it is undertaking.

The first experiment was split up into two groups of participants: the visual-visual group,
who visually assessed the size of poker chip-like discs on top of the Ebbinghaus illusion for the
entirety of the experiment, and the verbal-grasp group, who were told to assess the size of the
discs visually and then in the second trial were told to reach and grasp the disc they thought was
larger. The results showed that the effects of the illusion did decrease in the verbal-grasp trials.
Additionally, positive correlations existed between trials, which suggested that there exists a
relationship between perception, whether action oriented or not. This ultimately supports the
argument that the intent to act in a given way (in this example, grasping) changes how one
perceives the object, rather than judgments being made independently based on the original
perceptual judgment. Just by intending to act on an object, one’s perception changes to
accommodate the action.

The second experiment of Vishton et al. asked if the effect was due simply to feeling the
discs during the grasp trial, and this follow-up asked participants in the action condition to only
touch the discs. Half of the participants knew about both of the conditions (touching and verbal) beforehand and half were ignorant of each trial, to investigate whether just imagining reaching was enough to reduce the efficacy of the illusion. This experiment concluded that haptic feedback is not required. It also appears that simply listening to a description of a reaching task changes the way in which participants perceive objects; results comparing the preverbal-description condition to the other condition in experiment two approached significance, and the differences were significant when compared to results from experiment one (Vishton et al. 2007).

The third experiment tested how long the effects of action-driven perception lasted, and the answer appears to be several minutes; even after attempts to reach have stopped, the reduction in the illusion lasted for the duration of the visual portion of the test from experiment one.

The conclusion of the article was that, even if Milner and Goodale’s research is not entirely refuted by this work, the visual system is more flexible than one might imagine. Our visual system accommodates a wide range of actions and adjusting accordingly, even if these actions are only imagined. The character of size perception is, then, more complicated than proposed by Milner and Goodale (Vishton et al. 2007).
People frequently look for traits which separate human beings from animals, or things which make us fundamentally human. Tool use is often touted as a characteristically human attribute. While humans are not the only animals that use tools to accomplish tasks, using tools has been foundational to the development of human communities, social infrastructure, and scientific discovery. While we have used tools to shape our surroundings, tool use has reshaped and continues to reshape the way that we see and interpret those surroundings as well. There is a very real effect of our actions, our intention to act, and the tools that we use to carry out our actions, on the way that we see the world around us.

Simply changing the way that we utilize our bodies or how we make sense of our bodies within space affects the way that our minds perceive size. This has been demonstrated with the Ebbinghaus Illusion and other pictorial illusions many times, as detailed in Chapter I, but size perception research concerning action has been wide and diverse, and has shown that size perception relies on actions, plans, expectations, and circumstances in ways which suggest a complex array of neural interactions.

The interplay of action and visual size judgments begins with anecdotes and stories; for instance, a frequently cited experiment from 2005 by Jessica Witt and Dennis Proffitt began with the common observation related by baseball players that the ball appears larger when one is hitting the ball well that day. Likewise, players see the ball as smaller when they are hitting
poorly. Witt and Proffitt set out to investigate if this was a figure of speech or a real psychological phenomenon. They recruited softball players at a local intramural softball field with free sports drinks. They asked the softball players to describe their batting during that day, as well as indicate which circle on a poster the researchers designed looked to be the size of the softball they were hitting. The participants then picked from 8 circles, gradually increasing in size from smaller than a tennis ball to larger than a grapefruit (Witt & Proffitt, 2005).

There was a correlation of $r = 0.29$ between batting success during that day and the perceived size of the softball. Because this is correlational data, no conclusion could be made about whether the effect is primarily rooted in perception or in memory. Perhaps participants in the study were allowing their batting success to influence their recollection of the size of the balls that they were hitting, or perhaps they truly did perceive the balls as larger or smaller in the moment. Likewise, we cannot make conclusions about whether it is a trait of the individual or their performance which is altering their size perception based on this work.

This study (Witt & Proffitt 2005) adds another task (that being hitting a softball) to the many tasks that Proffitt and Witt have used to demonstrate an effect of actions utilizing tools on the perception of distance. Much of their research has asked questions related to how task performance alters perception. Most of their work has revolved around perceived spatial alteration due to performance factors. Throughout their combined investigations, Witt and Proffitt have demonstrated that wearing a heavy backpack increases the perceived steepness of a hill (Proffitt, Stefanucci, Banton & Epstein 2003); that using a pair of scuba-diving flippers makes sunken targets in a pool appear perceptually closer (Witt, Schuck & Taylor 2011); that performing well at kicking field goals increases the perceived aperture size between the posts...
(Witt & Dorsch 2009); as well as many other tasks which influence the way that performers perceive the space around them.

Using a toy common in German children’s birthday parties, Cañal-Bruland and van der Kamp (2009) validated and clarified the work of Witt and Proffitt (2005). Cañal-Bruland and van der Kamp wondered if the change in perceived size of a stimulus is contingent on the object being intrinsically linked to the action goal itself, and not just on the intermediate steps in the action required to achieve the goal. In softball, the ball is the object which is inherently related to the goal of the action (to cause the ball to fly). The researchers believed they had found a task where the object being used to accomplish the goal was only linked to the steps of the task, and not the motivational item of the task. Their method for testing this involved a well-known German birthday party game machine called Schokokusswurfmachine. The machine involves a contraption that fires a marshmallow or a soft foam ball back at a child if they throw a ball and hit the target. In this experiment, if children throw the ball at the target (the intermediate step in achieving the goal) successfully, they get another turn because a ball is fired back to them. The return of the ball is the motivational factor in this context, and is thus it is the child’s goal to receive a ball back; hitting the target is necessary for accomplishing the goal, but is not the goal itself. This study was conducted with German children who already had a basic understanding of the game (Cañal-Bruland & van der Kamp, 2009).

Cañal-Bruland and van der Kamp’s experiment (2009) was reliant on the idea that the target for aiming is an intermediate goal related to the end goal of getting a chocolate marshmallow, or getting the ball back. In this situation, the children’s actions are motivated by the reward, not to perform well on the target aiming. In order to ascertain perceptual changes, the
researchers asked the children to assess the sizes of targets (the intermediate goal) and balls (the final goal) on posters, which displayed sizes along a continuum (similar to Witt & Proffitt 2005). Note again that in studies of sports conducted by Witt and Proffitt (2005), the end goal object and intermediate are either the same, or linked directly to the size of the other, which is why the study described now was conducted with a different machine to answer this question (Witt, Linkenauger, & Proffitt 2011; Witt & Sugovic, 2010).

When children were not going to receive a ball back after hitting their target because the rules were that they won if they hit the target, the size of the target perceptually changed according to how well they threw, as in Witt and Proffitt (2005). Children who threw balls at targets in trials during which hitting the target was the end goal tended to perceive the size of the target based on their performance. However, children who threw the balls at the targets when receiving a ball back was the end goal did not see a significant change in size of the target depending on performance.

The researchers then proposed that perhaps the action-specific perception affected the target in children whose end goal was the ball because the ball’s size perception was changing instead. To investigate, they had children throw balls of different sizes than the one they received, to remove the confound of the ball size being influenced by prior experience with holding the ball. Catching tests used a net to catch the incoming ball so that size perception as a result of touching the ball was not a confound either. If the children hit the target, they tended to perceive the ball they received as larger. If they caught it successfully they also saw the ball as larger. This indicates even further that the action-specific perception in the first part of the
experiment was not due to the effects of planning. The thought of catching the ball was enough to affect the way that action impacted perception.

In this study, we observe once again the theme that the intention to act upon an object with a tool is an integral part of the effect that tool use, or any performative action, has on the way that people perceive size. Simply holding a tool does not change the way that we interpret the world around us; rather, an intention or plan to act upon some target, whether it be by grasping an optical illusion on a table or swinging at a softball flying towards us in the air, changes the way that we view the size of our target stimulus (Cañal-Bruland & van der Kamp, 2009).

In an unpublished study, Vishton found that tool use and intended tool use affect perceived magnitude of the Ebbinghaus Illusion (Vishton 2019). Utilizing the same methodology as Vishton et al. (2007), participants used a baton to point at the central discs within the illusory display. The results showed that participants’ use of tools perceptually reduced the magnitude of the illusion in the same way that reaching for the disc would. This study suggests that size perception within the Ebbinghaus Illusion is also susceptible to the effects of action which affect size perception in other tool use tasks.
Research in distance perception has reliably found that there is a perceptual transition which begins at about an arm’s length in our visual perception of space. Peripersonal space, which is space close enough around a person for them to perform manual action on an object within the area, is also referred to as “near space”, because peripersonal space exists within a consistent radius around the body, and this unconscious boundary forms a perceptual barrier between what is seen by the mind as manipulable and what is not. Peripersonal space gives way to extrapersonal space, or “far space”, at approximately an arm’s distance away from the body, just out of reach, and beyond which direct manual action can no longer occur (Berti & Frassinetti 2000).

Peripersonal space is characterized by perceptual and neurological patterns that are more closely associated with direct manipulation than in extrapersonal space, and attention to stimuli in peripersonal space is allocated based on its proximity and manipulability. This is an intuitive thought, given that all physical action that a person would have performed in evolutionary history would have been close to an arm’s distance from the body. Additionally, tool use has been shown to expand peripersonal space to incorporate the reach of the tool added to the length of the limb which is using the tool. In a study conducted to explore the idea that tool use affects the way the brain perceives these spatial boundaries, researchers showed that monkeys widen their neuronal receptive fields by using tools such as rakes, as if extending their hands (Iriki,
Tanaka & Iwamura, 1996). This is an example of an action or method which changes perception, and, similar to the findings of research in the field of size perception, the effects of the tool are conditional upon what sort of an action is being performed.

In the study (Iriki, Tanaka & Iwamura 1996), monkeys were given the tool (a small rake) for five minutes and then used it to pull food closer to themselves. The effects of the extension lasted while the monkeys were using the tool effectively as an extension of their hand, and diminished once the monkeys started using their hands again.

Some monkeys in another portion of the experiment of Iriki et al. (1996) were also given a rake but not instructed on its use. The monkeys in this experimental condition held the tool at their side, but did not reach out and use it. Their peripersonal space remained unchanged. This shows that just holding a tool alone, without an intention of using it, does not perceptually extend your body. The findings in Vishton et al. (2007) and Cañal-Bruland and van der Kamp (2009) align with this; tool use is often more about intentionality than the instrument itself. There is a neural basis established in this paper for the flexibility of the brain allowing for tool use: the brain literally changes to accommodate a new reaching capacity (Iriki, Tanaka & Iwamura, 1996).

Witt, Proffitt and Epstein (2005) provided another frequently cited example of a study which demonstrates that using a tool changes the way that we perceive objects at a distance, particularly in near space. Their study examined the contingencies of this effect more closely by examining specifically the effects of intent to act upon an object or stimulus. Previous research has shown that participants when given a tool have the tendency to perceive near space as extending further beyond near space without a tool. Witt et al. (2005) add a hypothesis to this: not only will near space expand to accommodate tool use (through the process of expanding
neuronal receptive fields, as found in Iriki, Tanaka, and Iwamura’s work in 1996), but this effect will be contingent on the way that a participant intends to apply the tool. In other words, just holding the tool does not change the perception of peripersonal space, but intending to use the tool does.

The study of Witt et al., consisting of three separate experiments, supports this hypothesis. In the first two experiments, participants were instructed to either reach for a projected image on a tabletop with a conductor’s baton, or estimate the distance to the image verbally. During the first experiment, the distances from the images to participants’ nondominant hands varied each trial. Nondominant hands were positioned on the table in a constant position. Participants then used the baton to reach the projected image, and then estimated distances from their hand to the target. Participants judged the distance from their hand to the image projection to be smaller when using the baton (Witt et al. 2005).

During the second experiment, participants indicated their perceived distances from a constant location (replacing their nondominant hand in this experiment) to the same projected image. They were instructed to do so nonverbally, by adjusting pieces of paper to be as far away from one another as the image was from the target. Half of the trials used the baton and half did not. The results indicated that use of the baton, which was handheld and 39 centimeters long, expanded peripersonal space and thus compressed perceived distance, and so stimuli appeared closer. In the third part of this experiment, participants held the baton used in experiments one and two, but held it passively, with no intention of using it to reach and no instruction to imagine using it. There was no effect of simply holding the baton on the perception of peripersonal space; one must intend to reach with an object in order to change perceived distance (Witt et al. 2005).
The observable differences in perception between peripersonal space and extrapersonal space can be isolated in cases of brain lesion patients who have hemispatial neglect either in near space but not in far space, or the opposite (Berti & Frassinetti, 2000). Hemispatial neglect is an inability to direct attention to one side of the visual field even while vision is unimpaired, and is often caused by neurological damage. The effects of hemispatial neglect are seen in trials of the line bisection task, during which a participant is asked to divide a line presented by the researchers in half, either by pointing to or drawing a mark where they perceive the half-way point to be. In individuals who have hemispatial neglect for peripersonal space, the patient would divide the line unevenly (in a ratio of about three-quarters to one-quarter, rather than half-and-half) when the line was presented within arm’s length; however, this effect was lessened when the line was presented at a distance.

The transition from peripersonal space to extrapersonal space can be difficult to describe due to disagreement among researchers as to how and where in visual space the shift in perception occurs. Some research has suggested that the transition from what the mind considers “near” to “far” occurs rather abruptly. Iriki, Tanaka and Iwamura (1996) demonstrated that there is a neural basis for a cut-off in peripersonal space at arm’s length by showing within the brains of monkeys that there are a select set of neurons that fire when interacting or preparing to interact with an object within that distance from the body. However, Longo and Lourenco (2006) designed a study to test if the transition from near space to far space was really so defined. A line bisection task was administered to adults from four different distances, and the effect of tool use on performance in the bisection task was measured (with the tool use or lack of tool use being the independent variable, and a laser pointer being a control). This article is one of many
utilizing a laser pointer as a control—the assumption being that a laser pointer cannot extend near space in the same way that a non-remote tool (like a baton) could do.

The authors assert that there is no hard cut-off for what the mind interprets as “near space.” The authors pose two questions to address gaps in the research of spatial perception and the transitional states of near-versus-far space. The first is whether tool use truly extends near space, as many have suggested. Their results showed that there was not an effect of distance on the bisection task when using a manual tool like a stick, whereas the laser pointer condition showed a clear and steadily linear deviation to the right in the line bisection task (whereas perception in the bisection task is often biased to the left in near space in healthy adult participants) (Longo & Lourenco, 2006).

Kirsch and Kunde in 2013 wondered what aspects of tool use contribute to the effects observed by so many distance perception researchers, that tool use of many kinds has the effect of compressing distal space (Kirsch & Kunde, 2013). The authors observed that in many studies related to distance perception, actions and characteristics of the actors in the moment affect perception of distance. Their primary question was what part of the action is leading to the changes in perception—the action itself and its amplitude (how powerful, long, or forceful the action was), or the location of the action, whether that be the starting point or goal of the action. This question could also be posed as does the action itself affect how the participant is perceiving the distance or stimulus, or does planning to act and interpreting the space prior to action? Through two experiments the authors concluded that the planning was separable from the amplitude of the action and that both have an impact on perception that is significant. These studies relied on a monitor set-up and a modified version of the line bisection task.
Alternative methodology while studying tool use and perception of size incorporate personal relationships with the tools presented, and the consequences of the tool’s use within a social context. The final part of an experiment by Davoli, Brockmole and Witt asked if spatial memory is affected by remote tool use (Davoli et al., 2012). Participants were asked to tell a story about animal pictures mounted on targets positioned at several varying distances from them in a long corridor. They could either be assigned to point at them with a laser, baton, or not at all. Those who used laser pointers remembered the furthest scene being closer than it actually was, indicating that those who use tools to relate to space within context may remember events according to their action-driven visual perception. It remains unclear what part of tool usage accounts for the changes in the way space is perceived. Is there a change in the attention devoted to the space when a tool is presented, or is the neural network which acts as the representation of the space altered based on one’s interaction with it?

The authors of the article suggest that our perception of the world might be driven by our potential to interact with things around us, and the reason that we see things the way we do is based on what we could do, not necessarily what is “real” (Davoli et al., 2012).

As with size perception, it is imperative to understanding research on tool use not as the tool’s effect on the perception of the object’s distance, but rather as the effect of the action, and the intention and attention associated with the tool’s use, on the change in spatial dynamics. It would be inaccurate to claim that the baton or laser pointer changed the way that a participant saw an object. The change in perception begins, as far as we know, in the mind with the planning to act, and the effects follow.
Chapter IV

Defining Tool Use in the Context of Perception Research & Introduction to Experimental Rationale

Research in the area of distance perception and size perception has supported the notion that tool use affects the ways in which we perceive our environment. However, the definition of tool and tool use varies between researchers and models. This variation has proven to be a tricky and divisive problem in psychophysics research on tool use, and therefore calls for closer examination before beginning work on this project utilizing remote tools.

To begin qualifying the definition of a tool, one can begin by turning to examine an object which nearly all observers would consider a tool, in order to ascertain what gives it its tool-like nature. For the purpose of this exercise, we will use a hammer as a universal stereotype for our tool definition, as a hammer would be defined as a tool by nearly every observer, perception researcher or not.

A hammer is an object which has been created with a specific purpose and intended use (in this case, that would be to hammer a nail into something, or remove a nail from something). A hammer is a manual instrument, and is generally easy to lift and hold. It requires action and attentional and physical effort on the part of the user. The physical effort exerted to use a hammer involves a planned sequence of arm and hand motions required to accomplish the action. The attentional effort of using a hammer is related to the focus and forethought required in preparing to use the tool and in the process of using it. A person is not using a hammer as a
tool by just holding it, for example; however, a hammer maintains its status as a tool even when not being used as a tool or while stationary, because of the capacity to cognitively engage with it in a specific purposeful way—that being, in the manipulation of a predetermined stimulus. And, finally, a hammer is used in a way that causes an effect on a stimulus.

So, by our definition of a tool according to a hammer, a tool is any handheld object with which a user ascribes an intended physical use, requiring cognitive and motor action to manipulate a stimulus. We can comfortably give the label of tool, then, to a wide variety of household items, including a screwdriver, a spatula, a pen, and so on, because these items without question fall into the category of tool as defined by our hammer. For this reason, we can also categorize items such as shelves, coat racks, and doors as non-tools, and with a degree of comfort in doing so.

Now consider someone using a hammer for a purpose other than for installing or removing nails in a wall. If a person were to use the head of a hammer to drag something on a workbench closer to them so that they could grasp it with their hands, most people would still view this use of a hammer as tool use. While the hammer is not being used as it was intended to be used in this case, it is the intention of the user to manipulate their environment that defines tool use in this case. Another example of this would be using a coat hanger to reach behind a washing machine to retrieve a fallen sock. A coat hanger would not originally fit the definition of tool we gave to a hammer, in part because it is not handheld, and in part because its intended physical use is passive and does not require cognitive and motor action to manipulate clothing, the stimulus for which it was designed. However, a coat hanger is certainly being used as a tool when it is used to fish an item from a crevice, and in this situation, it is clear that the hanger is
being used as an extension of the hand's ability to grasp an object, and its use may change the perception of the item it is acting upon, or the space in which it is being used.

The coat hanger example is emblematic of many of the problems with defining a tool, and one of the most obvious problems is the question of whether an item can cease being a tool based on the context of its use. Put another way, once a coat hanger is used as a tool, is the effect of the tool use on size perception and distal compression maintained the next time the coat hanger is handled? This question is relevant to a common example of a tool used in research on size perception and distance perception: the baton. When researchers refer to a baton, the instrument they have used is a conductor’s baton, a dowel, or a stick which has been cut to the proportions the researchers need in order for the baton to be used in their reaching task methodology. The participant is naive to use of this tool, but becomes accustomed to its use in the experiment, usually by playing with it before the trials begin.

A study conducted by Iriki, Tanaka, and Iwamura (1996) suggested that a novel item (a small rake) introduced to a monkey acquires the ability to extend perceptual reach, as a tool does, but only after the monkey becomes accustomed to using it as a tool. When the monkeys had no context for what the purpose of the rake was, and simply held the tool, there was no change in the receptive fields of the neurons. There was no effect of the tool on distance perception because the monkeys did not know its use and therefore did not plan its use. One might imagine that if an object not usually used to rake objects closer or farther, such as a coat hanger, was introduced to the monkeys as having the ability to rake objects in the same way as the researchers did, that the receptive fields would expand in the same way as they do when the monkey uses the rake. This would be because it is not necessarily the fact that the object is a
rake, but rather that the object is familiar and is known to be used to acquire food, which allows for the planning of related actions. We can now amend our definition of a tool to any handheld object that a person finds might be useful in some particular circumstances, regardless of its intended use, requiring cognitive and motor action to manipulate a stimulus.

Consider now a group of tools which do not manipulate a stimulus, but the group of tools manipulate one’s attention to a stimulus. A baton may also fall into this category; batons are used to refer to something, rather than push or pull or otherwise manipulate another object. The same can be said for a yardstick used by a teacher to point to some formula on the chalkboard, to direct their students’ attention to the front of the room. These objects are clearly used as tools, but are not being used to affect tangible change; rather, the change is an internal change in the way one directs attention. While these objects are directing attention in an intentional way, there are also objects which make us unconsciously alter our attention to certain elements of the environment. Wearing a heavy backpack while observing an incline makes the incline appear steeper, for example (Witt & Proffitt, 2005). One way to interpret this finding is that the tool being utilized (the heavy backpack) caused participants to focus on some elements of the terrain which they did not before putting the backpack on. The intention to act with the tool--in this case, hike with a bulky load--had therefore changed the way they perceived their surroundings.

So we must adjust our tool use definition once again, to any object with which someone interacts with the intention of manipulating something else.

Consider a laser pointer. First, is a laser pointer a tool? Some researchers would say it is not, because the definition of tool use is limited to how we defined the hammer, or the coat hanger reaching behind the washing machine. But, if it is a tool, a laser pointer is exclusively a
remote tool. Its actions are limited to what it can accomplish by directing attention to whatever it is illuminating. Its use is at a distance, often far beyond the normal reaches of peripersonal space. However, it is often used in the same way as a baton is used to refer to something. So there remains the question of, do remote tools engage with size perception and distance perception in the same way as a more direct tool does, or are remote tools’ effects different as they relate to their tasks?

These tools affect perception in similar, but not identical, ways to manual tools. Manual tools are often used as examples of the widening of peripersonal space and create distal compression; tools used to direct attention are shown to change the way people perceive their situation in more specific ways. Sometimes, these effects overlap. For instance, batons have been used as direct tools and remote tools (which Davoli et al. (2012) classify as any tool use “when an observer interacts with very distant objects”) in perception research.

A researcher’s endorsement of some definition of what is and is not a tool has the potential to determine the methodology of an experiment related to tool use. For example, the use of laser pointers in distance perception research methodology has often been as a control in studies of tools like batons, which were used to measure the change in perceived peripersonal space. The laser pointer’s place as a comparison in these tasks is likely due to a laser pointer’s indirect, nonphysical nature as an interactive tool, and the laser pointer’s inability to extend the length of a participant’s reach. I’ll be using the following study (Longo & Lourenco 2006) as an example of methodology which assumes that remote tools are not tools.
In their study designed to test the rigidity of the boundary between peripersonal space and extrapersonal space, Longo and Lourenco (2006) asked whether tool use indeed affects the extension of peripersonal space, as many authors have shown (Iriki, Tanaka & Iwamura 1996; Witt et al. 2005). Laser pointer usage in the Longo and Lourenco (2006) study, like many distance perception studies, was used as a control to compare the distance perception in the line bisection task against the use of sticks, which participants pointed like batons at the line bisection task. The laser pointer in this study was mounted on a tripod, and the laser was perpetually on throughout the comparison task during its use. The sticks used in the study were large enough to make it possible to touch the lines in the bisection task at every distance. The lengths of each stick also changed in each trial (Longo & Lourenco, 2006).

However, some researchers have treated laser pointers as tools in experimental hypotheses, and this outlook appears to have impacted the way that the studies were designed, and by extension the results and conclusions of these studies. For example, Davoli et al. in 2012 asked whether distal compression and an extension of peripersonal space could be achieved by using a laser pointer as a remote tool in much the same way that the use of a baton leads to the same effects.

Their first experiment in their three-experiment study examined if perceptual compression can be found in long-range “reaches” with a laser pointer, a more remote tool that does not extend physical reach. Participants stood at one end of a corridor, where targets were placed at eight distances (between four and thirty meters away from the participant), and participants were asked to give distance judgments to the targets after illuminating them with the laser pointer. Their experiment found that, indeed, the laser pointer reduced the space perceived
between the target and participant as the targets became further away. To prevent the question of if, instead of perceptual compression, a lack of tool use creates perceptual expansion, the experiment used a no-tool condition and a baton-pointing condition during which the participants again looked at the targets and judged distance. No significant difference was observed, and no expansion was observed with baton use; the researchers could conclude that the use of the laser pointer was creating the effect of perceptual compression that is so frequently documented in tool use perception literature. The researchers make a point at this point in the study that it is not necessarily an effect of the laser pointer itself, but its function as a means to act upon an object at a distance, which allowed for participants to compress distant space with its use. Thus, the intention to use the laser pointer as a tool was paramount to the effect of the laser pointer in this study; the intention to act with the laser pointer is shown to be just as effective as use of the laser pointer itself during a follow-up experiment when participants simply imagined using a laser pointer to point at the targets in the same methodology described above. This section of the experiment was influenced by findings of Vishton et al. (2007), which showed experimentally that imagined actions create similar results to performed actions in size perception research utilizing the Ebbinghaus Illusion.

Understanding the rationale behind assigning a laser pointer as a control and the resulting data, while also knowing that Davoli et al. found significant results while using a laser pointer in their experiments published in 2012, we can see that there is not a clear definition of what constitutes a tool in the study of distance perception. Davoli et al. (2012) used a laser pointer as a tool; Longo and Lourenco (2006) did not. Personal interpretations of what is considered a tool influences how the laser pointer is used within the study. In the Longo and Lourenco study, it
was on a tripod, and mobility was restricted, just as the same authors in their discussion section criticized studies of near space in which monkeys are restricted in their chairs in studies of near space (p. 980). While there is not an inherent flaw in using the laser pointer in this way as a control (mounted and less malleable than the “tool” condition), it does make the use of laser pointers in this line of research rather problematic because of the several different ways that we can define a tool and interpret one’s effects; are laser pointers capable of changing peripersonal space or compressing perceived distance, or aren’t they?

**Introduction to Experimental Rationale & Hypotheses**

It is clear that tool use changes the way we see the world in relatively predictable ways. When assessing size, the intention to act makes people less susceptible to illusions, and utilizing tools maintains that relationship by also decreasing the magnitude of the illusion. The use of tools in size perception research at a distance has demonstrated that actions utilizing tools determine how we perceive goal stimuli, and are affected by our perceived relationship to the tool being used. Our minds adjust size perception accordingly (Aglioti, DeSouza & Goodale, 1995; Vishton et al. 2007). In distance perception research, tools have been shown to become incorporated into our perceived body and potential action plans, expanding peripersonal space and compressing distances to target stimuli, making the world appear a bit closer (Witt, Proffitt & Epstein 2005; Iriki, Tanaka & Iwamura 1996).

We also know that tools associated with specific actions can impact the way that we perform and prepare to perform those actions. However, what is unknown is where the line is
drawn, so to speak, between what sorts of objects can create the effects described—essentially, what objects “count” as tools within a task’s context.

For the purpose of this study, I treat a laser pointer as a remote tool. As discussed in this chapter, the laser pointer is a remote tool because it acts indirectly on an object at a distance by changing the way we perceive a stimulus, and it does not physically extend the reach of a person using it. However, whether the laser pointer perceptually extends the reach of a person using it or not is a question I address in the experiment described in the next chapter. I ask whether a remote tool, like a laser pointer, behaves perceptually in the same way as direct tools. I compare the laser pointer tasks to verbal tasks, which should not have any effect on the magnitude of the Ebbinghaus Illusion or the perception of distal space; and to finger-pointing, which mimics the bodily actions required to use a laser pointer and which is a familiar action, but does not utilize tools.

First, I assess the effect of remote tools on the perception of distance to target stimuli. Participants will provide verbal judgments and then finger-pointing or laser-pointing judgments to objects around a classroom. If there is a similar effect of remote tool use to that of direct tool use on distance judgments, then the distance perception of the participants will be compressed in trials where they use the laser pointer as a tool to refer to objects.

Second, I assess the effect of remote tools on the magnitude of the effect of the Ebbinghaus Illusion. Participants will provide verbal judgments and then finger-pointing or laser-pointing judgments to a monitor several meters away, on which either two discs on no background will be displayed, or two discs surrounded by the Ebbinghaus Illusion inducers will be displayed. If remote tools, when used at a distance, behave the same way as direct tools on
perceptions of size within the context of a pictorial illusion, then the magnitude of the illusion will decrease as a result of the tool’s use.

Most research utilizing the Ebbinghaus Illusion as a measure of size perception has been conducted on a tabletop. Participants in these experiments are usually sitting down, viewing the stimulus within one meter away from their bodies, and looking down slightly to see the table. Aglioti et al. (1995) asserted that their study supported the conclusion that there are separate processing systems within the brain for perception and for action preparation; however, this study encompassed one very specific and controlled action. Vishton et al. (2007) showed that intended actions create the same reduced magnitude of the illusion within this specific task. While this methodology is useful for understanding how participants behave in one specific setting, conclusions should not be drawn about how action affects perception until multiple actions have been tested across various settings. This study is designed to move the Ebbinghaus Illusion, as a size perception measure, off of the tabletop, so to speak, and investigate whether intended actions continue to affect size perception at a distance. If the intention to act on the Ebbinghaus Illusion from a distance with a remote tool reduces the magnitude of the illusion, this study will suggest that context of a task has less effect on perceptual outcome than the intent to act.

This study also examines distance perception utilizing remote tools. Within this design, it will be possible to investigate whether there is a relationship between distance perception and size perception when using a remote tool. I specifically selected a remote tool to explore this question because of the capacity of the tool to reach greater distances than most manual tools, and because of evidence that remote tools behave in a similar manner to manual tools when
judging distances (Davoli et al. 2012). If there exists a pattern of results between the size perception and distance perception conditions, there might be a relationship between size and distance perception when using tools at a distance. If no such pattern exists, then the relationship between size and distance perception may be nonexistent or quite complex.
Chapter V

Experiment

In this experiment, I examined whether the effects of remote tool use on size perception and distal compression were similar to the effects of direct tool use on size perception and distal compression. Participants were asked to provide verbal distance judgments to common objects throughout a classroom and to provide size judgments of stimuli presented on a screen; after this, participants were randomly assigned to a laser-pointing condition or a finger-pointing condition to perform these tasks.

Procedures for this experiment were exempt from review by the Charles Center Student Institutional Review Board at the College of William & Mary.

Participants

Thirty-six undergraduate students (26 female, 10 male) at The College of William and Mary voluntarily participated in this experiment in return for course credit for a psychology introductory class. Thirty participants were right-handed \( n = 30 \) and six were left-handed \( n = 6 \); nineteen were right-eye dominant \( n = 19 \) and 17 were left-eye dominant \( n = 17 \). 18 participants reported visual impairment \( n = 18 \); of those participants, 14 reported wearing glasses or contacts for either near-sightedness or far-sightedness, one reported a scratched cornea, one reported being near-sighted, and two did not elaborate. Of these 18 students, three reported having received visual corrective surgery or vision therapy in the past \( n = 3 \).
Materials

The experiment was conducted in a long classroom located on the third floor of the Integrated Sciences Center building, room 3221, at William and Mary (Figure 3). The room had large windows on one side, and five tables. One of these tables was rectangular, and the remaining four were semi-circle shaped; these tables had monitors mounted on the walls above them. These monitors were off for the entirety of the study. To mark the position where participants were to stand, masking tape was left on a constant spot on the floor, located 7.36 m from the wall which they were instructed to face. Participants were instructed to stand on a strip of green tape on the carpeted floor. A digital monitor (1.77 meters by 1.01 meters, with a 2.54 centimeter frame) was mounted on the wall (with the height of the bottom of the monitor being 121.3 cm from the floor), and the monitor displayed the experimental conditions in a survey created on Qualtrics’s online survey software.

The laser pointer used in this study was 5 cm long, lightweight, and doubled as a backpack keychain (Appendix A).

Ebbinghaus Illusion stimuli and plain background stimuli were created in Microsoft Powerpoint. The images were exported as image files, and uploaded into Qualtrics online survey software to be used as visual stimuli for the Ebbinghaus Illusion portion. In their 2007 study utilizing the Ebbinghaus Illusion, Vishton et al. used discs which were 27 millimeters, 28 mm (the standard size), 29 mm, 31 mm, and 33 mm. When these stimuli were displayed on the monitor, the standard disc was 9.4 centimeters; comparison discs were 8.9 cm, 9.4 cm, 9.9 cm,
10.3 cm, 10.8 cm, and 11.4 cm\(^1\). Inducer sizes were standard throughout the entire study. The white background area was adjusted to best fit the Qualtrics area while in full screen view.

I used Qualtrics online survey software to design the experimental flow for this study. Recordings of the data collection were taken on camera, and were uploaded with participants’ consent to Databrary, an online data-sharing platform. Analyses were conducted in SPSS 25 statistical software.

**Experimental Methods**

Participants arrived at the classroom where the study took place and left their items by the computer console, where they could not be seen from the participant’s station throughout the experiment. Participants were asked for information on their gender, handedness, dominant eye, and corrective vision treatments or visual impairments before beginning the trials.

Participants stood on a strip of tape located 7.62 meters from the monitor in the front of the room which they faced. Participants were given orientation cues to the classroom by the researcher, who defined what would be the “front” of the room or the “end” of a table in the context of this experimental situation. The researcher instructed participants that during the first trial that they should avoid pointing to any reference object, either on the screen or throughout the room.

The experiment had two sections: verbal and pointing tasks, with verbal always preceding pointing tasks, due to a finding in Vishton et al. (2007) which demonstrated that the

\(^1\) The first visual illusion with the 11.4 cm comparison disc displayed to participants who were in the condition wherein the left disc was the standard size was displayed to participants; however, no data from this one stimulus was recorded from these participants due to an error in data recording in Qualtrics. This computer error was very unlikely to have affected results, given that participants received the stimuli and gave judgments to those stimuli in the same way as the other recorded data. Because two trials of each stimulus were recorded, there is only one data point for verbal judgments of the 11.4 cm disc for participants who saw the standard disc on the left.
effects of tool use on visual perception can persist for several minutes. Both verbal and pointing tasks had two sub-trials, presented in a randomized order: distance perception and size perception. Within the pointing task, there were two possibilities: participants could be assigned to the finger-pointing condition, or the laser-pointing condition. In the same order that they would have performed their verbal tasks, participants would then either use their hand or use a tool to perform the tasks (described below) at a distance.

**Distance Perception Verbal Task**

From the tape where they stood, participants were instructed to make distance judgments to ten reference objects throughout the room. The distances estimated were to be “from your eyes to the object.” The objects were positioned throughout the room, varying in proximity and kind. The closest object was located 1.97 meters away from the participant (a ceiling speaker directly in front and above the participant), and the furthest was located 8.45 meters away from the participant (the far right corner of the room). There were 20 distance judgments in total. Each stimulus of the 20 was either even or odd. A stimulus which was assigned an odd number was part of distance judgment set A. A stimulus which was assigned an even number was part of distance judgment set B. Nineteen of the participants were asked to judge the distances to set A (the odd distance judgment stimuli) for the verbal task, and 17 were asked to judge the distances to the even distance judgment stimuli for the verbal task. The tasks were assigned randomly prior to the participants’ arrival, and participants were ignorant of their assignment in either judgment set A or B. The stimulus numbers were for the purpose of analysis only, and participants were not aware of the stimulus numbers.
randomly. A complete list of stimuli and distances can be found in Appendix B, and I have described the layout of the room in a figure (Figure 2).

**Figure 2: Experimental Room Layout.** The room where the study was conducted was on the third floor of the Integrated Sciences Center at The College of William & Mary. Distance stimuli in this figure are represented by rectangles labeled with their numbers. The entrance to the room is represented in this figure by stimulus 20, which was the door handle. The wall opposite the entrance was slanted and had windows. There were four semi-circular tables in the room, three of which were located along the slanted wall; each of these tables had monitors above them. These tables each had five rolling chairs. A console with a computer station was located beside the entrance to the room. The participant stood 7.62 meters from the monitor mounted on the wall in what this figure depicts as the far left side. Participants were instructed that this was the front of the room.
After locating an object, participants made their distance judgments verbally, after reading the prompts presented on the monitor in front of them (for example, “What is the distance to the chair closest to the front left corner of the room in [preferred measure]?”). Participants were allowed to make these verbal judgments in either feet or meters; their answers were converted to meters after the experiment. The researcher sat at a semi-circular table behind the participants during all size perception judgment trials, in order to better see the screen from the participant’s perspective, and to maintain consistency during the pointing portion of the experiment.

**Verbal Size Perception Task**

Participants also were presented with a size perception task in the form of the Ebbinghaus Illusion, displayed on the monitor in front of them. Twelve visual stimuli were presented during this stage of the experiment; each was repeated once, for a total of 24 visual stimuli presented during the verbal size perception task. Each size perception item consisted of either two central discs with a white background on the screen, or two central discs surrounded by the annuli of the Ebbinghaus illusion on the screen. One central disc (on either the left or right side) was a standard, unchanging diameter (9.53 cm), and the other disc’s diameter varied randomly with each presentation. Participants were randomly assigned to identify which of the central discs appeared either larger or smaller to them for the duration of the experiment.

After a participant verbally indicated which of the discs (left or right) was either larger or smaller, the researcher pressed a coded key on the keyboard (z=left, x=right), and the questions automatically advanced, after a seven-second delay between stimuli, to the next size perception item. The delay was intended to clear any remaining afterimages left from the previous stimulus.
displayed, which could potentially disrupt participants’ view of the display. The researcher stood
behind the participants during all size perception judgment trials, in order to better see the screen
from the participant’s perspective, and to maintain consistency during the pointing portion of the
experiment. Participants completed either the verbal size perception task before the verbal
distance perception task, or the verbal distance perception task before the verbal size perception
task; assignments to these conditions were randomized.

### Distance Perception Pointing Tasks

After completing the verbal distance and verbal distance tasks, participants were
introduced to the experimental task to which they were randomly assigned: using one’s finger to
point to objects at a distance and the visual illusion prior to giving judgments, or using a laser
pointer to point to the distance judgment objects and illusory stimuli on screen.

Participants pointing with their fingers \( n = 18 \) pointed at a novel set of 10 distance
judgments positioned around the room, and their responses were once again recorded.

In the laser pointer condition \( n = 18 \), participants were introduced to the laser pointer,
which the researcher referred to as a tool. Participants were instructed to familiarize themselves
with the laser pointer by activating it and becoming practiced at illuminating objects around the
room. The researcher explained specific notes about the laser pointer which would be relevant to
this study—for instance, how to hold the laser pointer when using it to point to the monitor\(^2\), and
observing that the laser appears more faint in corners of the room which were more lit by the
sunlight. Participants then used the laser pointer to point at stimuli around the room, and then
provided distance judgments to those objects.

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\(^2\) Prior to running participants, I noticed that because of the optics of the LED screen of the monitor, seeing the laser
pointer beam on the screen was difficult unless the laser was held and used close to the line from the participant’s
eyes to the stimulus.
Size Perception Pointing Tasks

In the finger-pointing condition, participants were asked to point to the larger or smaller of the two central discs, presented on screen in the same manner as before. The researcher stood behind participants and coded their responses (left or right) with a keyboard, as before. Similarly, participants pointing a laser pointer indicated their choices with the laser pointer by illuminating the disc which they perceived as being larger or smaller.

Data Analysis

For the size perception task, the Point of Subjective Equality (PSE) was calculated for each participant in each condition: verbal size judgments of discs with a plain background, verbal judgments with an illusory background, pointing size judgments with a plain background and pointing size judgments with an illusory background. PSE was calculated as the largest comparison disc which a participant judged to be smaller than the 9.4 cm standard disc on at least one of the two trials in which a stimulus was presented.

A mixed model, repeated measures ANOVA was performed to assess the effect of the illusion background, the response behaviors (verbal versus pointing), and the types of pointing (finger-pointing versus laser-pointing). All significant results (results with $p < 0.05$) are reported.

For the distance perception tasks for each participant in each condition, the slope of the best fit line (relating actual distances to perceived distances) was calculated. For each condition, the mean ratio of actual distance divided by perceived distance was calculated. Data were also considered separately for “near” and “far” targets, where near was defined as closer than 5 meters, and far as beyond 5 meters.
Chapter VI

Results

Size Perception in Ebbinghaus Illusion Task

At a distance of over six meters, the Ebbinghaus illusion was still effective. There was a significant effect of the surrounding discs on the participants’ size judgments, $F(1, 33) = 206.1$, $p < 0.0005$.

In order to ascertain whether there was a difference between the magnitude of the illusion in the three separate conditions (remote tool use or finger pointing or verbal judgments), I compared an average distance measure of perceived size comparisons of the standard disc and the comparison discs. For each participant in each condition, I calculated the PSE. Results from duplicate stimuli were averaged together. Participants responded to two displays of each stimulus in each size perception task, and participants’ responses were coded as either a 0 or 1. The results of the average of the perception task data were either 0, 0.5, or 1, with 0 representing seeing both
of the standard size discs from the duplicate stimuli being larger than comparison, 0.5 as one of
the standard sized discs as being larger, and 1 equaling the comparison disc being larger. For
each size of the plain and illusion background trials, there was an average comparison disc size
participants that participants saw as equivalent to the standard disc. These scores were found by
determining the comparison disc size at which each individual’s transition from viewing the
standard disc to the comparison disc as larger occurred. These scores were averaged across
verbal and pointing conditions for the plain and illusion background stimuli.

There was a marginally significant effect of pointing on increasing the magnitude of the
illusion, \( F(1, 33) = 3.75, p = 0.061 \). This was a trend which approached significance that
suggests that the magnitude of the illusion was increased while pointing (laser-pointing and
finger-pointing).

**Distance Perception Task**

I interpreted the
distance judgments by
taking the average judgment
for each of the twenty
stimuli for each condition
for each participant within
the verbal, finger-pointing,
and laser-pointing
conditions. I then compared
the slopes of the best fit

*Figure 4: Average distance judgment scores for each stimulus across conditions.* The black central
dashed line represents y=x, or the true relationship between increasing distance and the actual distance
to stimuli. Best fit lines of the slopes of each condition are represented in this graph. The effects of
distance compression, although not significant, are visible in the finger-pointing and verbal judgments in
their shallower slopes. The laser-pointing slope appears to be greater than 1, suggesting there is an
expansion in perceived distal space as objects grow farther away. Whether the trends would remain or
dissipate at greater distances is unclear.
lines relating the perceived distances with the actual distances (Figure 6). Participants perceived items as being further away when they were indeed further from them, as was expected. There was a slight distance compression in verbal and finger-pointing conditions, which was expected, although the difference between these and the actual distances was not significant ($p > 0.20$). The laser pointer condition suggested that, contrary to my prediction, the laser pointer functionally expanded distal space. However, this difference was also not significant ($p > 0.50$).

I then calculated average ratio data. This was calculated by dividing actual distance by perceived distance for each stimulus, and then averaging these values across conditions. I used these data to graph and analyze the effects of tool use on distance perception.

Figure 5: Ratio data. Ratios of 1:1 (perfectly accurate perception data) would appear on top of the line $x=1.00$; as lines move further from $x=1.00$, the values become more different from each other. It appears that our hypothesis about the laser pointer compressing distal space is only supported when it is used in near space. Variance is higher among pointing tasks than the verbal task, and higher among near stimuli than far stimuli.
There appeared to be a compression effect for near stimuli when using a laser pointer, but this experiment found that, at approximately four meters, that relationship changed; verbal and finger-pointing judgments demonstrated a constant linear relationship with a smaller slope than that of the actual distances. However, this result was insignificant \((p > 0.10)\). At approximately 4 meters, the laser pointer relationship appeared to change, and the laser pointer’s relationship to verbal and finger pointing judgements shifted to appear more like distal expansion; the laser pointer’s slope is the steepest, suggesting that the laser-pointing condition’s perceived distance as a function of actual distance increases more quickly than finger-pointing’s perceived distance. Variance also was greater in closer distance judgments than in further judgments.
Figure 6a-b: Individual laser pointing data. Pictured are two examples of laser pointing participant scores. Demonstrated in the comparison between Figure 6a & 6b is the large variability in perception from participant to participant. Each of the 36 participants’ scores were averaged together to create the aggregate plots (Figures 4 & 5).
Chapter VII

Discussion

The prediction made prior to beginning this experiment had two parts: the effects of the Ebbinghaus Illusion would be reduced in the participants who used a laser pointer as a tool to indicate size, when compared to finger pointing and verbal indication; and that the use of a laser pointer would compress perceived distal space when compared to distance judgments given while finger pointing or given verbal assessments. The data collected returned results which indicate that the effects of remote tool use on visual perception are more complex and contingent on a greater scope of factors than originally predicted.

Illusory Effects and Size Perception

The Ebbinghaus Illusion, when displayed on a large surface, continues to be effective at a distance of over seven meters. The effects of the Ebbinghaus Illusion displayed at a distance have until this point been detailed very little within visual perception literature, as most research utilizing the illusion displays the illusion within reach of the participants. The fact that the Ebbinghaus Illusion works at such a distance, beyond the boundary of peripersonal space, suggests that the function of the visual pathway which interprets the illusory information within the Ebbinghaus Illusion is not contingent upon distance to the viewed object. Regardless of whether the illusion is positioned in front of a participant, on a table, or on an adjacent wall, the
effects of the illusory background consistently make the size of the disc with the smaller annulus of circles appear larger than its counterpart.

There was no difference between the effect of the illusion when participants used verbal indication to identify the larger or smaller disc, used their finger to point to the specified disc, or used the remote tool to point to the specified disc. I had hypothesized that the effects of laser-pointing would be significantly different from verbal judgments and finger-pointing judgments of the illusion because of tool use’s effect of lessening the magnitude of size perception illusions and altering size perception; this was not the case in this experiment.

Perhaps the actions taken in the studies demonstrating the lessened effects of tool use on the perception of the size perceptions in question rely on an intention to act upon an object in a specifically physical way. Vishton demonstrated that participants who reach for a specified central disc show a reduction of the effects of the Ebbinghaus illusion. Aglioti et al. (1995) also demonstrated this. However, Vishton et al. also demonstrated that the same effect was present when participants did not reach at all, but instead planned a reaching action or imagined haptically interacting with a central disc (Vishton et al. 2007; Aglioti, DeSouza & Goodale 1995).

Many studies (Tseng & Bridgeman 2011; Brockmole, Davoli, Abrams, & Witt 2013; Lin 2018) have suggested that a display’s proximity to the hands themselves affects the way that one perceives it. The interaction between tool use and hand proximity in near space has been historically difficult to control, due to the usually manual nature of tool use. In studies of size perception or perceptual tasks within peripersonal space examining hand proximity, the nearness of the hand, rather than the visual input of observing and potentially comparing the size of the
hand to inducers, produced the effect of greater accuracy in size judgment. Hand proximity was not a factor in these results. During the verbal task, during which participants judged the size of the central discs against each other, participants’ hands were by their sides, outside of the visual field. During the pointing or laser-pointing tasks, the pointing hand was in front of the participants’ eyes, providing visual input for size comparison, but not near the display.

However, the likelihood that the distance itself disallows the alteration of size perception based on action, or intended action, in general is uncertain. Research out of the labs of Dennis Proffitt and Jessica Witt has demonstrated an effect of tool use on the perception of size at a distance; however, these studies have not utilized the Ebbinghaus Illusion within the same framework as Milner and Goodale’s work.

Perhaps when assessing size perception at a distance outside of visual near space, there is only a significant effect when the tool is familiar to the participant, and the actions performed using the tool are within a context that is familiar to the participant. No data were collected about a participant’s familiarity with using laser pointers, and while participants in the laser condition were given about a minute to familiarize themselves with the use of the laser pointer in the classroom, it is unknown how familiar the task of using a remote tool like a laser pointer was to each participant.

Cañal-Bruland and van der Kamp (2009) suggested that motivation plays a large part in size perception at a distance. While this study utilized the same general methodology as Vishton et al. (2007) while participants were at a distance, perhaps there must be some intrinsic or extrinsic goal (as there is in the games they described) to create an effect similar to that of a direct tool. In the case of Cañal-Bruland and van der Kamp’s study, their participants used balls
as a direct tool. If a remote tool could be used in a similar capacity, within a game or other motivated task, the resulting magnitude of the illusion might be different from the illusion without motivated viewing.

**Distance Perception**

Perceived distances across participants increased as the actual distances increased, which suggests that participants viewed objects as increasing in distance as they became further away, as expected. Within the data presented in this experiment, there is not an indication that there is a difference between the distance judgments given while pointing with a finger compared to verbal judgments. Pointing with a finger was used as a comparison to the laser pointer tool use condition. Pointing with one’s finger utilizes nearly the same large muscular motion as the pointing of a laser pointer: the extension of the arm, tightening of the core, and positioning of the upper body to accommodate a reaching motion is similar across both movements. Thus, any effect of the laser pointer on distance perception could be compared to pointing with a finger and should be captured by this procedure. Based on these data, the opposite of my prediction is true for this study: participants who used the laser pointer to act on distant objects perceived objects as increasingly far away when compared to verbal judgments or finger pointing.

Researchers have hypothesized that tool use compresses perceptions of distal space by becoming incorporated into the body’s reach, and expanding peripersonal space. However, when examining the same effects of remote tool use, a different paradigm is used to discuss the compression of distal space: perhaps it is an association between an object and the manual interaction that the remote tool is indirectly fulfilling which creates this distortion in distance perception, and the effect of distance perception is more a learning phenomenon than a
perception phenomenon (Davoli, Brockmole & Witt 2012). In this experiment, I predicted that the use of the laser pointer would result in distal compression, as Davoli et al. found. However, the results of this study demonstrate a perceived increase in distance from the verbal and finger-pointing trials. As participants using a laser pointer saw objects and pointed their tool at them, they saw the objects as farther away than participants who used their finger or verbally judged the same visual stimuli.

The laser pointer itself was unlikely to have caused an expansion of peripersonal space for the same reason that the laser pointer was unlikely to be causing a compression of peripersonal space: the neurons responsible for detecting peripersonal boundaries can, as far as researchers understand, only expand their receptive fields so far. In a study of macaque monkeys, researchers found that most specialized visual-tactile neurons that deliver information about peripersonal space have receptive fields which extend 20 cm from the body; this is approximately the length of two hands (Graziano & Gross, 1993; Graziano, Hu & Gross, 1997). A fraction of these neurons which code peripersonal space have the capacity to extend their receptive fields up to one meter from the body (Graziano & Gross, 1995), but, as Davoli et al. (2012) explain in their study regarding remote tool use, perception of peripersonal space is unlikely to stretch much beyond that point, simply because of the constraints of the abilities of our neural circuitry.

Rather, the perceptual effects of the laser pointer (or, for this matter, any remote tool, like a remote control, or perhaps a computer mouse) are sufficient to create the perceptual effects of other manual tools. Davoli et al. utilized methodologies which produced distance compression with a remote tool due to its association with manual interactions (2012).
While interpreting these data, I returned to the original study of Davoli et al. (2012) which found a distal compression effect. This study and the study of Davoli et al. (2012) use two very similar procedures. There are a few key differences in their methodology and mine which might account for the opposing effects: characteristics of the laser pointer used, transition from one stimulus to the next, and the stimuli themselves.

The laser pointer used in my experiment was a small keychain, cylindrically-shaped with a cone-shaped pointing end by the lens, and about five centimeters long. The laser pointer used in the study conducted by Davoli et al. was three times as long, and heavier than the one used in my procedure. Perhaps the tool used in their experiment was more readily associated with more traditional manual tools due to its size and weight, while the tool in my experiment failed to arouse the same memory. This would suggest strongly that the effects of remote tool use are contingent on the tool’s similarity to manual tools, and that the effect of the remote tool may be activated by some kind of checklist in the mind for what qualifies as close enough to a tool to create some effect, based on memories of using manual tools. If the tool is heavy like a manual tool, or long like a manual tool, it is likely to behave like one, and if so many of these conditions are met, the compression effect appears.

Another possibility is that the difference is not in the tools, but in the stimuli. In the Davoli et al. (2012) study, participants pointed at mobile targets. In one experiment, these targets were shaped like standard shooting targets. In another, these targets were covered with pictures of animals (a frog, a salamander, and a turtle) that participants were instructed to use as characters in a narrative. In both of these tasks, the targets were mobile--participants turned around while an experimenter moved the target or targets to some distance between 2 and 30
meters from the participant. Locations were unpredictable, and only in the animal-target experiment were there other targets to compare to each other (in the case of that experiment, the animal targets were present together, and moved randomly in relation to each other). Both of these experiments produced distal compression effect. In my experiment, however, the objects judged were positioned throughout the room, and were not repositioned throughout the entirety of the study. Participants could continue to see a stimulus they had already judged the distance for. While the participants could hypothetically remember their distance judgments for other stimuli in the room to use for comparison, this did not affect the compression of distal space in the final experiment of Davoli et al. (2012). The participant always gave their verbal distance judgment first, eliminating holdover effects from tool use or the intention to act. The participant also had a size judgment task between their verbal and pointing distance judgment task to intentionally buffer this memory effect. So the difference may be in the stimuli themselves.

Acting on mobile stimuli, as in the 2012 study, may cause us to prepare to act differently than if we were to prepare to act on a stationary object, and the distance perception might adjust according to our specific intentions to act. Or, perhaps the difference is due to the novel nature of the shooting targets, or the animal pictures, while my study presented a setting and stimuli which were familiar to participants. It may be that people, when presented with a new task and given a tool to solve for it, always underestimate distances when using a tool, but when put in a familiar setting (like a classroom familiar to a psychology undergraduate research participant), someone can better account for their capabilities to directly act, and adjust their perception accordingly.

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3 Vishton et al. found in 2007 that the effects of tool use on perception are maintained for several minutes.
Another option for the difference is the act of turning around. Participants in the study conducted by Davoli et al. (2012) were asked to turn around so that a researcher could move the targets, while in my study that was not necessary. Perhaps the act of turning around allowed participants to start their perceptions with a “fresh” pair of eyes, so to speak; participants may have been less likely to compare their current judgment task to the one immediately preceding it. The difference in effect between these studies could be a combination of all of these factors, or none of these; future experimentation manipulating one of these factors at a time may yield more detailed results about what exactly causes the distal compression effect seen in the 2012 study.

When looking at the data, it is unclear if the laser pointer in this study provided a true distance expansion, or, if there were stimuli at a greater distance, the effect would cease to be linear and the laser pointer judgment trend would stay its course very close to the true distance judgments. In other words, the effect of the laser pointer in this context could really be a distance expansion, or it could be that the judgment with a laser pointer is simply more accurate beyond a certain distance. Without further investigation, no conclusions can be drawn about what the effect truly is; within the context of this study, the effect appears to be a distance judgment expansion, but a future study has the potential to investigate the data that show that the laser pointer judgments tend to become more accurate as the items become further away. Greater analysis is also necessary to unpack the effects of the laser pointer and finger pointing in near space. From 1.5 to approximately 4 meters from the body, the laser pointer does produce the effect of distal compression; items appear closer to participants than the finger pointing judgment. However, beyond this point, the laser pointer appears to expand distance judgments, and the average judgments given by laser-pointing participants is larger for items beyond 4
meters than judgments given by finger-pointing participants. More stimuli, as well as greater and smaller distances from the participant, may illuminate this effect more.

**Future Directions**

In a future study, I would ask participants, immediately prior to their use of laser pointers, what their experience is with using laser pointers in the past. This should give some idea of what degree familiarity with the tool affects the use of remote tools.

I would also hope to take into account optical differences between finger-pointing and laser-pointing. The laser pointer produces a dot of red light on an object, and the dot, like an inducer for the Ebbinghaus Illusion, might affect the perceived size or distance of an object. This possibility should be explored further.

I would also like to know about a perception researcher comparing a handheld laser pointer to one mounted on a tripod as an extension of this research. This would first demonstrate the difference in remote tool use research and controls for distance perception baton use experiments nicely, and second would look into what the mind conceives is perceptually considered a tool.

**Defining a Tool**

As discussed in Chapter V, this experiment utilizes a methodology which treats remote tool use as a kind of tool use. Throughout this thesis the definition of a tool has been discussed based on a tool’s intended use, actual use, and effects on perception. This study provides intriguing evidence that the mind uses and treats an object as a tool only if it satisfies conditions based on the task performed. In this experiment, the conditions for altering size perception were not met by the remote tool used at a distance. In the distance perception condition, the laser
pointer met some conditions for changing perception of visual space, but whatever conditions the laser pointer met in this experiment produced effects counter to what I had predicted. There was a clear dissociation between the neural system which measures size at a distance, and the neural system which assesses distances. While this does not necessarily mean that Milner and Goodale’s hypothesis about two mental streams of information is incorrect, the data here suggest that the story of visual perception is much more complicated when we take a step back—literally. The intention to act changes the way that we perceive the space around us, but does not change the size of the items affected by visual illusions perceived within that space. Excitingly, this poses many questions about tool use research utilizing remote tools. For instance, what degree of impact does the environment in which a tool is used affect the way people interact with a tool, and thus incorporate it into their perceptual frameworks?
REFERENCES


P. M. Vishton, personal communication, February 8, 2019.


Laser pointer used in experimental procedure.
Appendix B.

Questions used to identify stimuli for distance perception task.

Dist1. (6.695 m)
“What is the distance to the chair closest to the front left corner of the room?”

Dist2. (7.290 m)
What is the distance to the chair closest to the front right corner of the room?

Dist3. (5.89 m)
What is the distance to the closest foot of the table which is nearest to the front right corner of the room?

Dist4. (5.537 m)
What is the distance to the chair at the end of the front-most left table?

Dist5. (7.493 m)
What is the distance to the top corner of this monitor?

Dist6. (7.391 m)
What is the distance to the middle of the white panel in the wall below this monitor?

Dist7. (3.660 m)
What is the distance to the index card on the floor to the right?

Dist8. (5.105 m)
What is the distance to the index card on the floor to the left?

Dist9. (3.48 m)
What is the distance to the corner closest to you of the white rectangular table?

Dist10. (2.36 m)
What is the distance to the chair at the end of the middle table on the right?

Dist11. (8.45 m)
What is the distance to the top right corner of the dry erase board (to the right of the monitor)?

Dist12. (7.747 m)
What is the distance to the front left corner of the room?

Dist13. (7.366 m)
What is the distance to the camera in the front of the room?

Dist14. (4.97 m)
What is the distance to the middle of the window between the front-most and middle tables on the right?

Dist15. (2.43 m)
What is the distance to the fire alarm on the ceiling, which has the word "FIRE" in red letters?

Dist16. (1.969 m)
What is the distance to the grey circular ceiling speaker directly above and in front of you to the left?

Dist17. (6.756 m)
What is the distance to the left water sprinkler on the ceiling at the front of the room?

Dist18. (7.348 m)
What is the distance to the top right corner of this monitor?

Dist19. (3.683 m)
What is the distance to the center of the monitor on the right side of the room above the middle table?

Dist20. (3.429 m)
What is the distance to the doorknob?