Reachability Influences Perception via Motor Simulation

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Abstract

For over 100 years, researchers have attempted to delineate the information involved in distance perception, and in so doing, have focused solely on optical information. However, what we see reflects more than what is in the environment; what we see depends on our abilities to act and our intentions to act. Although this phenomenon is often experienced by athletes (for example, baseball players sometimes report that the ball looks bigger when they are hitting well), the notion that a perceiver's ability to act influences perception has only been recently entertained in perceptual research. In a series of studies, I manipulated people's bodies to enhance their ability to perform an action. Specifically, I gave people tools, which extended their ability to reach to targets, and measured corresponding changes in distance perception. I demonstrated that targets looked closer when they were within reach as a result of holding the tool compared with when the participants did not hold a tool and could not reach to the targets. However, these effects are contingent on intention. Only when the perceiver intends to reach does holding a tool influence perceived distance. With the rest of the experiments, I explored possible mechanisms that underlie the effect of reachability on perceived distance. Specifically, I propose that when perceivers intend to perform a given action, they run an implicit motor simulation of the action, and the outcome of this simulation influences their perception. The experiments demonstrate that perception is a function of optical information as well as the perceiver's ability to perform intended actions and that the mechanism underlying these effects involves a motor simulation of the intended action. This work calls for a new conceptualization of perception, namely that perception is not an informationally-encapsulated, modular process as has been previously thought, but

rather is a process that integrates information from the environment with information about the perceiver’s body and intentional states.

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Chapter 1

1. Introduction

1.1 Overview

What is the point of visual perception if not to convey the world around us so that we may move around and act in ways that satisfy our needs and desires? Perception informs the perceiver of what is in the environment, yet perception goes beyond simply representing the environment. One way that perception helps perceivers achieve their goals is by biasing the spatial dimensions of the environment in ways that relate to the perceiver's body, physical abilities, energetic potential, and future intentions.

This dissertation has two main aims. The first is to demonstrate that perception is malleable and influenced by changes to the perceiver's body. By holding a tool, the functional lengths of participants' arms were expanded thus increasing the range of reachable space. I will show that when targets beyond arm's length become reachable, as a result of holding the tool, they look closer than when they were not reachable. This result demonstrates that perception is influenced by the perceiver's ability to perform an action. The second aim is to explore the processes by which the perceivers' abilities get integrated into perception. Specifically, I propose that one of these processes is motor simulation, which is the unconscious imagining of an action without necessarily executing it.

The structure of the dissertation is as follows. In Chapter 1, I discuss other experiments that have shown that perception is malleable and influenced by the perceiver's ability to act. These effects have been demonstrated in perceived slant, distance, and size. Moreover, the effects are conditioned by intention, so only the perceiver's ability for the intended action influences perception. In Chapter 1, I also discuss an ability that may also influence perception, namely the ability to reach to targets. I review the literature on reachability that shows neurological and behavioral differences between targets that are within and beyond reach. Chapter 1 ends by motivating the experiment designed to assess whether reachability may influence perceived distance.

In Chapter 2, I present 2 experiments demonstrating that targets within reach look closer than targets beyond reach, even when distance is held constant. Participants reached to targets with and without a tool. They also estimated the distance to the targets either by giving a verbal report of the distance or by doing a perceptual distance matching task. In both experiments, the targets looked closer when participants held and reached with the tool. In a third experiment, participants also held and did not hold the tool, but they never reached to the targets. Thus, they never had the intention to reach. In this experiment, there was no effect of tool since reachability does not affect perception when there is no intention to reach. Chapter 2 concludes with a discussion of how these findings relate to Gibson's (1979) concept of affordances.

In Chapter 3, I motivate the idea that motor simulation may be involved in these effects. I describe some of the characteristics of motor simulation that make it an ideal candidate. I also review several experiments demonstrating that motor simulation exists, is neurologically realized, and plays a role in several types of situations including executing, imagining, or making judgments about actions.

In Chapter 4, I present 5 sets of experiments designed to test the idea of motor simulation. In the first two studies, I dissociate between a person's physical ability, anticipated ability, and imagined ability. If simulation is involved in the effects of reachability on perception, then people should perceive targets in terms of their anticipated and imagined abilities, since these abilities will be simulated, rather than their actual abilities. In the remaining experiments, I used interference paradigms. The logic is that if participants perform another task that interferes with the simulation, they will not be able to simulate reaching to the target, so even if the target is within reach, it will not look closer.

In the final chapter, I discuss the implications that these findings have for the current major theories of perception. Most of these theories have not considered that factors such as the perceiver's ability to act could influence perception and instead focus on optical and oculomotor information. Thus, revisions would be necessary to incorporate our findings into these theories.

1.2 Perception is Malleable

In addition to optical information, perception is informed by the perceiver's ability to perform intended actions. People perceive the world in a way that relates to their abilities to act in the world; however, only the ability to perform the intended action influences perception. To date, there is evidence that perceived slant, distance, and size are influenced by a person's action repertoire, performance capabilities, physiological state, and intentions.

1.2.1 Slant Perception

The ground plane has two components: orientation and extent. Although many of our actions take place on this ground plane, and typically do so without error, perception of these basic dimensions follow normative biases. For example, people grossly overestimate the slant of hills (Proffitt, Bhalla, Gossweiler, & Midgett, 1995; Witt & Proffitt, in press). Perceived slant was measured in several ways. For one, participants gave a verbal estimate in degrees of how steep they thought the hill was with 0° being a flat slope and 90° being a vertical cliff. A second measure involved a perceptual matching task. Participants adjusted the cross-section of a metal disk so that the angle of the cross-section matched the angle of the hill. Another matching task involved a disk with a straight line drawn across the middle, and participants simply had to orient the line to be the same as the slant of the hill. For all three measures, perceived slant was grossly overestimated both for hills viewed straight on (Proffitt et al., 1995; Witt & Proffitt, in press) and hills viewed as cross-sections from the side (Proffitt, Creem, & Zosh, 2001; Witt & Proffitt, in press). Typical results reveal that a 5° hill looks to be about 20° and a 10° hill looks to be about 30°.

Slant perception has also been measured by using a haptic task (Proffitt et al., 1995; Proffitt et al., 2001; Witt & Proffitt, in press). Participants placed their palms on top of a rotating platform and set the angle of the platform to match the angle of the hill. Unlike the visual matching tasks described above, participants' estimates were accurate when they estimated slant with the haptic task. However, the haptic task differs from the other matching tasks because it requires a motoric response and participants performed the task without looking at their hands, so the task does not require a visual comparison of two angles. Performance on this task may rely on perceptual processes that drive visually-guided actions rather than those processes responsible for explicit awareness, so unlike the other types of slant estimates, the haptic task does not provide a measure of conscious perception. The haptic task and its underlying processes will be discussed in more detail in Section 5.1.3. For the remainder of this section, I will be referring to the tasks that measure conscious perception of slant and not the haptic task.

Perceived slant is also influenced by the perceiver's ability to ascend the hill. For example, hills that can be traversed look shallower than hills that are too steep to traverse (Proffitt et al., 1995). Participants estimated the steepness of hills from the top and the bottom of the hill. Their estimates were the same from both vantage points until about 25°. At this angle, hills appeared steeper from the top than from the bottom. This is the angle at which it is still possible to ascend a hill, but it is biomechanically much more difficult to descend the hill without falling. In other words, a 25° hill still affords walking if the person is at the bottom of the hill, but it does not afford walking if the person is at the top of the hill. The hill looks steeper from the vantage point where walking is no longer possible than at the vantage point where walking is possible.

In addition, the energetic requirements to ascend a hill influence perceived slant (Bhalla & Proffitt, 1999; Proffitt et al., 1995). Participants who viewed hills while wearing heavy backpacks perceived the hills to be steeper than participants who did not wear the backpacks. Similarly, hills looked steeper after going on a long, fatiguing run than before the run. In these two experiments, the energetic requirements were manipulated by the experimenters. However, pre-existing differences in energy potential also affects perceived slant. Bhalla & Proffitt (1999) found a negative correlation between fitness, as assessed by heart rate and maximal oxygen uptake while exercising, and perceived slant. That is, participants who were less fit perceived the hills to be steeper than participants who were more fit. A similar correlation was found between perceived slant and age and perceived slant and health. Elderly participants and those of declining health perceived the hills to be steeper than younger and healthier participants.

1.2.2 Distance Perception

Like perception of slant, distance perception also has normative biases; however, these biases depend on how perceived distance is measured. Verbal reports of the distance, which are typically given in feet and inches, tend to be compressed for distances beyond 2m (e.g. Loomis, Da Silva, Fujita, & Fukusima, 1992). Similarly, perceptual matching tasks also reveal underestimation of distance. In these tasks, participants adjust a set of cones so that the distance between the two cones matches the distance to the target. However, there are other measures of perceived distance that are accurate. In blindwalking tasks, participants close their eyes and either walk to the target or walk the same distance as the distance to the target but in a different direction. When performing these tasks, participants are quite accurate (Loomis et al., 1992). Even though verbal estimates and blindwalking measures give different absolute values of perceived distance, they are both driven by the same underlying percept of distance and show corresponding changes when the percept is altered (Philbeck & Loomis, 1997). Thus, either measure can be used when evaluating changes in perceived distance.

As with slant perception, distance perception is also influenced by the perceiver's energetic potential. Perceived distance increased when participants wore heavy backpacks (Proffitt, Stefanucci, Banton, & Epstein, 2003). Distances also looked farther when they were placed up steep hills since steep hills require more effort to ascend than flat ground (Stefanucci, Proffitt, Banton, & Epstein, 2006). This latter result is especially interesting since the geometric layout of extents on an incline would lead to the prediction that perceived distance should be foreshortened. Instead, perceived distance is influenced by energetics.

Effort for walking has also been manipulated by using a perceptual-motor recalibration to induce the illusion that walking to a target would require more energy than normal. This adaptation was induced by having participants walk on a treadmill. Participants had to exert effort to stay on the treadmill, but they never went anywhere. Therefore, their visuomotor system learned that it took a lot of energy to go nowhere. After recalibrating to the new expectation of forward gain from walking effort, participants perceived targets to be farther away (Proffitt et al., 2003; Witt, Proffitt, & Epstein, 2004). In other words, when participants anticipated having to expend more energy to walk to a target, perceived distance increased.

The effect of effort on perceived distance is not limited to walking effort. Effort for throwing also influences perceived distance (Witt et al., 2004). Participants who threw heavy balls, which weighed 2 pounds, to targets perceived the targets to be farther away than participants who threw light balls, which weighed less than a pound. Although other actions have not yet been tested, we imagine the effects will generalize to actions beyond walking and throwing.

1.2.3 Size Perception

The fact that a person's ability to act affects perception is a common experience in sports. For example, many baseball players report that the ball looks bigger when they are hitting well and smaller when they are in a slump (see Witt & Proffitt, 2005). Other anecdotal evidence suggests that when playing well, golfers' perception of the cup size, tennis players' perception of the ball size, and basketball players' perception of the hoop size all increase.

We have confirmed this phenomenon in softball players and golfers. After softball games, players viewed an array of varying sized circles and selected the one they thought best matched the size of the softball. They also reported their batting average for the just played game or games. Batting average was positively correlated with apparent ball size. Players with a higher batting average selected a larger circle as matching the size of the softball. In other words, the ball looked bigger to players who were hitting well (Witt & Proffitt, 2005).

We used a similar paradigm with golfers (Witt, Linkenauger, Bakdash, & Proffitt, 2006). After golfers played a round of golf, we showed them an array of circles, and the players selected the circle that they thought matched the size of the hole. We collected information on players' score for the course that day, their handicap, number of strokes taken on the 18^{th} hole, number of putts taken on the 18^{th} green, and several subjective measures on the players' assessment of their own performance that day. Players who played better judged the size of the hole to be bigger than players who played worse. However, handicap, a measure of longer-term playing ability, was not correlated with judged hole size. Put simply, better players do not see the hole as being bigger, but a player that is playing better on a given day does see the hole as bigger. Furthermore, apparent hole size was correlated with putting performance on the last hole but not with overall performance on the last hole suggesting that these effects are specific to the relevant task. Finally, apparent size was not related to subjective measures of performance. Players who think they are playing better do not necessarily see the hole as being bigger.

A similar finding was observed in dart throwers (Wesp, Cichello, Gracia, & Davis, 2004). Participants dropped darts onto targets. Those who were able to hit the target with fewer throws perceived the target to be bigger than participants who had more trouble hitting the target. These results demonstrate that perceived size is influenced by people's ability to perform the task.

1.2.4 Effects of Intention

It is not the case, however, that ability and effort always influence perception. Rather, the effects of ability and energetic costs on perception are conditioned by intention. People see the world in a way that relates to their goals and intentions, so only their ability to perform the intended action influences perception (Witt et al., 2004). In one experiment, two groups of participants threw a heavy ball to targets ranging from 4 – 10 m and verbally estimated the distance to each target. Then, one group of participants threw the heavy ball again while the other group of participants blindwalked to the target. Thus, one group viewed the target with the intention to throw again, and the other group viewed the target with the intention to walk to it. The "throwers" perceived the targets to be farther away than the "walkers" even though both groups had just thrown the heavy ball prior to estimating the distance. This result reveals that people perceive the world in terms of the actions they intend to make, not the actions they just performed.

We found a similar result when we manipulated effort for walking (Witt et al., 2004). Participants verbally estimated the distance to targets in a hallway. After each estimate, one group blindwalked to the target while another group threw a beanbag to each target. Thus, one group viewed the targets as “walkers” while the other group viewed the targets as “throwers”. Then both groups walked on the treadmill, so they both recalibrated to expect to have to exert more effort to walk to a target. Afterwards, both groups were led to the hallway again to make another distance judgment. The “walkers” perceived the target to be farther away relative to when they saw the target before walking on the treadmill compared with the “throwers.” Effort for walking increased for both groups, but only the walkers saw the target as being farther away since effort for throwing had not increased and effort for walking is not relevant for throwing.

Intention was not manipulated in all of the experiments, yet researchers still found effects of effort. For example, hills looked steeper and distances looked farther when wearing a heavy backpack even though participants were never told to walk to the target. One explanation is that the default affordance of the ground plane is to walk. When perceivers see the ground, they automatically and implicitly see its affordance for walking.

In summary, perception is not just a function of optical information from the environment but it is also a function of the abilities and intentions of the perceiver. People see the world in a way that relates to their goals and their potential to achieve these goals.

1.3 Near Space and the Body

In the previously described studies, perception was influenced by two aspects of the perceiver: energetic potential and performance. However, given the tight coupling proposed between perception and the perceiver, manipulating the perceiver's body should also influence perception. A perceiver's behavioral repertoire is determined by the body and its capabilities for action. Thus, changing the body should have corresponding effects on the perceiver's ability to act. For example, when people hold a tool, their effective arm length is extended, so they can reach farther. Recent research demonstrates neurological and behavioral differences in people's responses to the space that is within and beyond reach. Furthermore, this space, and people's responses to it, can be manipulated by giving people tools with which to reach. In the first set of studies, I investigated whether there were perceptual differences between near and far space.

1.3.1 Visual Sensitivities for Reachable Space: Evidence from Electrophysiology, Clinical Case Studies, and Behavior Studies of Visual Attention

Near space (also called *personal space*, Cutting & Vishton, 1995; and *peripersonal space*, Lavadas, 2002) is defined by the extent that can be reached or just slightly beyond. Evidence that the brain codes space in terms of reachability can be found in electrophysiology studies. Iriki, Tanaka, and Iwamura (1996) demonstrated that monkeys possess visual neurons that code for reachable space. They found neurons in the intraparietal sulcus that fired when a raisin was presented within the monkeys' arm's reach but not beyond. The monkeys were then taught to reach with a rake, which extended their reach. The "reachability" neurons adapted to this change and responded to raisins that were presented further away but within reach with the rake. This research suggests that there exist visual neurons that code for what is within reach and that these neurons adapt to changes in reachability resulting from tool use.

Research on neglect patients demonstrates behavioral differences between what is within and beyond near space as well as the ability to remap near space. Neglect patients tend to ignore the left side of their visual field. When asked to bisect a line, they bisect only the right half, resulting in responses far to the right of true center. A double dissociation between near and far space has been shown when the bisection of lines in near space is compared with the bisection of lines in far space (Cowey, Small, & Ellis, 1994; Halligan & Marshall, 1991). Some patients show neglect only for near lines and not for far lines (Halligan & Marshall, 1991), whereas other patients show neglect only for far lines (Cowey et al., 1994). For patients who showed neglect in near space only, it has been shown that reaching to far lines with a stick influences their responses to the far lines (Berti & Frassinetti, 2000; Pegna et al., 2001). When bisecting far lines with a stick, these patients showed neglect, indicating that the space had been remapped as near space as a result of using a tool. This suggests that the behavioral differences observed between space within and beyond reach are because of the ability to reach not because of absolute distance.

Experiments in cross-modal interference also suggest different patterns of behavior to objects within and beyond reach. Participants were asked to report when and where they felt a tactile stimulus on their hand. A distracting light was presented either near or far from their hand. When the light was close, participants were less accurate and slower to report a tactile stimulus, but when it was far, accuracy was unaffected. However, when they were given a tool long enough to reach the far light, the distracting light did interfere with tactile detection (Maravita, Spence, Kennett, & Driver, 2002). This finding and those of similar studies (e.g., Farne & Ladavas, 2000; Maravita, Husain, Clarke, & Driver, 2001) demonstrate that near space is remapped with tool use and that this remapping affects visual attention within this space.

The studies reviewed above show that the visual system is sensitive to the extent of reaching, either with the hand or with a held tool. Given this sensitivity, it could be the case that the extent of reachability serves as a perceptual metric in vision. That is, reaching extent could mark a perceptual discontinuity such that everything that falls within this range is perceived to be in near space, whereas everything located beyond this boundary is perceived to be outside of this immediate action space. The essence of this notion is that reachable targets are perceived as having a quality of “nearness” that targets beyond this boundary lack. Consequently, targets that cannot be reached without a tool will appear closer when a tool is held compared with when it is not.

Chapter 2

2. Near Space Experiments

In the following experiments, target distances were held constant while reachability of the targets was manipulated. Targets were presented at varying distances within and beyond reach, and participants made verbal and visual judgments of the distance to the target. Half of the time participants held a tool allowing them to reach to all the targets. It was found that targets that were out of reach without the tool appeared closer when the tool was used to reach to the target than when the tool was not used.

Experiment 1: Verbal Estimates

The first experiment investigated the influence of reachability on perceived distance. I manipulated reachability by having participants reach either with or without a tool. Perceived distance was measured by having participants give verbal reports of the distance to targets.

Method

Participants. Sixteen students from the University of Virginia (10 male, 6 female) participated for pay or for research credit. All gave informed consent.

Apparatus and stimuli. The participants sat in front of a rectangular table onto which stimuli were projected from a projector pointing downward from the ceiling (see Figure 1). The table top was 122 cm wide and 183 cm deep and was 97 cm above the floor. The table was uniformly white so as to minimize landmarks, which could influence distance judgments. A vertical wooden handle was fixed to one end of the table, and participants held this handle with their non-dominant hand. The handle specified the location from which the distance to the target was to be estimated. The table was in a typically cluttered laboratory environment; however, there were no objects in the space immediately surrounding the table. During half of the experiment, participants held a 39 cm long orchestra conductor's baton.

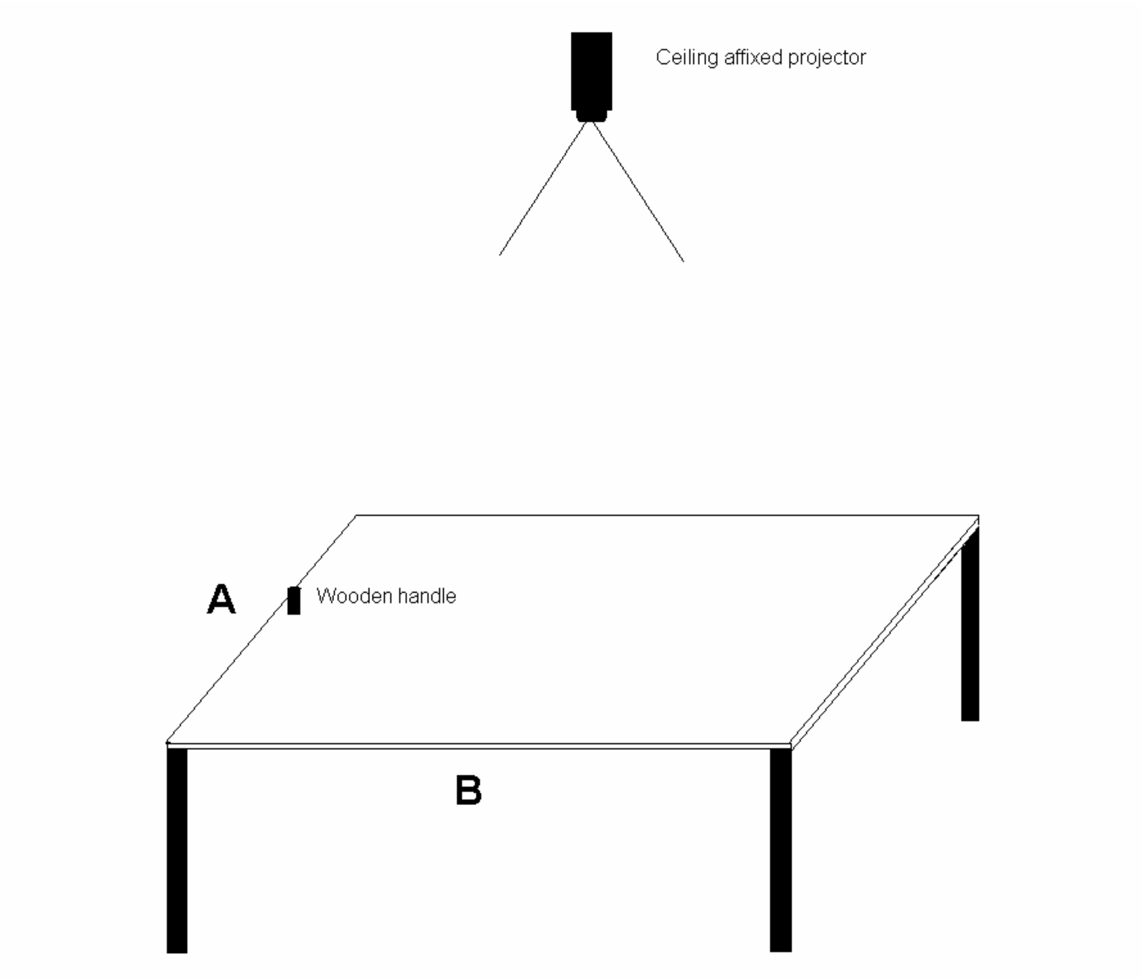

Figure 1. Set-up for the experiments. Stimuli were projected from a ceiling affixed projector onto a flat, homogeneous, white table. A wooden handle was fixed to one end. In Experiment 1, participants sat near the handle (marked by the 'A'). In rest of the experiments, participants sat at the location marked by 'B'.

Procedure and design. A 2 cm white circle was projected onto the table top for 500 ms. After it disappeared, a computer-generated voice said "touch" or "estimate." If it said “touch,” and the location previously occupied by the circle was within reach, then the participant reached out and touched it; if it was beyond reach, the participant pointed to where it had been. If the computer said “estimate,” the participant verbally estimated the distance in inches from the wooden handle to where the circle had been. Participants did not know whether they would have to touch or estimate the distance to each target until after the target was extinguished. Participants were not given prior training on estimating distances, and no feedback was given on reaching or estimating accuracy. Participants were not told the range of distances that would be used and were not given a source with which to calibrate their estimates.

Participants completed two blocks of trials one with the baton and one without the baton. Each block consisted of 50 targets. Participants reached to half of the targets and estimated the distance to the other half. Reaching trials were randomly intermixed with estimating trials, so participants could not anticipate the kind of trial that would follow from the previous one. Participants were told to touch the target with the tip of their finger or with the tip of the baton. The distances used were 38.10, 40.64, 45.72, 48.26, 53.34, 54.61, 58.42, 60.96, 63.50, 71.12, 73.66, 78.74, 82.55, 91.44, 92.71, 95.25, 96.52, 99.06, 106.68, and 109.22 cm. Half the participants held the baton for the first block and half held the baton for the second block. They were not aware that they would complete two blocks, so participants who held the baton in the first block did not know they would do the task again without the baton and participants who reached with their finger in the first block did not know they would complete a second block with the baton.

Data Analyses. I measured each participant’s reach with and without the baton. Participants had been instructed not to lean forward; however, all participants did lean slightly forward. To take forward lean into account, I had members of our lab informally reach towards the targets, and I measured how far they were apt to lean. The average amount of forward lean (13 cm) was added to the arm lengths of the participants to account for forward lean[1]. The data for analyses included the estimates for distances that were beyond arm length without the baton and within arm length with the baton. This is the area of space that is remapped into near space when reaching with the baton. The following distances were included in the analyses: 78.74, 82.55, 91.44, 92.71, 95.25, 96.52, and 99.06 cm.

Statistical outliers were defined as values above or below 1.5 standard deviations from the mean as determined using box plots. I excluded the data from two participants because 50% or more of their estimates were statistical outliers, and I excluded 4 individual data points that were greater than 1.5 standard deviations from the mean. These outliers will be further discussed in the next section.

Results and Discussion

I ran a repeated measures ANOVA with tool and distance as independent factors and perceived distance as the dependent measure. There was a main effect for distance ($F(6, 93) = 3.556$, $p < .01$, $d = 0.187$). There was a main effect for tool ($F(1, 93) = 8.599$, $p < .01$, $d = 0.085$). Participants estimated the targets to be closer when they reached with a baton than when they reached or pointed with their fingers (see Figure 2). When the targets were beyond reach they appeared to be farther away than when they were

[1] Adding slightly different amounts of forward lean such as 12 cm and 14 cm did not change the pattern of results.

within reach. The interaction between distance and tool was not significant ($F(6, 93) = .333$, $p > .9$).

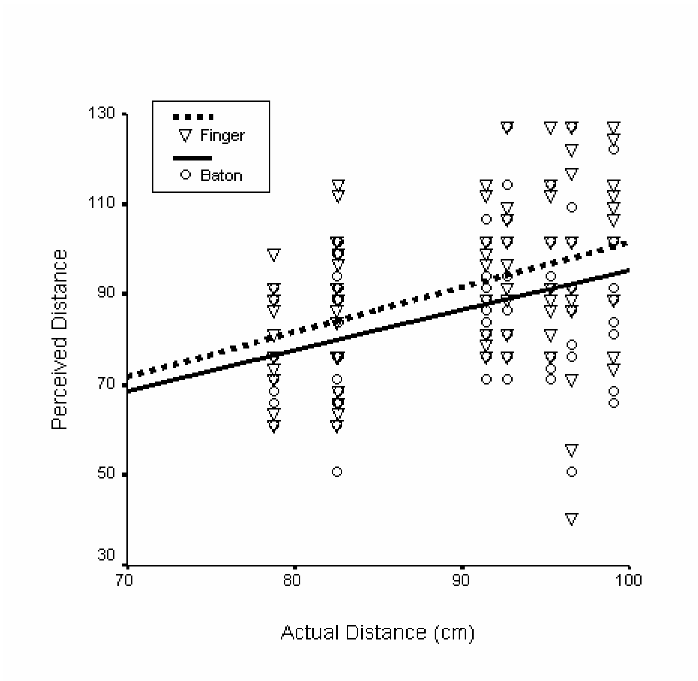

Figure 2: Verbal estimates of distance as a function of the actual distance in the finger and baton conditions of the preliminary experiment. Lines represent regression lines for each tool.

These results suggest that there is a difference in perceived distance when wielding a baton. The variability of the verbal estimates was quite high for all of the subjects (variance = 767.23, range = 147.32) even after removing outliers (variance = 382.39, range = 121.92). Given this high variability and the necessity of removing outliers, I considered this first experiment to be a preliminary study. In the second experiment, I used a measure of perceived distance that had less variability, and therefore, would be more sensitive to differences in perceived distance due to reachability.

Experiment 2: Perceptual Matching

In this study, I used the same reachability manipulation and measured perceived distance with a perceptual matching task. On the horizontal table, two comparison circles were positioned perpendicular to the line between the participants and the targets. Participants adjusted the distance between the two comparison circles to match the perceived egocentric distance to the target (see Figure 3).

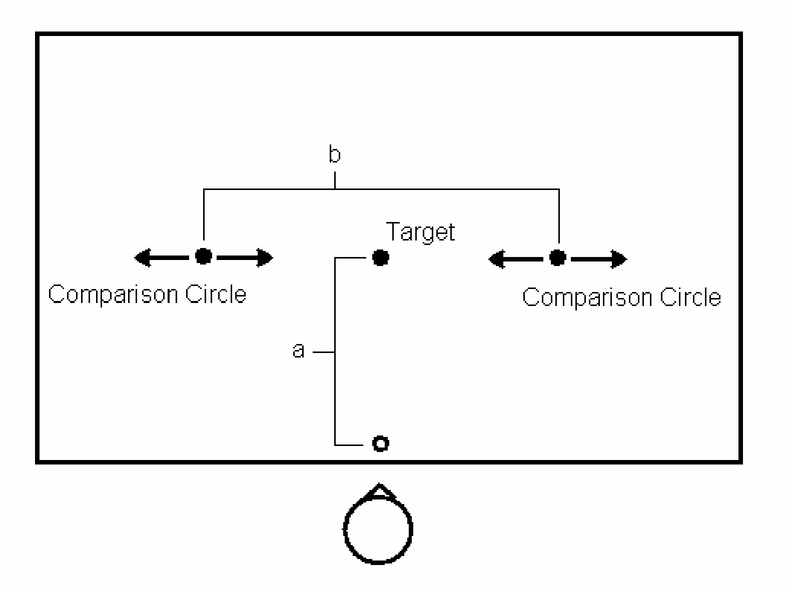

Figure 3: Perceptual matching task in Experiments 2 and 3. Participants use a keyboard to move the two comparison circles closer together or farther apart until they judge the distance between the two comparison circles (b) to be the same as the distance to the target (a).

Method

Participants. Eight University of Virginia students (2 male, 6 female) participated for pay or for research credit. All gave informed consent.

Apparatus and stimuli. Each participant sat along the long side of the same horizontal white table as in Experiment 1 (see Figure 1). This time the table was only 36 cm off the ground to increase the size of the projected area. There was a small white paper circle directly in front of the participants. This circle served the same purpose as the handle in Experiment 1; the distances that were judged were the distances between this circle and the target. Participants matched the distance between the comparison circles to the distance between the paper circle and the target (see Figure 3). Participants completed half of the trials holding the baton and the other half without holding the baton.

Procedure and Design. On each trial, a small circle (1 cm in diameter) was projected beyond reach of the hand but within reach of the baton. Participants reached out and touched the circle or reached as far as they could when the circle was beyond reach. After 4 seconds, two comparison circles appeared 5 cm on either side of the target circle (see Figure 3). Participants repositioned the comparison circles by tapping the left and right arrow keys on a keyboard with their non-dominant hand. On every trial, participants adjusted the comparison circles closer together or farther apart until the distance between the comparison circles appeared to be same as the distance to the target (see Figure 3). After positioning the comparison circles, participants hit the enter key, and all the circles disappeared. Then they reached to where the target circle had been. After 4 seconds, the next trial began.

Participants completed four blocks, two with the finger and two with the baton. One group of participants completed the first two blocks with their finger and then two blocks with the baton. The other group of participants completed the first two blocks with the baton and then two blocks with their finger. Each block consisted of 10 trials with targets placed at 73.66, 78.74, 83.82, 88.90, 93.98, 99.06, 104.14, 109.22, 114.30, and 119.38cm. Participants were unaware that they were going to perform the task with both tool conditions.

Results and Discussion

Tool, distance, and order were included in a repeated measures ANOVA with the distance between the two comparison circles as the dependent measure. There was a main effect for distance ($F(9, 137) = 31.857$, $p < .0001$, $d = .677$). There was a main effect for tool ($F(1, 137) = 55.729$, $p < .0001$, $d = .289$). Participants perceived targets to be farther away when reaching with their finger than when reaching with the baton (see Figure 4). They perceived targets that were beyond finger reach as farther than targets within reach holding the baton even though the targets were in the same spatial location. When holding the baton, near space expanded and targets that were remapped into near space were perceived as being closer. Regression equations show an intercept difference of 7cm between the two tool conditions (Finger: $y = .65x + 27.22$; Baton: $y = .67x + 20.70$), which is much less than the 39cm extension provided by the tool. This indicates that reachability is only one type of information contributing to perceived distance. Optical and oculomotor information also provide robust specification of apparent distance. The interaction between tool and distance was not significant ($F(9, 137) = 0.938$, $p > .494$).

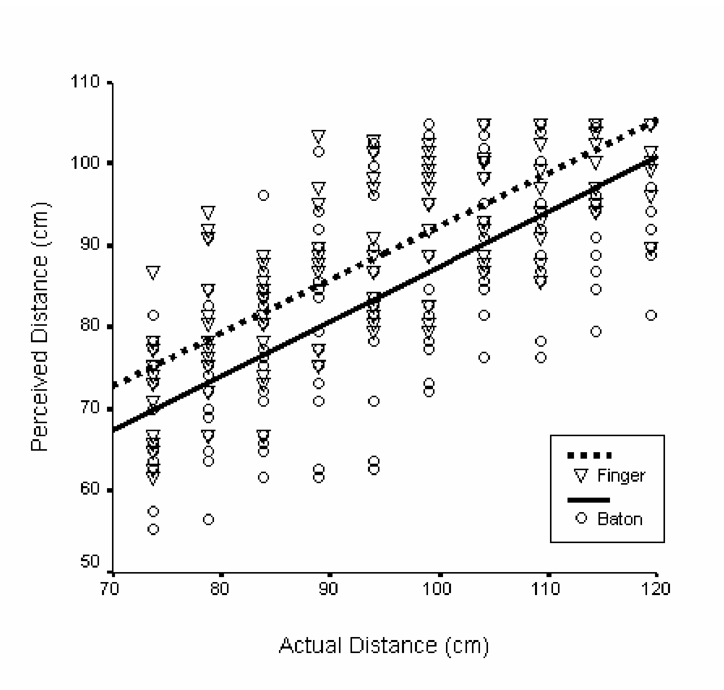

Figure 4: Perceptually matched distance as a function of the actual distance in the finger and baton conditions of Experiment 2. Lines represent regression lines for each tool.

There was a significant effect for order ($F(1, 137) = 12.864$, $p < .0001$, $d = .086$). The first block ($x = 89.74$, $SD = 11.28$) looked farther than the second block ($x = 85.42$, $SD = 12.55$). Although the interaction between session and tool was not significant ($F(1, 137) = 1.21$, $p > .72$), I ran a separate ANOVA comparing just the first block across subjects. In this analysis, tool is a between-subjects variable, and since subjects did not know that they were going to complete another block with the alternative tool, this analysis would reveal if the within subjects effects were contaminated by cognitive correction. The tool used during the first block and actual distance were the independent measures and perceived distance in the first block was the dependent measure. There was a main effect for tool ($F(1, 58) = 4.016$, $p < .05$, $d = 0.065$), which suggests that perceived distance was influenced by the ability to reach and that the effects were not due to cognitive correction. The regression equation for finger was y = .63x + 29.11, and the regression equation for the baton was y = .73x + 15.62. There was a main effect for distance ($F(9, 58) = 14.555$, $p < .0001$, $d = 0.693$), and the interaction between tool and distance was not significant ($F(9, 58) = 0.264$, $p > .98$).

Individual participants showed different patterns of results across the two tool conditions. Regression lines for individual subjects are shown in Figure 5. Although some subjects did not show an effect of tool, this may be due to ceiling effects (see Table 1). The maximum distance that the comparison circles could be positioned was restricted by the size of the projected area, which was smaller than the width of the table. For the farther distances, many participants tried to set the comparison circles farther apart, but they were limited to this maximum distance. The participants who did show an effect of tool had less than 3 estimates that were at the limit. The participants who did not show the effect of tool had 7-15 estimates that were at the limit (see Table 1). Therefore, it is possible that these participants did not show an effect of tool because the limited space did not allow them to express differences in perceived distance. However, more work is needed to explain possible individual differences in the relationship between reachability and perceived distance.

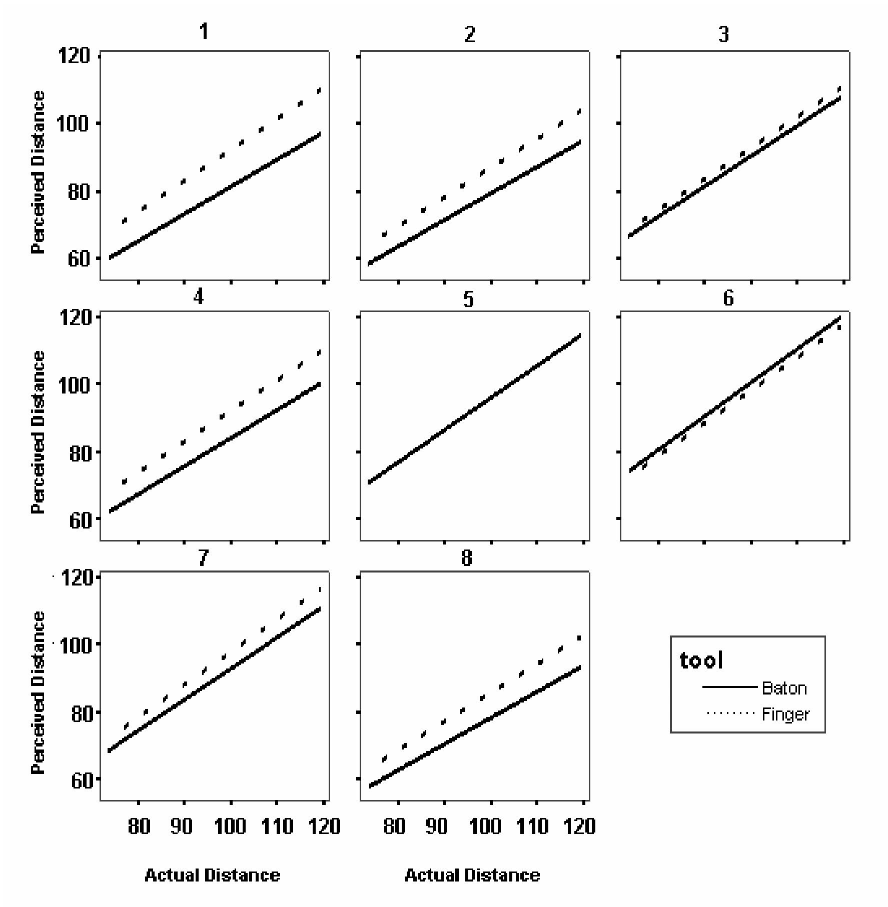

Figure 5: Perceptually matched distance as a function of the actual distance in the finger and baton conditions for individual subjects in Experiment 2. Lines represent regression lines for each tool.

Table 1

The tool effects and ceiling counts for individual participants in Experiment 2

Participant	*F*(1, 10)	*d*	# maximum estimates[a]
1	33.45*	.77	0
2	15.12*	.60	2
3	3.08	.24	7
4	168.39*	.96	2
5	0.02	.00	12
6	2.48	.20	15
7	3.43	.27	12
8	36.50*	.79	1

[a]Total number of estimates = 20

*p < .01.

The boundaries of the target distances were not calibrated for each participant, so some participants were able to reach to some of the targets without the baton and others were unable to reach to some of the targets with the baton. However, when I excluded these data points, the analyses did not differ qualitatively from the analyses reported above. It is unclear whether there is a well-defined boundary of near space that produces a discontinuity in perceived distance. Perceivers' judgments of what is within reach tend to fall somewhere in between what is actually within reach if their bodies are constrained from leaning forward at the waist and what is within reach if they are allowed to bend at the waist and raise up on their toes (Rochat & Wraga, 1997). Therefore, perceived reachability does not fall at either boundary of actual reachability. Additionally, research on neglect patients that showed differences between near and far space did not demonstrate an abrupt change in rightward bias (Cowey, Small, & Ellis, 1999). Even definitions of near space do not describe near space as being a definite boundary. For example, Cutting and Vishton (1995) described near space or personal space as "generally within arm's reach and slightly beyond" (p. 100). Thus, it seems unlikely that there would be a sudden discontinuity in perceived distance.

Experiment 3: Perception without Action

Near space is defined as an action space: it is reachable space. This definition implies that the perceiver must intend to reach to this space; therefore, simply holding a tool without using it to extend reach should not expand near space. In relevant studies with monkeys, visual receptive fields did not elongate when monkeys did not intend to reach (Iriki et al., 1996), and deficits in visual attention were not influenced by distracters near the end of a tool that was just being held but never manipulated (Maravita et al., 2002). In order to expand near space, the tool must be used to reach. In this study I examined the influence of holding a tool without reaching on the perception of distance. If near space is an action space and only expands when the perceiver intends to reach, then simply holding a baton and not reaching should not expand near space. Therefore perceived distance should not be affected by holding the baton.

Method

Participants. Eight University of Virginia students (4 male, 4 female) participated for pay or for research credit. All gave informed consent.

Apparatus and stimuli. The materials and stimuli were the same as was used in Experiment 2.

Procedure and design. The procedure and target distances were the same as in Experiment 2 except that participants never reached to the targets. On half the trials the participants held a baton and on half the trials they did not. Participants simply watched the target circle appear without reaching to it. When the comparison circles appeared, they matched the distance between the comparison circles to the distance to the target. Then all the circles disappeared and they waited for the next circle to appear. Participants were not told to do anything with the baton nor were they given a reason for holding the baton.

Results and Discussion

I ran a repeated measures ANOVA with tool and target distance as independent measures and the distance between the two comparison circles as the dependent measure. Some participants did not understand the matching task at first, and these trials were excluded. There was a main effect for distance ($F(9, 150) = 35.588$, $p < .0001$, $d = .68$). However, there was no effect for tool ($F(1, 150) = 1.814$, $p = .18$). Near space did not expand when participants held the baton but did not reach with it. Consequently, perception of this space was unaffected by holding a tool (see Figure 6)[2].

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[2] The graph suggests that there may be a difference between the two conditions for the smaller distances. However, an analysis on only the smaller distances (70-100cm) and an analysis using a logarithmic scale both show that there was no difference between the two conditions ($p > .15$; $p > .18$; respectively).

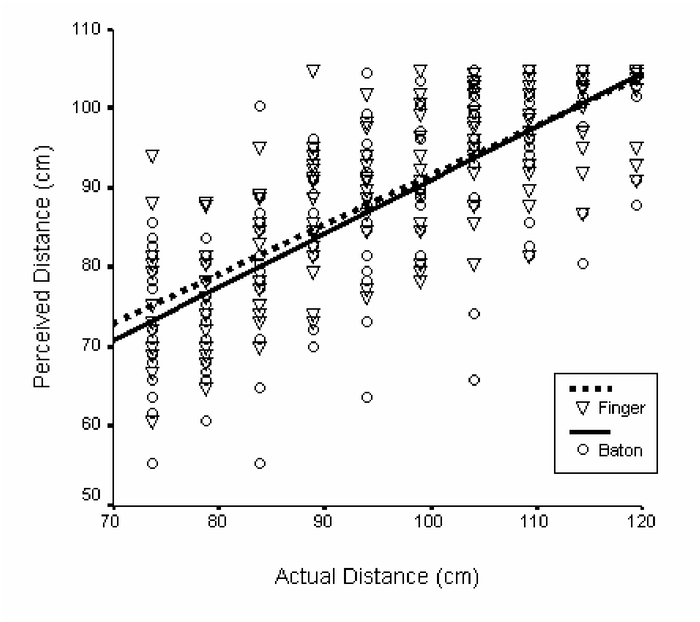

Figure 6: Perceptually matched distance as a function of the actual distance in the finger and baton conditions of Experiment 3. Lines represent regression lines for each tool.

It is not surprising that holding a tool without reaching does not influence perception since many other experiments have demonstrated that effects of tool use are conditional on intention. Reachability neurons did not fire when the monkey did not intend to reach (Iriki et al., 1996) and visual attention was not affected by holding a tool when the tool was not used to reach (Maravita et al., 2002). Our previous work also demonstrated an effect of intention: only effort associated with an intended action affected perception (Witt et al., 2004). Effort for throwing only influenced perceived distance when the perceivers intended to throw and not when they intended to walk. Likewise, effort for walking only influenced apparent distance when the perceivers intended to walk and not when they intended to throw.

A potential concern with the current set of findings is that the results may be due to cognitive correction. In other words, it may be the case that participants perceived the targets to be at the same distance in tool conditions, but for reasons related to cognition as opposed to perception, reported them to be at different distances when holding the baton. The issue of cognitive correction versus perception has been brought up with respect to perceived reachability. Heft (1993) argued that the overestimation commonly found for perceived reachability (e.g. Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989; Rochat & Wraga, 1997) was due to an analytic attitude that influenced judgments. When participants were not given time to adjust their estimates, they were less likely to overestimate how far they could reach (Heft, 1993). However, the results from Experiment 3 suggest that the effect of tool on perceived distance is perceptual rather than analytical. If the effects in Experiments 1 and 2 were due to their holding a baton, then they should have also adjusted their estimates when they held the baton in Experiment 3. Since the effect was only present in Experiments 1 and 2, it is probably the case that holding a baton did not induce cognitive correction.

Interterm Discussion

Perceptual metrics derive from optical and oculomotor variables and from factors associated with the perceiver's body and abilities to act. The current experiments demonstrated that the perceiver's ability to reach to a target location is an instance of an action-based perceptual metric.

In the first two experiments, participants reached to targets with and without a baton and estimated the distance to the target. I assessed perceived distance in two ways.

In the first experiment, participants verbally reported the distance to the target, and in the second experiment, participants performed a perceptual matching task. In both experiments, participants perceived the targets to be closer when they reached with a baton than when they reached with their hands. Targets within reach are perceived to be closer than targets beyond reach.

In the third experiment, I investigated whether intention mediates the influence of reachability on perceived distance. I measured perceived distance using the same perceptual matching task as in the second experiment; however, in this experiment, participants never reached. They simply did or did not hold a baton. Therefore, unlike the first two experiments, participants never intended to reach. In this latter experiment, perceived distance was found to be the same when holding the baton as when it was not held. This suggests that reachability is a metric for perceived distance only when the perceiver intends to reach. Although it seems unlikely that the effects in the first two experiments were due to differences associated with holding the baton and not to differences in reachability, this experiment demonstrated that simply holding the baton does not influence perceived distance. Perceived distance is affected only when changes in the perceiver's ability to reach are coupled with an intention to reach.

Actions, Affordances, and Perception

Gibson was one of the first perceptual researchers to emphasize a closely coupled relationship between perception and action. Gibson (1972/2002) proposed that perceivers detect the changes in the environment that are a consequence of their movements. This relationship between perception and action develops in a reciprocal fashion, such that perceivers come to anticipate the perceptual outcomes whenever an action is planned and executed.

We have extended this notion of perception/action coupling further by suggesting that perceived spatial layout is directly influenced by intended actions. Not only do perceivers detect or anticipate changes in the environment based on current or anticipated actions, but also they actually see the layout of the environment in terms of their ability to act. More specifically, when perceivers anticipate the consequence of reaching to objects, they see the distance to the objects in a way that is scaled to their ability to reach.

In his later work, Gibson (1979) put forth a theory that proposed an even tighter link between action and perception: the theory of affordances. Affordances are the possibilities for action that the environment provides to a perceiver given the perceiver's action repertoire (Gibson, 1979). Thus, affordances capture the mutual fit between the environment and the perceiver. For example, only organisms having the potential to throw will perceive objects in terms of throwability, moreover only an object that has the potential to be thrown will be perceived as having this affordance. Therefore, the affordance of throwing is only available to certain perceivers under certain environmental conditions. Furthermore, on a given occasion perceivers will detect only a subset of the affordances that are available to them. Perceived affordances, in contrast to available affordances, depend on the perceiver's intentions. If a perceiver intends to throw, then a rock will be seen as a potential projectile; however, if the perceiver intends to break open a nut, then the rock will be seen as a nutcracker.

Perceiving affordances is finely tuned to the potential for action. Perceivers are sensitive to the boundaries at which an action is or is not possible. For example, if the height of a chair increases, there is a specific point at which the chair does not afford sitting. Perceivers judged chairs that were within their individual boundary for sitting as being sit-able and over this boundary as being not sit-able (Mark, 1987). Other research has demonstrated that for each perceiver, stairs that are climbable look climbable (Warren, 1984; Mark, 1987), gaps that are crossable look crossable (Mark, Jiang, King, Paasche, 1999), and doorways that are passable look passable (Warren & Whang, 1987). Furthermore, perceivers are sensitive to changes in the boundary of possible actions. Affordances are scaled to the perceiver's body, so manipulating the body affects the affordances that are available. For example, when participants wore blocks under their feet, the range of chairs that afforded sitting increased. As the participants adapted to their increased ability to sit, they judged the taller chairs to be sit-able whereas without the blocks, they judged these chairs to be not sit-able (Mark, 1987).

The current findings extend Gibson's theory of affordances in showing that perceived distance is scaled to the perceiver's intentions and abilities to act. Not only are targets perceived in terms of their reachability, but also this affordance influences their apparent distances. Reachable targets are perceived as having a quality of "nearness" that targets without this affordance lack.

Although the current results are about near space and reachability, we do not believe that the effects of action potential on perception are limited to the affordance of reaching and perceived distance. There are many ways to manipulate the body, and these changes affect the affordances that are available. Many changes to the body are internalized into the perceiver's body schema (e.g. Imamizu et al., 2000; Inoue et al., 2001). We hypothesize that any change to a perceiver's body schema will influence the perception of the surrounding environment so long as the change is relevant for the intended action. For example, if a perceiver is wearing a cast on her hand and as a result is unable to pick up larger objects, we predict that she will perceive the objects to be bigger than if she could pick them up. Perhaps a perceiver who is carrying an umbrella and cannot pass through a doorway with the umbrella will perceive the doorway to be smaller. These effects may even extend as far as the inclusion of one's car as an extension of the body. Parking spots could look bigger when in a Porsche Boxster compared to a Lincoln Navigator. Future research is needed to delineate the generality of these effects.

Summary

At any moment in time, there are surfaces and objects surrounding us that can either be touched with our hands or are too far away. The extent of our reach defines the boundary of our immediate action space. The range of this space can be extended by having a hand tool. Perception is influenced by this affordance for immediate action. Objects that are within reach are perceived to be closer than those that are not. When a hand tool is used, objects that were previously out of reach become reachable, and consequently, they appear closer than when the tool was not held. Importantly, this is true only when one intends to use the tool; holding a tool without anticipating its use does not influence perception. Perceived distance is a function, not only of distal extent, but also of our ability and intention to act within the prescribed space.

Chapter 3

3. Motor Simulation as the Proposed Source of Information

Thus far, there have been several demonstrations that a person's ability and intention to act influence perception. However, the underlying processes that are responsible for driving this effect have not yet been explored. In particular, one process that is likely to be involved in these effects is a process that represents the person's ability to perform the intended action. This process should have access to both the anticipated outcome of the action as well as the energetic costs associated with the action since both of these aspects of the person influence perception. Furthermore, the process is likely to be future-oriented in that the outcome relates to future actions because people perceive the world in terms of the actions they intend to perform, not the actions they just performed (Witt et al., 2004). In addition, the process should be sensitive to the person's physical limitations so that the outcome, which influences perception, is constrained by the person's abilities.

Given these requirements, a possible process for representing a person's abilities and providing information that influences perception is a type of internal motor simulation. For the purposes of this paper, a motor simulation is the imagining of an action, either covertly or explicitly, without necessarily executing the action. As a theoretical construct, motor simulation has the desired properties of a process that would be involved in these effects. According to Jeannerod, a motor simulation is "a representation of the future, which includes the goal of the action, the means to reach it, and its consequences on the organism and the external world" (Jeannerod, 2001, p.

S103). Thus, motor simulations are future-oriented and have access to the outcome of anticipated actions. Furthermore, there is behavioral and neurological evidence that suggests that motor simulation is constrained by the limitations of the body.

3.1 Implicit Simulation

Some of the most compelling behavioral evidence for motor simulation comes from research on mental rotation of hands. The task is to judge whether a picture of a rotated hand is of a left or a right hand. In typical mental rotation tasks, the time to make a judgment corresponds with the angle of rotation (Shepard & Metzler, 1971). Interestingly, when the task involves a body part, judgment time corresponds with the time to move one's own body part to the depicted orientation (Parsons, 1987a, b). For example, participants took longer to judge that a right hand rotated 120 degrees clockwise was a right hand than that a left hand rotated 120 degrees clockwise was a left hand because they only had to simulate rotating their left hands 120 degrees while biomechanical constraints forced them to rotate their right hands 240 degrees, which took longer (Parsons, 1987a). In addition, reaction times increased when the starting hand position was at an impossible orientation, thereby delaying the ability to simulate a hand rotation and forcing participants to rely on additional processes (Petit, Pegna, Mayer, & Hauert, 2003).

More direct support for the use of motor simulation during mental rotation of hands comes from interference paradigms. Judgment times were affected when participants had to physically rotate their own hands while performing the mental rotation task. Reaction times increased when the physical movement was in the opposite direction as the simulated movement, and they decreased when the physical movement corresponded with the direction of mental rotation (Wohlschlaeger & Wohlschlaeger, 1998). Interference occurred because the same processes are used to simulate and execute actions. Engaging the process by simultaneously rotating one's own hand interfered with participants' ability to mentally rotate their hands.

Motor simulations have also been implicated in tasks that require making judgments about the ease of an action. Participants took longer to judge that a difficult grasping task was difficult than that an easy grasping task was easy (Frak, Paulingnan, & Jeannerod, 2001). The authors suggested that participants had to simulate grasping the object in order to make a judgment, and that judgments of difficult tasks took longer because simulating a difficult task took longer than simulating an easy task.

3.2 Explicit Imagery

Evidence also suggests that people recruit motor simulation processes when explicitly imagining an action as indicated by the parallel characteristics found between imagining and executing actions. For example, the amount of time it takes to explicitly imagine performing an action is consistent with the amount of time it would take to execute the action. Participants took just as long to physically walk to a target as they did to imagine walking to the target (Decety, Jeannerod, & Prablanc, 1989; Papaxanthis, Pozzo, Skoura, & Schieppati, 2002). Similarly, the time it takes to imagine reaching for a target is the same as the time it takes to actually reach for the target (Papaxanthis, Schieppati, Gentili, & Pozzo, 2002). The time to reach and imagine reaching continued to be the same even after weight was added to the participants' hands. However, when weight was added to participants' backs, there was a discrepancy between actual and imagined walking times (Decety et al., 1989). Participants took longer to imagine walking to the target than to actually walk to it. A possible explanation for this result is that participants may have perceived the target to be farther away. Proffitt et al. (2003) showed that perceived distance increases when wearing a heavy backpack. Thus, the imagined time to walk a seemingly farther distance should also increase even though the actual distance did not increase, so physical walking time was unaffected. Corresponding durations between imagined and executed actions have been found for other tasks such as writing sentences (Decety & Michel, 1989; Papaxanthis et al., 2002), drawing figures (Decety & Michel, 1989), and pointing to targets (Maruff & Velakoulis, 2000).

Another similarity between imagined and executed actions is that they both conform to Fitts' (1954) Law. Just as participants were faster to point to large targets, they were also faster to imagine pointing to large targets compared with smaller targets (Maruff & Velakoulis, 2000; Sirigu et al., 1996). Participants were faster at both tracing figures of large amplitudes and imagining tracing large figures compared with figures of small amplitudes (Decety, 1993; Decety & Michel, 1989). Also, both executed and imagined walking times increased when the path width was narrow (Decety & Jeannerod, 1995).

Furthermore, imagined and executed actions activate peripheral systems to similar degrees. Heart rate and pulmonary ventilation increased during imagined actions such as walking on a treadmill (Decety, Jeannerod, Germain, & Pastene, 1991; Decety, Jeannerod, Durozard, & Baverel, 1993; Wuyam et al., 1995). Furthermore, this increase was proportional to the amount of effort required to perform the action (Decety et al., 1991; Decety et al., 1993). Heart rate increased more when participants imagined walking with a heavier load or at an increased speed.

3.3 Predicting Outcomes

Motor simulations are also implicated in tasks that require predicting the outcomes of observed actions. Many researchers propose that people run a motor simulation when they observe someone else performing an action (e.g. Decety & Grezes, 1999), and Knoblich and colleagues further demonstrated that simulation produces an output that allows people to predict the outcome of an action. In one experiment, participants watched videos of themselves and others throwing darts to the top, middle, or bottom portion of a target. The video only showed the throw itself, and participants had to guess where each dart would land. People were good at predicting where their own darts would land; accuracy was around 80% when participants viewed videos of their entire bodies while making their throws. Moreover, people were better at predicting where their own darts would land than where other participants' darts would land. Knoblich & Flach (2001) argued that people are better at predicting the outcome of their own actions because the observed action more closely matches the simulated action when viewing themselves than when viewing someone else. Thus, the outcome is more likely to be correct.

A similar paradigm was used with handwriting movements (Knoblich, Seigerschmidt, Flach, & Prinz, 2002). Participants' movements were recorded while they wrote the number "2". This movement required two strokes. One stroke started at the top left and curved down to the bottom left. The second stroke started at the bottom left and moved horizontally to the right. Movements were recorded when the two strokes were performed sequentially and in isolation of each other. One week later, participants viewed displays with a moving dot that replicated the movement of the pen when they either drew the “2” all at once or just the first stroke of the “2” in isolation. Participants saw the dot move along the path of the first stroke and then had to predict whether a second stroke would follow or if the first stroke had been performed in isolation. Judgments were better when participants saw their own handwriting compared with other participants’ handwriting. Knoblich et al. (2002) argued that participants simulated the observed movement, and because the observed movement more closely matched the simulated movement when viewing their own handwriting, they were better able to simulate the next movements as well. Mental stimulation can be used to predict the outcomes of the movements and consequent movements as well.

3.4 Neuropsychological Evidence

Research from cognitive neuroscience provides support for a neurological realization of motor simulation. Converging lines of evidence suggest that several motor related areas such as premotor cortex, supplementary motor cortex, cerebellum, and parietal cortex are involved in simulation processes. The tasks that have been used to tap into simulation include both explicit and implicit imagery. Using an explicit imagery paradigm, researchers recorded brain activations during execution and imagination of an action such as moving a joystick in a sequence of movements (Stephan et al., 1995), handwriting (Decety, Philippon, & Ingvar, 1988), hand clenching to the pace of a metronome (Ingvar & Philipsson, 1977), tapping one’s fingers to a designated sequence

(Gerardin et al., 2000; Hanakawa et al., 2003; Roland, Skinhoj, Lassen, & Larsen, 1980), or grasping objects (Decety et al., 1994). In implicit imagery paradigms, participants had to make decisions about how they would act on an object. For example, in one experiment, participants saw pictures of dowels and had to determine whether they would use an underhand or overhand grip to grasp the dowel (Johnson et al., 2002). Other implicit imagery paradigms involve judging whether a depicted hand was a left or right hand (Parsons & Fox, 1998; Parsons et al., 1995) or judging the outcome of a pointing movement (Chaminade, Meary, Orliaguet, & Decety, 2001). These experiments also demonstrate involvement of the areas listed above. Further support comes from patient studies that demonstrate damage to the parietal cortex (Sirigu et al., 1996) and basal ganglia (Dominey, Decety, Broussolle, Chazot, & Jeannerod, 1995) interferes with the ability to imagine actions although damage to motor cortex (Sirigu et al., 1995a) leaves imagined actions unimpaired. Thus, there is some, though not complete, overlap in the areas involved in motor execution and simulation (see Grezes & Decety, 2001, for review).

3.5 Summary

Taken together, these studies make several points. One is fairly compelling evidence that motor simulation processes do exist and are neurologically realized. The second is that motor simulations are used in a variety of different situations, all of which involve action whether it is executing actions, imagining actions, or making judgments about actions. Thus, it is possible that motor simulation is also used when perceiving the world with the intention to act. Third, the process has desirable characteristics such as its future-oriented nature, access to anticipated action outcomes, and sensitivities to biomechanical limitations. Therefore, there are reasons to believe that motor simulations may be involved in the effects of a perceiver's abilities on perception.

Chapter 4

4. Simulation Experiments

Two methods were used to test whether motor simulations are involved when perceiving the world with an intention to act. The first involved dissociating between the perceiver's current and anticipated abilities to act. If a feedforward process such as motor simulation is responsible for the effects, then participants should perceive the targets in terms of their anticipated ability. To dissociate between current and anticipated abilities, participants viewed targets without holding the tool. However, when participants reached for the targets, they first picked up the tool and reached with it, so their ability when first viewing the target was that they could not reach the target, but they could anticipate that the target would be within reach. I tested whether participants would see the targets in terms of their current ability when viewing the target, in which case the target would look farther away because it was beyond reach, or in terms of their anticipated ability to reach, in which case the target would look closer because it would be reachable.

The second method entailed interfering with the simulation. This method is motivated largely by the brain-imaging literature suggesting that the neural mechanisms involved in motor simulation are also involved in other tasks such as physically executing an action. If simulation is involved in the effects of the perceiver's ability on perception, then performing concurrent tasks that engage the simulation mechanisms should interfere with the effect.

Experiment 4: Dissociating Physical and Simulated Abilities

People's abilities change constantly. When a person grasps a tool, they instantly become capable of reaching to farther targets. What would happen if people viewed a target without holding the tool but knew that they were going to be able to use the tool to reach to the target? Would they perceive the target in terms of their current ability to act, which is that the target is beyond reach and therefore looks farther away? Or would they perceive the target in terms of their anticipated ability to act, which is that the target will be within reach once they pick up the tool? According to the hypothesis, perception is about what you are going to do next and should take into account your future abilities. Therefore, people should perceive the target as being closer if they know that they are going to pick up the tool even if the target is beyond reach when they estimate distance.

Another way to dissociate between simulated and physical abilities is to have participants imagine holding the tool when they reach. As discussed in the Chapter 3, the processes involved in simulating an action are also used when explicitly imagining an action. Thus, reaching with an imaginary tool should produce the same outcome from a simulation, namely that the target is within reach, as actually reaching with a tool. By dissociating between the outcome of a simulation and the perceiver's physical capabilities at the time that they judge target distance, I can determine which ability (simulated or physical) influences perception.

Method

Participants. Thirty-two students (20 female, 12 male) participated in exchange for credit in a psychology course. All were naïve to the purpose of the experiment.

Materials and Stimuli. Stimuli were presented on a large rectangular table (183 cm wide, 122 cm deep) from a downward facing projector (see Figure 1). Directly in front of the participant, a small white paper circle (3 cm in diameter) was on the table. Participants used this circle as a reference point for estimating distances. There were no other marks on the table and the surface was homogenous and provided no landmarks for help with estimating distance. Stimuli consisted of 3 white, projected circles, each 1cm in diameter. Target distances ranged from 74 cm to 120 cm. Some participants used a conductor's baton that was 39 cm in length.

Design. On each trial, participants estimated the distance to a target by performing a perceptual-matching task (described below) and then reached to the location where the target had been presented. I manipulated the participants' ability to reach to the target. Participants were assigned to one of four conditions. In the No-Tool condition, participants reached with their hand, which prevented them from being able to reach most of the targets. In the Hold-Tool condition, participants held the baton throughout the entire experiment and were able to reach to all targets. In the Anticipate-Holding-Baton condition, the baton was lying on the table while participants made their distance judgments. Then participants picked up the baton and reached to the target. In the Imagine-Holding-Tool condition, the baton was lying on the table and participants reached to the target while imagining holding the baton in their hands.

Procedure. On each trial, participants completed the perceptual-matching task and then reached to the target. The perceptual-matching task involved manipulating two comparison circles in the fronto-parallel plane so that the distance between these circles was the same as the distance between the perceiver and the target (see Figure 3). A small paper circle was placed directly in front of the participant, and participants judged the distance from that circle to the target. The comparison circles always started 5 cm on either side of the target. To move the comparison circles, participants pressed the left and right arrow keys on a keyboard with their left hands. The keyboard was positioned on a stand to their left. After the participants matched the distances, the target and comparison circles disappeared, and the participant reached to the location where the target had been. In the No-Tool condition, participants were instructed to reach as far as they could and then touch the target or, if it were out of reach, point to its location. In the Hold-Tool condition, participants reached to the target with the baton. In the Anticipate-Holding-Tool condition, they picked up the baton after matching the targets, reached with the baton, and then put the baton back on the table before the next trial started. In the Imagine-Holding-Tool condition, participants imagined that they held the baton and touched the location of the target with the imagery end of the baton. Each participant estimated the distance to 10 targets ranging from 74 cm to 120 cm. They estimated the distance to each target twice.

Results and Discussion

As can be seen in Figure 7, participants in the Finger condition perceived the targets to be farther away than participants in the other three conditions. I ran an ANOVA with tool condition and distance as independent factors and matched distance as the dependent factor. Distance was significant, $F(9, 600) = 76.21$, $p < .001$, $d = .53$. Tool was significant, $F(3, 600) = 12.23$, $p < .001$, $d = .06$. Post-hoc tests revealed that the Finger condition was significantly different from the three baton conditions (all *p*s <

.001), and that the various baton conditions were not significantly different from each other (all *p*s > .48). The interaction between tool and distance was not significant, $F(27, 600) = 0.33$, $p > .99$.

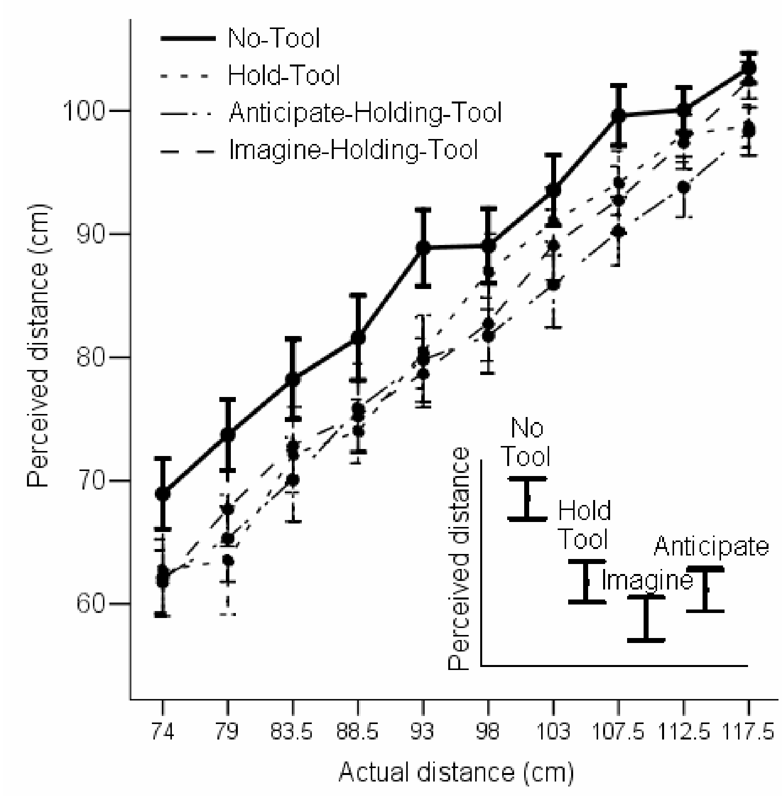

Figure 7. Perceptually matched distance as a function of the actual distance to the target for the four conditions in Experiment 4. Error bars represent one standard error. The insert shows the main effect of condition collapsed across all target distances.

I replicated my results from Experiment 2, which demonstrated that perceived distance is compressed when targets are within reach while wielding a tool compared with when targets are beyond reach without the tool. In addition, the results show that people perceive the world in terms of their anticipated abilities to perform an action rather than their current abilities. Even though the targets were beyond reach for the Anticipate-Holding-Tool group when they made their distance estimates, this group still perceived the targets to be closer because they knew they would have the tool when they reached to the target and therefore simulated reaching to the target with the tool. This result suggests that the outcome of the simulation, rather than the perceiver's ability at the time of estimating distance, influences perception.

It makes sense that the process of simulation allows people to simulate anticipated abilities since that may be how people know what size tool they would need to acquire in order to reach a target. When people cannot perform an action, they must be able to figure out what change in the body or environment would be necessary to complete the task. Being able to simulate using a tool that one is not currently holding allows the perceiver to test out different situations mentally rather than pick up and try to use different tools to figure out which one would get the job done.

I also found that simply imagining holding a tool influences perceived distance. Targets looked closer when people held an imaginary tool while reaching to them compared with people who just reached with their finger. So although both groups had the same physical ability to reach (or not reach) the target, the group that imagined holding a tool perceived the targets to be closer. This finding is consistent with my simulation hypothesis because the outcome of the simulation of reaching with an imagined tool is that the target is within reach, whereas the outcome of simulating reaching with no tool is that the target is beyond reach. Thus, a simulation process would relay two different outputs to perception for the two groups and thus could account for the differences between the No-Tool and Imagine-Holding-Tool conditions.

Experiment 5: Imagining Impossible Actions

Admittedly, it is a little strange that one can see the world in terms of imagined abilities, and the result begs the question of whether there any limitations to this effect. Thus, I ran a second experiment where I instructed some participants to imagine an impossible action. Specifically, I asked them to imagine that their arms could extend all the way to the targets (similar to Inspector Gadget from the popular children's cartoon). According to my account of simulation, they will not be able to simulate imaging an impossible action because the processes involved in simulation are restricted by the person's physical abilities. Instead, they must rely on other processes such as visual imagery to imagine that their arms can extend to the target. Therefore, the outcome of the simulation will be that the target is beyond reach and thus will look farther away. Alternatively, if simply telling them to *think* about the target as being within reach is enough to get these effects such that imaging an impossible action makes the targets look closer, then we should reconsider these effects as being a product of cognitive correction or something other than perceptual effects.

Method

Participants. Twelve students (7 female, 5 male) participated in exchange for credit in a psychology course. All were naïve to the purpose of the experiment.

Materials and Stimuli. The materials and stimuli were the same as in Experiment 4.

Design. As in Experiment 4, participants estimated the distance to the target by performing the perceptual matching task and then reached to the target. I used the same two control conditions with one group of participants reaching to targets with their finger (No-Tool condition) and one group holding and reaching to targets with the baton (Hold-Tool condition). The critical condition in this experiment was the Imagine Arm Stretch condition. When these participants reached to the target, I instructed them to imagine that their arms could stretch out and extend all the way to the target. I gave them the example of Inspector Gadget. Although the participants thought the experiment was strange, they all understood the task.

Procedure. The procedure was the same as in Experiment 4 except that participants completed 3 trials at every target distance.

Results and Discussion

As can be seen in Figure 8, participants in the Imagine-Arm-Stretch condition perceived the targets to be just as far away as people in the No-Tool condition. An ANOVA with condition and distance as independent factors and perceived distance as the dependent factor revealed a significant effect for condition, $F(2, 330) = 19.69$, $p < .001$, $d = .11$. Post-hoc analyses showed that the Imagine Arm Stretch group perceived the targets to be farther away than the Hold-Tool group, $p < .001$. There was no significant difference between the No-Tool condition and the Imagine Arm Stretch condition, $p > .53$. As expected, the Hold-Tool group perceived the targets to be closer than the No-Tool group, $p < .001$. The effect of distance was also significant, $F(9, 330) = 90.52$, $p <$

.001, *d* = .71. There was not a significant interaction between distance and condition, $F(18, 330) = 0.20$, $p > .99$.

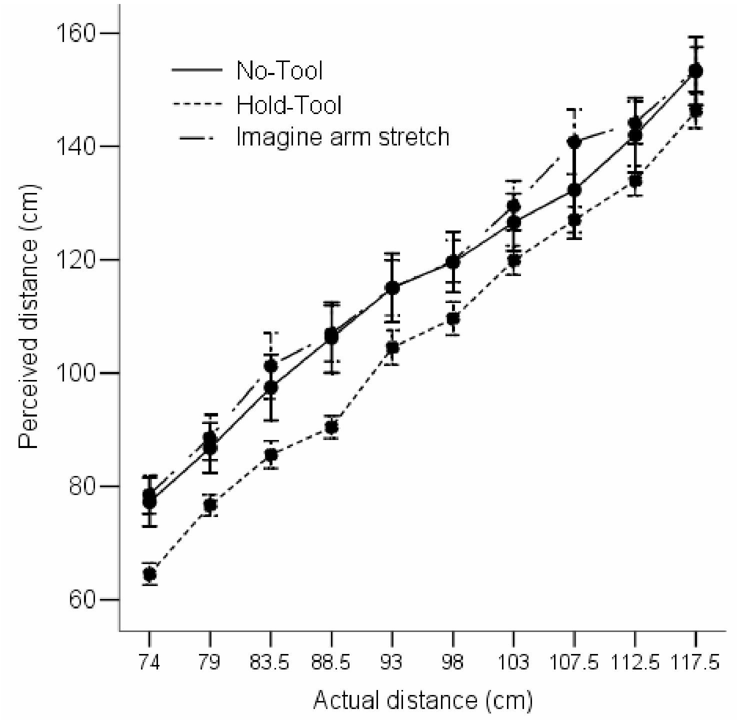

Figure 8. Perceptually matched distance as a function of the actual distance to the target for the three conditions in Experiment 5. Error bars represent one standard error.

This result suggests that the effects are limited to actions that are possible and therefore could be simulated using the same processes as those used to plan and execute actual movements. Furthermore, this result is evidence that the effects of reachability on perceived distance are not due to cognitive correction since participants were told to think about the target as if it were within reach. If previous results had been due to cognitive correction, then we would have seen a similar pattern here where participants who were told to imagine that their arm could extend to impossible lengths would also have reported the targets as being closer than participants in the No-Tool condition.

In other words, if participants in the previous experiments had *perceived* the targets to be the same distance away regardless of whether they were within reach or not but had *reported* them to be at different distances, perhaps because they anticipated my hypothesis, then the participants in this experiment would also have made the same corrections to their distance estimates. If participants think that they should report that targets within reach are closer, then we would have seen similar effects of reachability in this experiment. In contrast, even though participants were told to think of the targets as being within reach, the targets still looked farther away.

Experiment 6a: Interfering with Simulation

Although the results from the last two experiments are consistent with an account of simulation, they by no means prove that simulation is responsible for the effects of reachability on perceived distance. In order to obtain more direct evidence, I decided to interfere with processes of simulation directly to see if interference would eliminate the effect.

Given the overlap in neural activations between executing and simulating actions, performing concurrent actions should interfere with people's ability to simulate. Indeed, behavioral evidence supports this conclusion. As discussed above, physically rotating one's own hand influences handedness judgments of depicted hands, which rely on a motor simulation of hand rotation (Wohlschlaeger & Wohlschlaeger, 1998; Wexler, Kosslyn, & Berthoz, 1998). Similarly, walking interferes with perception of point-light walkers (Jacobs & Shiffrar, 2005). Participants' judgments of the speed of the point-light walkers were impaired when participants had to walk on a treadmill while making their judgments compared with when they just stood still. Interestingly, interference is specific to the simulated task. Walking interfered with perceiving point-light walkers, but riding on a stationary bike did not show interference (Jacobs & Shiffrar, 2005). Similarly, physical hand rotations in a different plane (Wohlschlaeger & Wohlschlaeger, 1998) or even at different speeds (Wexler et al., 1998) did not interfere with mental hand rotation.

If the processes involved in simulation engage the same neural systems as those responsible for planning and executing actions, then performing a concurrent action should interfere with simulation, so there should be no outcome of the simulation to inform perception of whether or not the target is within reach. Therefore, even if the target is within reach as a result of holding a tool, the target should only look closer for participants who are able to simulate reaching and not for participants who cannot simulate a reach.

Method

Participants. Sixteen students (10 female, 6 male) participated in exchange for credit in a psychology course. All were naïve to the purpose of the experiment.

Materials and Stimuli. The materials and stimuli were the same as in Experiment 4. In addition, a squishy yellow ball 6 cm in diameter was also used.

Design. Participants estimated the distance to the target by performing the perceptual matching task and then reached to the target with the baton. The baton was lying on the table while they made their distance judgments, and then they picked up the baton prior to reaching and put the baton back on the table after completing their reach (analogous to the Anticipate-Holding-Tool condition in Experiment 4). There were two groups in this experiment. The Squeeze group squeezed the yellow ball with their right hands while making their distance judgments. They put the ball down and picked up the baton to reach, and put the baton down and picked the ball back up and started squeezing before making their next estimate. The No Squeeze group did not do anything extra with their right hand. Both groups used their left hands to manipulate the comparison circles by pressing the left and right arrow keys on a keyboard positioned to their left.

Procedure. On each trial, a target appeared with two comparison circles on either side. Each participant estimated the distance to 10 targets ranging from 74 cm to 120 cm. They estimated the distance to each target twice. While making their distance estimates, the Squeeze group applied tension to the squishy ball with their right hands. Both groups picked up the baton to reach to the targets.

Results and Discussion

As can be seen in Figure 9, participants in the Squeeze condition did not perceive the targets to be as close as participants in the No Squeeze condition. An ANOVA with condition and distance as independent factors and perceived distance as the dependent factor revealed a significant effect for condition, $F(1, 300) = 19.09$, $p < .001$, $d = .06$. The effect of distance was also significant, $F(9, 300) = 70.79$, $p < .001$, $d = .68$. There was not a significant interaction between distance and condition, $F(9, 300) = 1.27$, $p = .25$.

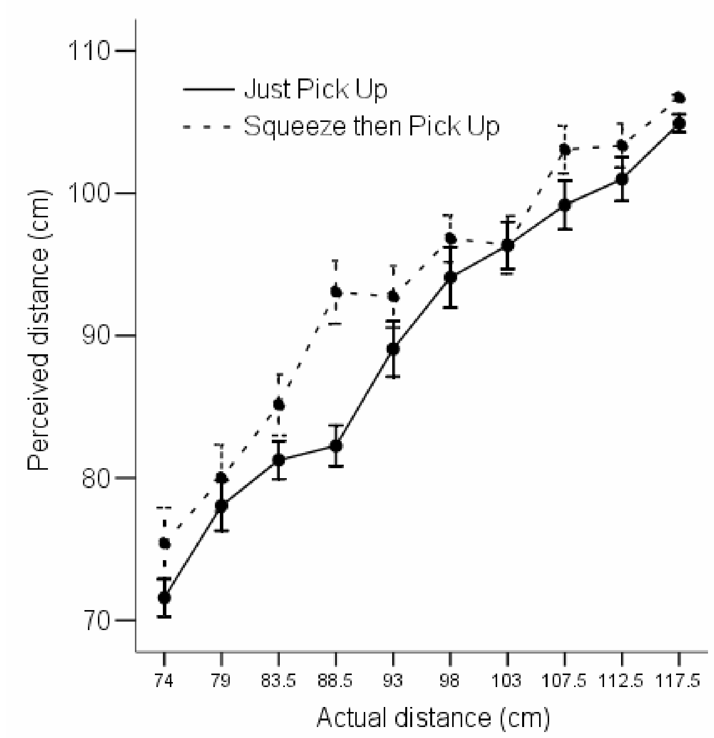

Figure 9. Perceptually matched distance as a function of the actual distance to the target for the Squeeze and No Squeeze conditions in Experiment 6a. All participants reached to the target with the tool. Error bars represent one standard error.

We know from Experiment 4 that people who perceive targets with the intention to pick up a tool and reach to them perceive the targets to be closer compared with people who reach with their finger. However, when participants squeezed a ball when making their distance judgments, the effect was eliminated. I propose that squeezing the ball interfered with people's ability to simulate reaching to the target with the baton. Without having the outcome of a simulation indicating that the target is within reach, the target should not look closer. This is what I found.

These results also suggest that the interference is effector-specific because both groups of participants used their left hands to press buttons on the keyboard to move the comparison circles. Thus, their left hands were engaged in another task, but only concurrent actions with their right hands interfered with the simulation and the effect of reachability on perception.

It is unlikely that the results are due to demands on working memory or attention because participants did not pump-squeeze the ball. They simply applied a constant tension to the ball, so attention was not necessary. However, in case there was something strange about squeezing the ball, I ran a follow-up study using the ball squeeze manipulation but participants reached without the tool. We would not expect any differences between the two groups, but if the ball squeezing task was affecting perceived distance independent of its effects of interfering with simulation, then we would find a difference in the no-tool experiment as well.

Experiment 6b: Interference without a Tool

In order to ensure that squeezing a ball did not interfere with something other than simulation, I ran a control experiment where people estimated distances and reached to targets without a tool. One group of participants squeezed a ball while making their distance judgments.

Method

Participants. Sixteen students (9 female, 7 male) participated in exchange for credit in a psychology course. All were naïve to the purpose of the experiment.

Materials and Stimuli. The materials and stimuli were the same as in Experiment 6a except that the baton was not used.

Design and Procedure. The design and procedure were the same as in Experiment 6a except that participants reached with their fingers instead of with the baton.

Results and Discussion

As can be seen in Figure 10, participants in the Squeeze condition perceived the targets to be just as far as participants in the No Squeeze condition. An ANOVA with condition and distance as independent factors and perceived distance as the dependent factor revealed only a significant effect for distance, $F(9, 300) = 35.94$, $p < .001$, $d = .52$. The effect of condition was not significant, $F(1, 300) = 0.35$, $p = .56$. There was not a significant interaction between distance and condition, $F(9, 300) = 0.50$, $p = .87$. Thus, the results from Experiment 6a are likely to be due to the interference caused by squeezing a ball on simulating reaching with the tool rather than to something inherent to squeezing a ball.

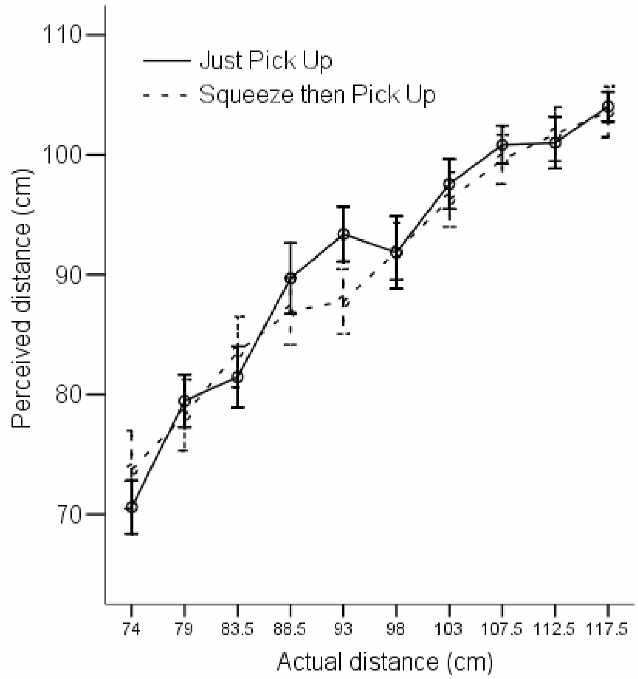

Figure 10. Perceptually matched distance as a function of the actual distance to the target for the Squeeze and No Squeeze conditions in Experiment 6b. Participants reached to the targets without the tool. Error bars represent one standard error.

Experiment 7: Generalizing Simulation to Effort

The previous study provides strong support of a simulation account being responsible for the effect of reachability on perceived distance. It is hard to imagine another account of these effects that could explain why simply applying tension to a squishy ball while making distance judgments prior to reaching with a tool would have an impact on distance perception. In this experiment, I tested whether this account of simulation generalizes to the effect of effort on perception. In early research, we demonstrated that effort for throwing influences perceived distance (Witt et al., 2004).

Participants who threw a heavy ball perceived targets to be farther than participants who threw a light ball. Using the same ball squeeze manipulation, I tested if simulation was responsible for the effects of effort on perception as well.

Method

Participants. Ten females[3] participated in exchange for credit in a psychology course. All were naïve to the purpose of the experiment.

Materials and Stimuli. Participants made distance judgments in a flat, grassy field. Golf tees were used to mark distances ranging from 3 to 11 m from the observer. The tees were placed flush with the ground so that participants could not see them. Four rows of tees were arranged in a radial pattern with the observer being located at the center. The tees facilitated the placement of a small orange disc cone used to mark each target distance. Practice distances were placed at 3, 5, 7, and 9 m. Test targets were placed at 4, 6, 8, and 10 m. The target cone was placed on a different radius each time, so participants could not use previous estimates to aid in follow-up estimates. Participants threw a medicine ball (19 cm in diameter) that weighed 0.91 kg. Participants in the Squeeze conditioned used the same squishy ball as in Experiment 6.

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[3] We only ran females because only females signed up for the study. We should note, however, that sometimes we see greater effects in females than males even though we never have enough power to get a statistical effect. For the purpose of this experiment, having only females actually works to our advantage because we know that throwing a heavy ball influences females' perception of distance and what we are testing is whether we can interfere with that effect by having participants squeeze a squishy ball while making their distance judgments. We have no reason to believe that interference would have different effects on males and females.

Design and Procedure. Participants were assigned to the Squeeze condition or the No Squeeze condition. They completed a practice block and a test block. During the practice block, both groups threw to each target 3 times regardless of whether they hit the target. Then they verbally estimated the distance to the target in feet. Distance order was randomized, and each distance was presented on a different radius.

During test, both groups estimated the distance to the target first. The Squeeze group squeezed the rubber ball while viewing the target and estimating the distance. Both groups were told to face the other direction when the target was being set-up, and the Squeeze group was told to start squeezing the ball before turning around to view the target. Neither group held the heavy ball when making their distance judgments, and both groups were given the ball immediately after they made their judgments. Then both groups threw the heavy ball to the target until they hit it or for a maximum of 3 throws. Distance order was randomized, and each distance was presented on a different radius.

Results and Discussion

As can be seen in Figure 11, participants in the Squeeze condition perceived the targets to be closer than participants in the No Squeeze condition. An ANOVA with condition and distance as independent factors and perceived distance as the dependent factor revealed a significant effect for condition, $F(1, 32) = 23.89$, $p < .001$, $d = .43$. The effect of distance was also significant, $F(3, 32) = 25.26$, $p < .001$, $d = .70$. There was not a significant interaction between distance and condition, $F(3, 32) = 1.37$, $p = .27$.

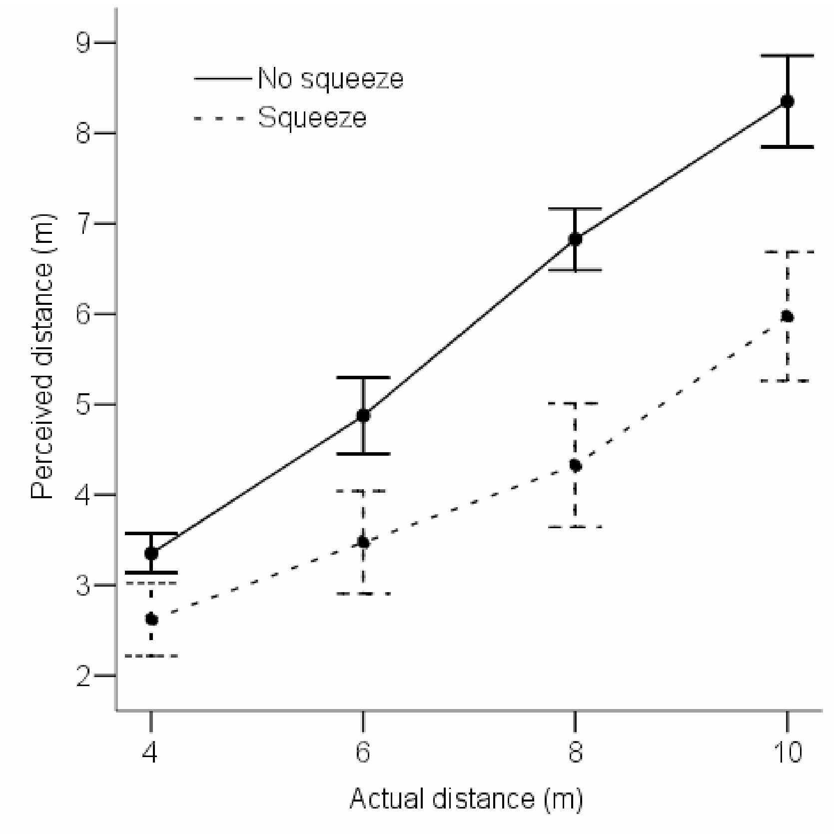

Figure 11. Verbal estimates of distance as a function of the actual distance to the target for the Squeeze and No Squeeze conditions in Experiment 7. All participants threw the heavy ball. Error bars represent one standard error.

Consistent with the findings in Experiment 6a, interfering with the ability to simulate the intended action eliminates the effect. In this experiment, the initial effect was that throwing a heavy ball makes the targets look farther away. However, when participants could not simulate throwing the heavy ball, the targets did not look farther away and hence looked closer compared with the group that could simulate throwing. In Experiment 6a, the initial effect was that targets looked closer when reaching with a tool, so interfering with the ability to simulate reaching eliminated the effect of the targets looking closer, so the targets looked farther away compared with participants who could simulate reaching. In other words, even though the effects in Experiment 6a and 7 go in different directions, the same basic effect is occurring. Performing a concurrent action when estimating distances interferes with the ability to simulate the intended action and thus eliminates the effect of effort or ability on perception.

It should be noted that distances beyond 2m are typically underestimated (e.g. Loomis et al., 1992). So it is not that the No Squeeze group was more accurate but rather that the No Squeeze group perceived the targets to be farther away than the Squeeze group because the No Squeeze group was able to simulate throwing the heavy ball and thus perceived distance expanded.

Although Experiment 6b suggests that squeezing a ball does not influence distance perception itself, I ran a small control study with the ball squeeze manipulation and throwing a lighter ball, which takes much less effort to throw. The ball was slightly larger than the medicine ball (23 cm in diameter) but weighed only .35 kg. I ran 8 participants using the same design as Experiment 7 and found no difference between the squeeze (x = 17.38, SD = 6.32) and no squeeze (x = 16.56, SD = 9.08) conditions, $F(1, 24) = 0.16$, $p = .69$. There was a significant effect for distance, $F(3, 24) = 10.86$, $p < .001$, d = .58. The interaction between condition and distance was not significant, $F(3, 24) = 0.11$, $p = .94$. Thus, the effect observed with the heavy ball is likely to be due to squeezing the small ball inhibiting participants' ability to simulate throwing the heavy ball.

These results suggest that simulation processes are involved in the effects of ability, specifically reachability, and effort, specifically effort for throwing, on distance perception. Thus, the account of simulation generalizes to different effects of the perceiver's abilities and energetic costs on perception as well as to perception in different spaces, namely near space and far space.

Experiment 8a: Interference through Vocalization

In order to provide converging support that simulation relates the perceiver's ability to perception, I sought to inhibit simulation using a different interference manipulation. Vocalizing or listening to action-related words also engages the simulation mechanisms for action. For example, Tettamanti et al. (2005) recently demonstrated that listening to sentences that described actions involving the mouth, hand, or leg activates the same neural areas as those that are active when observing and executing actions with the corresponding body part. Thus, if participants say action-related words, then this should interfere with their ability to simulate reaching, and the targets should look farther away.

Method

Participants. Eight students[4] (3 females, 5 males) participated in exchange for credit in a psychology course. All were naïve to the purpose of the experiment.

Materials and Stimuli. The set-up was the same as in Experiment 5.

Design and Procedure. I used a within-subjects design. Participants completed two groups of trials: one during which they said an action word and one during which

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[4] Given the size of the effects in these studies, only a small number of participants are necessary in order to determine whether there will be an effect. Since this is the first time that these types of interference tasks have been used in this reaching paradigm, I opted to run fewer participants and try more types of interference tasks for Experiments 8 and 9.

they said a non-action word. On every trial, participants performed the perceptual matching task and then picked up the baton and reached to the target. While performing the matching task, but not while reaching to the target, participants repeated a word over and over again. For Action Word trials, the word was “squeeze”. Prior to the start of the Action Word trials, participants were given the squishy ball and told to squeeze it several times, so the word “squeeze” had specific meaning. The word during the Non-Action trials was “blue”. Participants did not perform any additional actions prior to these trials. Participants completed all of the Action Word trials before starting the Non-Action Word trials or vice versa, and order was counterbalanced across subjects. For each group of trials, participants completed two blocks, and each block had 6 distances ranging from 89 cm to 114 cm.

Results and Discussion

As can be seen in Figure 12, there was no difference in perceived distance between the two word conditions. To confirm, I ran a repeated-measures ANOVA with distance and word as within-subjects factors and perceived distance as the dependent factor. There was no effect for word, $F(1, 6) = .03$, $p = .88$. The effect of distance was significant, $F(5, 30) = 115.23$, $p < .001$, $d = .94$. The effect of order was not significant, $F(1, 6) = .13$, $p = .73$. There were no significant interactions, ps > .15.

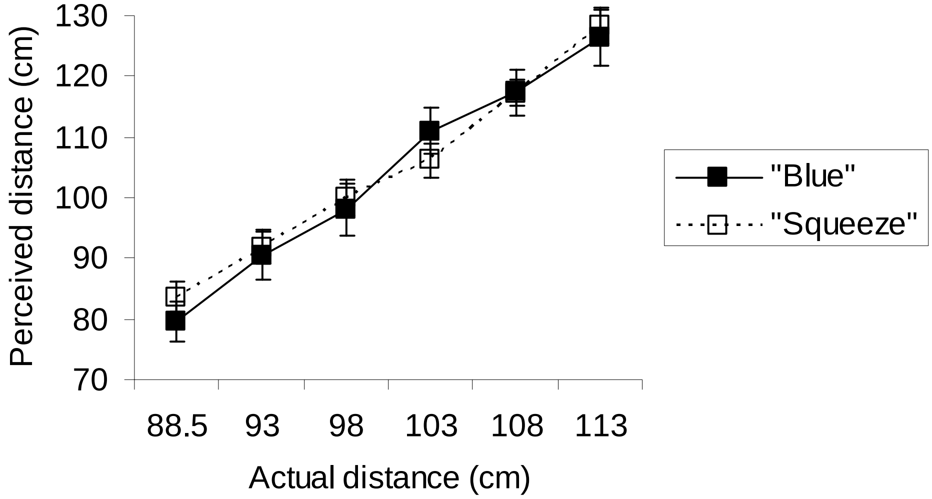

Figure 12. Perceptually matched distance as a function of the actual distance to the target for the two word conditions in Experiment 8a. Error bars represent one standard error.

One problem with this experiment was that participants repeated the word so quickly that they did not really enunciate the word. It is possible that while saying action related words activate a simulation mechanism, inaudible mumbling of an action-related word might not activate the mechanism. Thus, I attempted to correct for this in the next experiment.

Experiment 8b: Interference through Vocalization

I used the same basic procedure as in Experiment 8a except that instead of repeating a single word, participants repeated a phrase, which they were told to speak deliberately and to enunciate.

Method

Participants. Ten students (9 females, 1 male) participated in exchange for credit in a psychology course. All were naïve to the purpose of the experiment.

Materials and Stimuli. The set-up was the same as in Experiment 8b.

Design and Procedure. Everything was the same as Experiment 8a except that instead of saying “squeeze” and “blue”, participants said “throw the ball” and “red blue green”. All participants said both phrases, and order was counterbalanced. Prior to the start of the entire experiment, participants practiced throwing a yellow squishy ball into an empty fishbowl. They were given 10 tries and were told that they would get one more try at the end of the experiment. I did this to ensure that “throw the ball” had meaning with the hope that when they said “throw the ball” they would think about trying to throw the ball into the bucket. Everything else was the same as in Experiment 8a.

Results and Discussion

As can be seen in Figure 13, there was no difference in perceived distance between the two phrase conditions. I ran a repeated-measures ANOVA with phrase and distance as within-subjects factors, order as a between-subjects factor, and perceived distance as the dependent measure. There was no effect of phrase, $F(1, 8) = .71$, $p = .42$. The effect of distance was significant, $F(5, 40) = 162.23$, $p < .001$, $d = .95$. Order was not significant, $F(1, 8) = .07$, $p = .80$, and none of the interactions were significant, ps > .26.

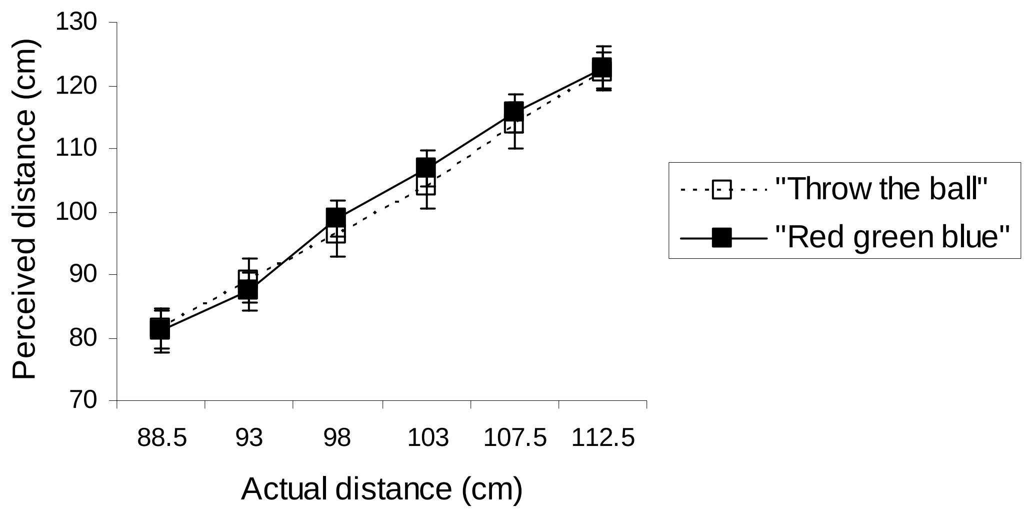

Figure 13. Perceptually matched distance as a function of the actual distance to the target for the two word conditions in Experiment 8b. Error bars represent one standard error.

Although participants did enunciate the words, I still did not get the effect. One possible problem is that there may have been word satiation. In other words, participants could have repeated the phrase without actually thinking about what the phrase was because after saying it for so many times, it becomes automatic. Saying a phrase that has become automatic is unlikely to engage the simulation mechanism.

Experiment 8c: Interference through Vocalization

I tried one more method to invoke interference through vocalization. Instead of giving participants a word or a phrase to repeat, I gave them a category and they had to come up with objects in that category. One category had to do with actions while the other category was not related to actions.

Method

Participants. Eight students (5 females, 3 males) participated in exchange for credit in a psychology course. All were naïve to the purpose of the experiment.

Materials and Stimuli. The set-up was the same as in Experiment 8a.

Design and Procedure. While performing each perceptual matching task, participants were given a category and told to report as many instances within that category that they could. Once they finished matching the two distances, they stopped coming up with category items, picked up the baton, and reached to the target. The categories for the Action Category condition were things that you turn, objects you stir things with, things that fit into your palm, objects that are heavy to pick up, foods you eat with a fork, and objects that you can throw with one hand. The categories for the Non-Action Category condition were beers, colors, colleges, furniture, psychology professors, and streets in Charlottesville. Order of category type was counterbalanced. For each category type, participants completed one block of trials with 6 distances ranging from 89 cm to 114 cm.

Results and Discussion

As can be seen in Figure 14, there were no differences in perceived distance between the two category conditions. This was confirmed with a repeated-measures

ANOVA with category type and distance as within-subjects factors, first category as a between-subjects factor, and perceived distance as the dependent variable. There was no effect of category, $F(1, 6) = .01$, $p = .91$. There was a significant effect of distance, $F(5, 30) = 32.26$, $p < .001$, $d = .82$. None of the interactions were significant, *p*s > .12.

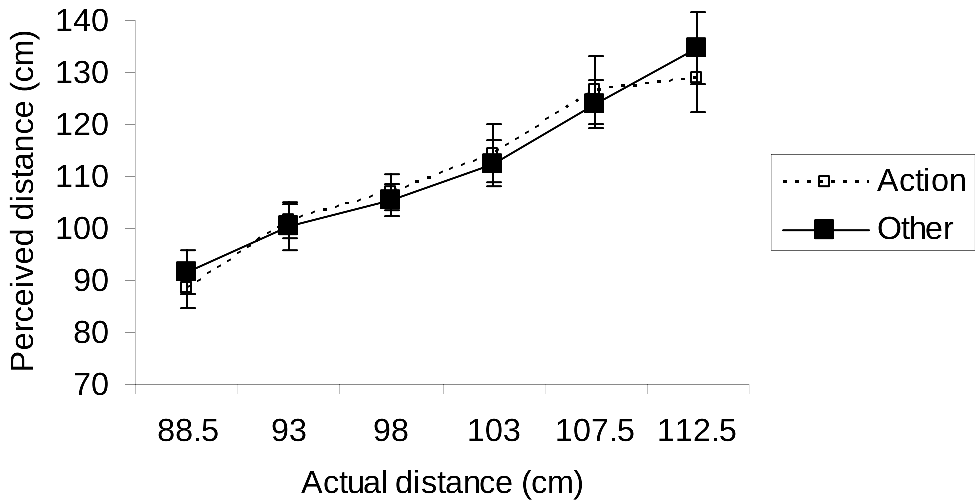

Figure 14. Perceptually matched distance as a function of the actual distance to the target for the two word conditions in Experiment 8c. Error bars represent one standard error.

However, there was a marginally significant effect of first category, $F(1, 6) = 4.72$, $p = .07$, so I re-ran the analyses as a between-subjects design and included data from only the first block of the experiment. As can be seen in Figure 15, when only the first block was included, perceived distance differed between the two groups, $F(1, 36) = 10.67$, $p < .01$, $d = .23$. However, the difference was opposite of what I predicted. Participants in the Action Category condition perceived targets to be closer than participants in the Non-Action Category condition. The effect of distance was significant, *F*(5, 36) = 14.67, *p* < .001, *d* = .67. There was not a significant interaction between distance and condition, *F*(5, 36) = .91, *p* = .48.

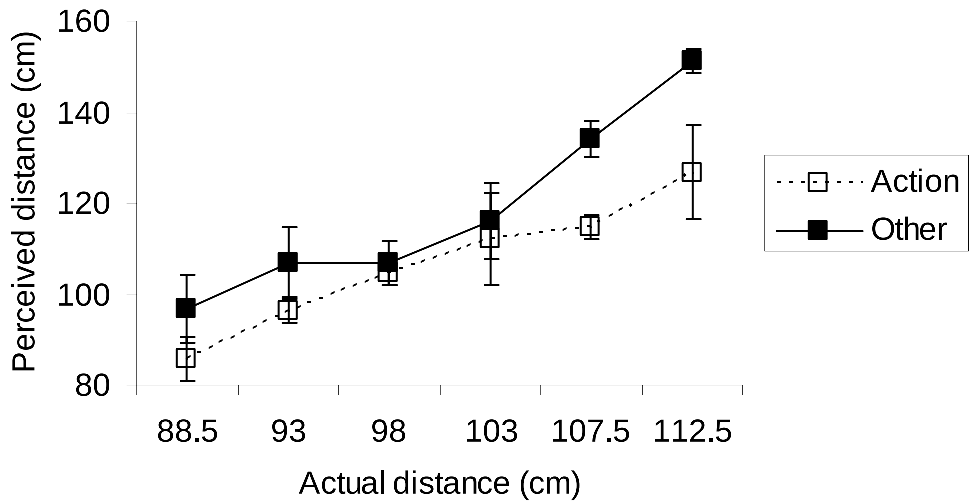

Figure 15. Perceptually matched distance as a function of the actual distance to the target for the two word conditions treated as between-subjects factors in Experiment 8c. Error bars represent one standard error.

The expectation was that participants who were engaged in thinking about actions would to be unable to simulate reaching to the targets and therefore see the targets as being farther away. Instead, participants who were thinking about actions perceived the targets to be closer.

One possibility for explaining the current set of results is that saying any kind of word is such a demanding task that it causes some type of interference, either with simulating reaching or the perceptual-matching task. Since I did not run proper control groups in these experiments, it is possible that even though participants always reached with the tool, the targets may have still looked farther away. For example, in Experiment

8a, the targets may have looked just as far as if the participants had not been reaching with the tool. The same may be true for Experiment 8b. However, when the word *does* relate to an action, then perhaps this facilitates the simulation of reaching and allows the targets to be seen in terms of reachability.

Of the few experiments on simulation that have used an interference paradigm, sometimes the researchers found interference and sometimes they found facilitation. For example, in the mental rotation task, participants were faster to judge the orientation of an object when they rotated their hands in the same direction as the direction they mentally rotated the object and were slower when they rotated their hands in the opposite direction of the mental rotation (Wohlschlager & Wohlschlager, 1998). Moreover, response times decreased, indicating that there was facilitation, when participants rotated their hands at the same speed as that which they were mentally rotating, but response times increased, indicating interference, when the two speeds were different (Wexler et al., 1998). In other words, the facilitation is very specific both to direction and speed.

It is unclear what types of dual-tasks should cause interference and facilitation in my paradigm. I picked the phrase "throw the ball" because it seemed very different than reaching, but in hind-sight, throwing requires an extension of the arm similar to how reaching requires an extension of the arm, which may explain the trend I found in Experiment 8b where the targets looked closer when participants said "throw the ball" than when they said "red green blue." Similarly, when I re-examined the action categories in Experiment 8c, several of them also involve extending one's arm. Thus, there may in fact be facilitation when the word conjures up an action image of arm extension.

Although I do not know of any evidence that the attentional demands of saying words or thinking of items in a category should interfere with simulation or the perceived distance task, I did find a correlation between number of items recalled on each trial and perceived distance, $r = .24$, $p < .05$ (see Figure 16). On a given trial, when more items were recalled, the distance was judged to be farther away. Although very indirect, this is at least supportive of the idea that just saying a word causes interference with my task.

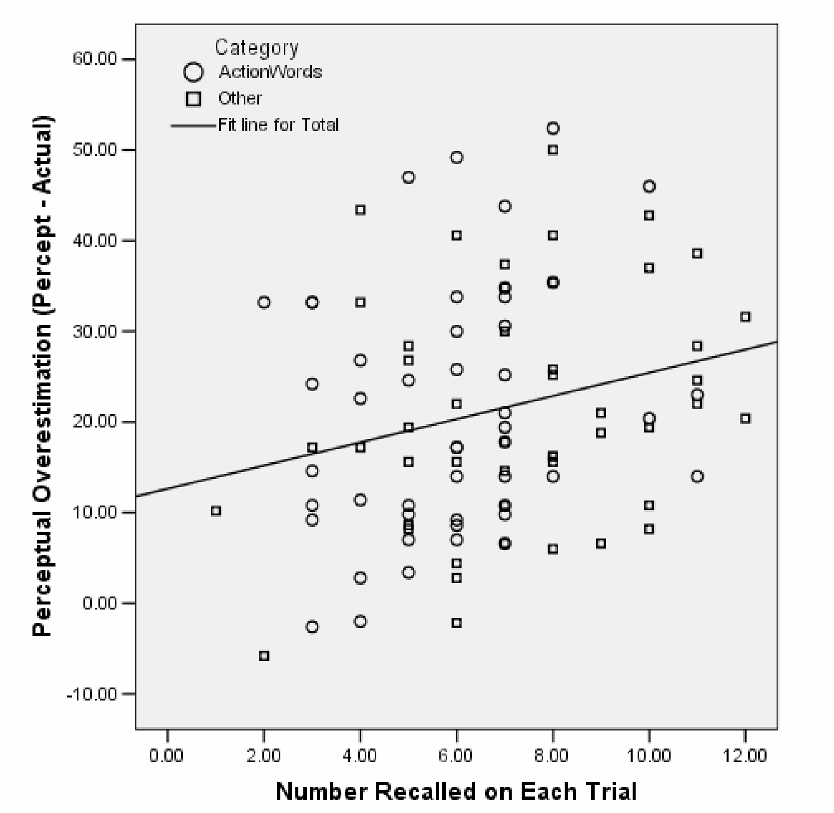

Figure 16. Perceptual overestimation (as calculated by subtracting the actual distance from the perceived distance) as a function of number of items recalled on a given trial. The solid line is the regression line across categories.

In summary, there is no evidence that saying an action-related word creates interference with participants' ability to simulate reaching with a tool. There may be some support that there is facilitation instead, although more experiments would be needed in order to make this claim. Given that there are many neural areas that are activated during simulation and only some of these areas are also activated when saying action-related words (see Decety & Grezes, 2001), it is important to know whether vocalization does or does not facilitate with these effects in order to differentiate which of the simulation processes are involved in the effects of reachability on perception. Future experiments should include using action-related words that conjure up an image of an action where the arm does not extend out but rather pulls in or does not move.

Experiment 9a: Interference through Imitation

Some simulation processes are also involved when observing someone else perform an action, especially when the observer intends to imitate the other person (Iacoboni et al., 1999). Similar neural overlap has been found between executing, simulating, and observing other's actions (see Decety & Grezes, 1999). Behavior evidence suggests that performance on a motor task is impaired when watching someone else perform an incompatible task (Kilner, Paulignan, & Blakemore, 2003). Participants made either horizontal or vertical arm movements. These movements were more variable when watching someone else move their arm in the opposite plane than when they watched someone else move in the same plane or when they watched a non-biological object move in either plane. Thus, watching someone else activates the same underlying processes that are involved in execution and presumably in simulation, and observing someone else perform an action may interfere with simulating reaching with a tool.

Method

Participants. Eight students (3 females, 5 males) participated in exchange for credit in a psychology course. All were naïve to the purpose of the experiment.

Materials and Stimuli. The set-up was the same as in Experiment 8. An experimenter sat on the opposite side of the board as the participant. During the experiment, the experimenter performed a series of hand gestures. These gestures were mutations of American Sign Language (ASL) such that they did not have any obvious meaning. None of the participants were familiar with ASL. Each gesture had two separate components to it that required different hand postures and different types of movements. There were 8 total gestures.

Design and Procedure. Participants were assigned to the Imitate condition or the Just-Reach condition in alternating order. On each trial, the Imitate group watched the experimenter perform a gesture prior to making a distance judgment with the perceptual matching task. Immediately after making each distance estimate, the participants repeated the gesture back to the experimenter, who recorded how well they performed each gesture. Then the participants picked up the baton and reached for the target. Thus, participants watched the experimenter perform the movement with the intention to imitate it. This should interfere with their ability to simulate reaching to the target with the baton while making their distance judgments. Participants completed two blocks of trials with 8 distances in each ranging from 83 cm to 118 cm.

Results and Discussion

As can be seen in Figure 17, participants in the Imitate group perceived the targets to be farther away than participants in the Just-Reach group, $F(1, 112) = 10.42$, $p < .01$, $d = .09$. Participants who observed another person make a gesture simulated the gesture, so they could not simulate reaching to the target with the tool and thus saw the targets as being farther away. The effect of distance was significant, $F(7, 112) = 25.83$, $p < .001$, $d = .62$, and the interaction between group and distance was not significant, $F(7, 112) = .23$, $p = .78$.

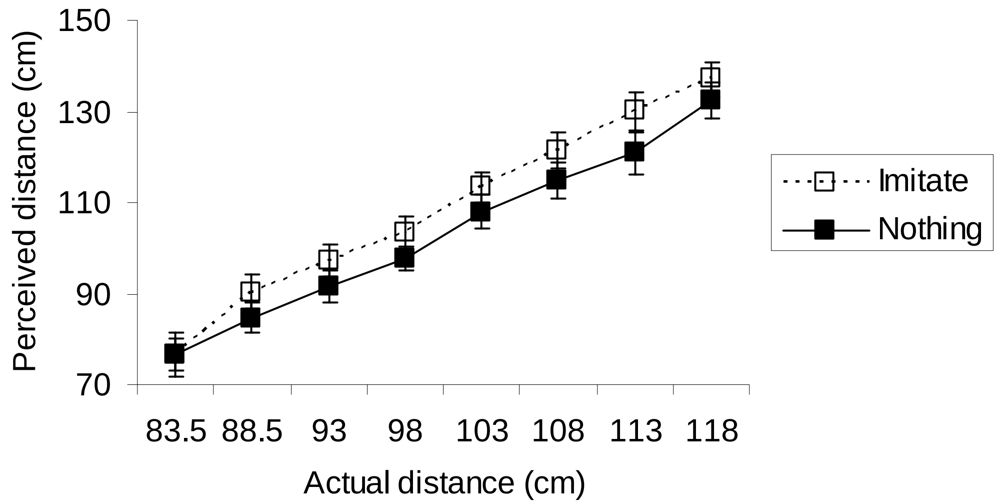

Figure 17. Perceptually matched distance as a function of the actual distance to the target for the two word conditions in Experiment 9a. Error bars represent one standard error.

This result is consistent with the hypothesis that simulation is involved in the effects of reachability on perceived distance. However, the control group did not have to perform any additional actions, so we cannot be sure that the difference between the two groups was due to simulation alone. Perhaps watching someone else perform an action and having to make any kind of judgment of their action would interfere with the task somehow.

Experiment 9b: Interference through Imitation

Experiment 9b is identical to 9a except that I used a different control condition. Instead of simply picking up the baton and reaching, participants in the control condition also watched the experimenter perform a gesture, and then they made a judgment about whether a specified hand posture was involved in each gesture.

Method

Participants. Eight students (4 females, 4 males) participated in exchange for credit in a psychology course. All were naïve to the purpose of the experiment.

Materials and Stimuli. The set-up and stimuli were the same as in Experiment 9a.

Design and Procedure. Participants were assigned to the Imitate condition or the Judge condition in alternating order. Both groups watched the experimenter perform a gesture and then did the perceptual-matching task. Then the Imitate group repeated the gesture back to the experiment. The Judge group judged whether the gesture involved a hand posture with only the first two fingers extended. Then both groups picked up the baton and reached. Participants completed two blocks of trials with 8 distances in each ranging from 83 cm to 118 cm.

Results and Discussion

Similar to Experiment 9a, participants in the Imitate group perceived the targets to be farther away than participants in the control group (see Figure 18). This was confirmed statistically with an ANOVA with group and distance as independent factors and perceived distance as the dependent factor. There was a significant effect for group, $F(1, 112) = 20.18$, $p < .001$, $d = .15$. The effect of distance was also significant, $F(7, 112) = 40.31$, $p < .001$, $d = .72$, and the interaction between group and distance was not significant, $F(7, 112) = .77$, $p = .62$.

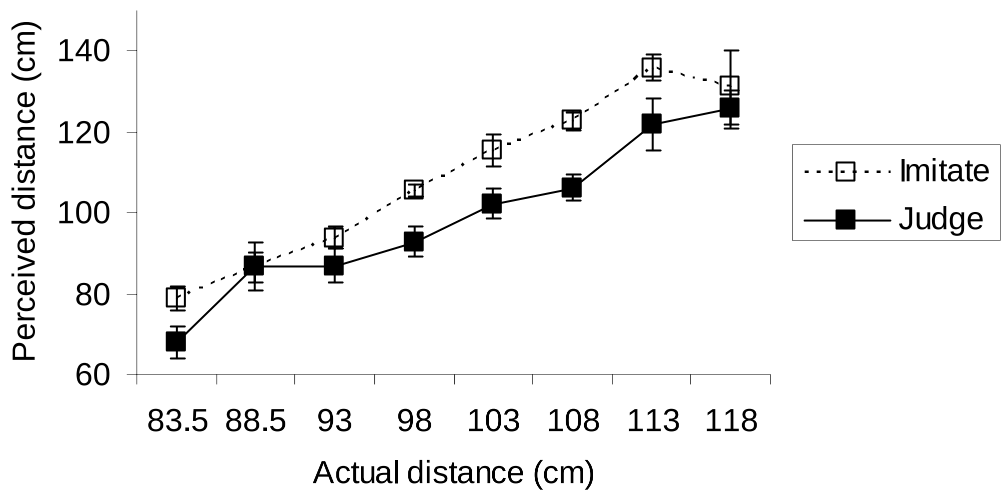

Figure 18. Perceptually matched distance as a function of the actual distance to the target for the two word conditions in Experiment 9b. Error bars represent one standard error.

This result supports my hypothesis that simulation is involved in the effects of ability on perception. Observing another person with the intention to imitate their movements engages the simulation mechanisms responsible for simulating reaching with a tool, thus eliminating the effect of reaching with a tool on perceived distance.

However, even though I used a better control condition in this experiment, there are still several differences between the Imitate condition and the Judge condition in addition to their differential effects on simulation. For example, the Imitate condition had to remember a sequence of movements in space, thus making it a spatial task whereas the Judge group, once they made their judgment, only had to remember their answer, which is not a spatial task. Since the perception task is also a spatial task, it is possible that we interfered not just with the Imitate group's ability to simulate but also their ability to perform the perceptual-matching task. In order to control for this possibility, I reran this experiment without the tool. If the difference between the Imitate and Judge groups is only with respect to the simulation of reaching with a tool, we should not see a difference when participants do not reach with the tool.

Experiment 9c: Imitation without the Tool

Experiment 9c is identical to 9b except that participants reached with their fingers instead of with the baton.

Method

Participants. Twelve students (7 females, 5 males) participated in exchange for credit in a psychology course. All were naïve to the purpose of the experiment.

Materials and Stimuli. The set-up and stimuli were the same as in Experiment 9b except that the baton was not used.

Design and Procedure. The design and procedure were the same as in Experiment 9b except that participants reached with their fingers instead of with the baton. Since the targets were beyond reach with the finger, they were told to point to the targets that they could not reach.

Results and Discussion

As is apparent in Figure 19, I got the same effect as in the previous two experiments. However, I was expecting no difference between the two groups because the targets were beyond reach for both groups and thus inhibiting simulation should not have influenced perception. An ANOVA revealed a significant effect for group, $F(1, 176) = .34.65$, $p < .001$, $d = .16$, and distance, $F(7, 176) = 90.02$, $p < .001$, $d = .78$. The interaction between group and distance was not significant, $F(7, 176) = .17$, $p = .99$.

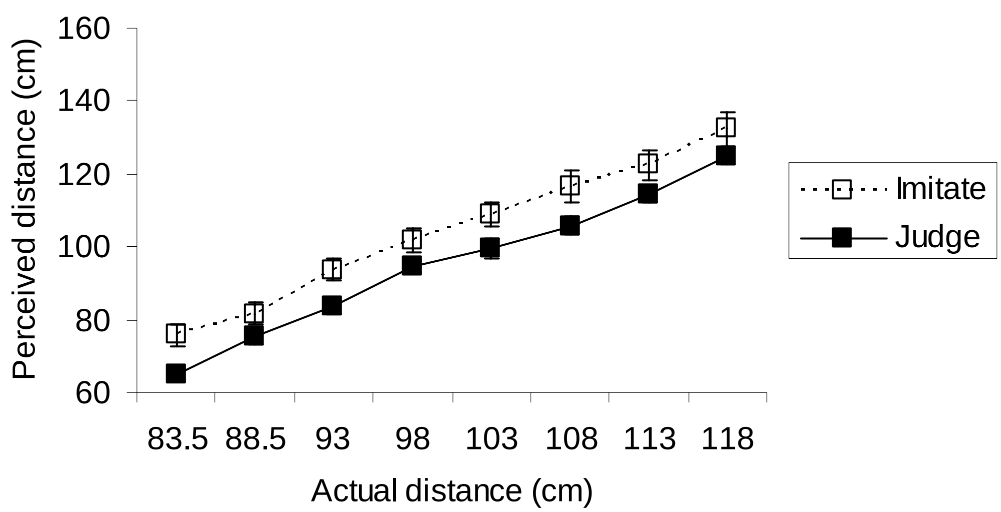

Figure 19. Perceptually matched distance as a function of the actual distance to the target for the two word conditions in Experiment 9c. Error bars represent one standard error.

This finding is inconsistent with the previous results. The ball squeeze manipulation interfered with participants' ability to simulate reaching with a tool, so the manipulation had no effect when participants reached without the tool. In contrast, watching someone with the intention to imitate their movements also causes a type of interference, but that interference is not specific to reaching with a tool because the manipulation resulted in the same pattern of results when participants reached with and without the tool.

One possibility is that while squeezing a ball interferes with *simulation* of reaching, having the intention to perform a gesture interferes with the *intention* to reach. Although the participants reached to the targets, the action they made immediately after judging the distance was to imitate the experimenter's gestures. Thus, perhaps they are not viewing the target with the intention to reach but rather with no intention at all. However, this cannot explain the difference in Experiment 6c since perceived distance with the intention to reach with one's finger should be the same as perceived distance without the intention to reach[5]. Another possibility is that the Imitate group's task involves spatial working memory whereas the Judge group's task does not. Perhaps having a dual task that involves spatial working memory interferes with participants' ability to perform the perceptual-matching task rather than influencing perception itself.

Interterm Discussion

There are now several demonstrations that a person's ability to act influences perception. Distances appear farther with increased effort to walk (Proffitt et al., 2003; Stefanucci et al., 2005) or to throw (Witt et al., 2004). Hills appear steeper with

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[5] I am not claiming that the outcome of a reaching simulation that says the target is beyond reach is the same as not having an outcome of the simulation. Rather, for a specific target at a predetermined distance, perceived distance to that target will vary as a function of the perceiver's ability to act on the target as well as their intention. At some point along this curve, there will be the value of perceived distance when there is only optical information specifying the distance. For a reaching curve, this point happens to be the same point as when the outcome of simulation is that the target is beyond reach, so in the case of reaching, perceived distance of a target beyond reach is the same as perceived distance of a target that has no outcome of a reaching simulation. Whether this is just a coincidence or a type of recalibration remains unknown.

increased walking effort (Proffitt et al., 1995; Bhalla & Proffitt, 1999). Perceived size is influenced by the perceiver's ability to hit the target (Wesp et al., 2004; Witt & Proffitt, 2005; Witt et al., 2006). And the current findings show that targets within reach look closer than targets beyond reach. However, the processes that inform perception about a person's physiological abilities have not yet been characterized.

In this dissertation, I proposed that when perceivers view an environment with the intention to perform an action, they run an internal, motor simulation of the action and that the outcome of this simulation influences perception. As described in Chapter 3, the simulation is a type of first-person motor imagery, which can be unconscious. I tested the hypothesis of simulation in two ways. First I dissociated between the perceiver's current and anticipated ability to act. Participants estimated the distance to targets that were beyond reach of their hands but within reach if they held a tool. When they made their distance judgments, they were not holding the tool, so the targets were beyond reach. However, participants knew that they would be able to pick up and reach with a tool, so I hypothesized that they would simulate reaching with the tool. The outcome of simulating a reach with a tool would be that the target was within reach even though the target was physically beyond reach at the time that the estimate was made. I found that targets looked closer to participants who anticipated being able to reach to the targets with the tool compared with participants who did not use the tool.

I also found that targets looked closer when participants reached to them with an imaginary tool. In this situation, participants should still simulate reaching with a tool, so the outcome of the simulation should be that the target was within reach even though the target was never physically within reach. The processes underlying simulation are also recruited when explicitly imagining an action (see Chapter 3). Thus, these processes will be engaged when simulating an anticipated action and when simulating an imagined action. When the outcome of a simulation was that the target was within reach, the target looked closer even though participants only imagined holding a tool.

However, when there was no outcome of the simulation indicating that the target was within reach, then the target did not look closer. In Experiment 5, participants imagined a physically impossible action, namely that their arm could stretch beyond its physical limits. Simulation is limited by the physical constraints of the body, so participants were not able to simulate the impossible action of stretching out one's arm and had to rely on other processes such as visual imagery to perform the task. Even though participants were told to imagine that the targets were within reach, they did not perceive the targets to be closer.

I hypothesized that the participants in Experiment 5 could not simulate reaching to the targets because they could not simulate an impossible action, and since there was no outcome of the simulation indicating that the targets were within reach, the targets did not look closer. Experiment 5 raises several questions about the nature of simulation and what kinds of actions can be simulated. Impossible actions are generally one of three sorts. One is that the task is impossible for an individual person even if that action could be possible for another person. For example, the chair of my dissertation cannot perform the splits. Splits are not an impossible action for everyone, but they are impossible for him. Although unlikely, he might be able to perform the splits with practice. Other actions, however, are impossible for everyone and will always be so such as stretching one's arm out two feet beyond its limit. A third reason that actions may be impossible is that an action that once was possible may no longer be possible. For example, people who have amputated limbs can no longer reach the way they could before their limb was amputated. In summary, there are actions that are not possible but could be possible, actions that will never be possible, and actions that were once possible but are no longer possible. It would be interesting but beyond the scope of this paper to explore all types of imagined actions to determine which ones do and do not influence perception. However, I have set up the boundaries of the effect. Experiment 4 showed that imagining a simple and immediately possible action did influence perception whereas Experiment 5 showed that imagining an action that has always been and will always be impossible did not influence perception.

The second way that I tested the hypothesis that simulation processes are involved in the effects of reachability on perception was to use an interference paradigm. Given the research suggesting neurological and behavioral overlap between simulating and executing actions (see Chapter 3), performing a concurrent action when estimating distance should interfere with the simulation. If there is no outcome from the simulation to inform perception of the perceiver's abilities to act, then any effects of ability on perception should be eliminated, and people should perceive the distance to the targets on the basis of optical information alone.

I demonstrated that interfering with the simulation by having participants execute a concurrent task eliminated the effects of ability on perception in two different contexts. In Experiment 6a, participants reached to targets with a tool, so the targets should have looked closer. However, one group of participants squeezed a squishy ball while making their distance judgments. Thus, they could not simulate that the targets were within reach. This eliminated the effect of reachability on perception, so the targets looked farther away to these participants than to participants in the No Squeeze condition who reached with a tool and could simulate reaching. Since both groups of participants were performing a concurrent action with their left hands, namely pressing the left and right arrow keys in order to move the comparison circles, it is likely that the effects of interference are specific to the effector used to perform the intended action.

Performing a concurrent action also interfered with the effect of effort for throwing on perceived distance. Targets look farther away to people who throw a heavy ball compared with people who throw a light ball (Witt et al., 2004). However, if the throwers can not simulate throwing the heavy ball, then even though it takes more effort to throw the heavy ball to the target, it should not look farther away because there is no outcome from the simulation to inform perception that the action will take more effort. In Experiment 7, targets looked farther away to participants in the No Squeeze condition who threw the heavy ball and could simulate throwing than to participants in the Squeeze condition who threw the heavy ball but could not simulate throwing. When participants could not simulate the action, they perceived the targets based on optical information and were not influenced by their abilities to act, but when they could simulate the intended action, they perceived the targets based on optical information as well as on their ability to perform the intended action.

Squeezing the squishy ball did not require attention nor did it place any demands on working memory. Control experiments demonstrated that squeezing the ball itself did not influence distance perception. However, the simple act of squeezing the ball altered the way the world looked for participants whose abilities and energetic costs were manipulated. An account of perception that is consistent with these findings is that perceivers simulate their intended actions and the outcome of the simulation gets into perception.

However, when using a different dual-task paradigm, I did not find similar effects of interference on simulation. In Experiment 8, participants had to say a word or words that related to actions involving their right arms. The hypothesis was that saying these words would evoke the same processes involved in simulating a reach, thus preventing the participants from simulation. Instead of interfering, the data hint that there may have been facilitation when saying action-related words. More research is needed to determine if there is, in fact, facilitation and if the facilitation is specific to words relating to extending one's arm.

In Experiment 9, I used an imitation dual-task paradigm. Participants watched the experimenter perform a gesture, judged the distance to the target, imitated the experimenter's gesture, and then reached to the target. Although I did find interference with this design, the interference was not specific to reaching with a tool since I found the same interference in Experiment 9c when participants reached with just their hands. Instead, the imitation task may have interfered with the spatial task of matching the distance between the comparison circles and the distance to the target.

Implications for Theories of Simulation

Exploring our environments is a powerful ability that our actions and our perception allows us to do. Simulation affords a different kind of exploration but one that is also very useful. Through simulation, people can examine different possibilities for action. They can try several actions before committing to perform a specific one. If an action is not possible given their current bodies, people can simulate using various tools in order to determine which tool to acquire in order to achieve their goals. People can also determine which route to take or what speed to move based on simulations of different routes or speeds. Simulation is useful for determining and planning the next action and allows for this type of exploration at a very minimal cost and with minimal risks. Little energy is wasted simulating various options whereas much energy would be necessary if one were to try all possible actions before deciding which was best. Prior simulation also helps prevent an observer from performing an action that is harmful because if the outcome of the simulation suggests that the perceiver will experience harm or pain should they actually carry out the action, the perceiver will likely find an alternative course of action.

Accounts of simulation are pervasive in a variety of situations. For example, simulation is argued to be used when planning to pick up objects (Frak et al., 2001) and when predicting the consequences of one's own and another's actions (Knoblich & Flach, 2001; Knoblich et al., 2002). However, most of the previous research, while consistent with accounts of simulation, does not give direct evidence for simulation. The interference paradigm developed here may provide one avenue for a more direct test of simulation. If simulation is responsible for planning easy and difficult grasps, then performing a concurrent action when making these judgments should interfere with the effect. Similarly, if simulation is responsible for predicting the outcomes of actions, then performing a concurrent action should interfere with one's ability to predict the outcomes. Studies are currently underway to test these predictions.

One question that remains to be addressed is the neurological locus of the effects of simulation on perception. Single-cell recording studies and imaging experiments specify several possible locations including the prefrontal, parietal, and supplementary motor cortices and cerebellum (see Chapter 3, see also Grezes & Decety, 2001, for review). Once we determine the neurological mechanism supporting simulation, we can begin to explore other processes that are engaged by this mechanism, which could lead to other methods for interfering with simulation that would strengthen this account.

Summary

In summary, perception is a function of optical information, the perceiver's intention, and the perceiver's ability to perform the intended action. One process that may be involved in these effects is an internal, motor simulation. When intending to perform an action, the perceiver simulates the action, and the outcome of that simulation influences perception. When I dissociated between the perceiver's physical abilities and simulated abilities, I observed that perception was influenced by the simulated abilities (i.e. their anticipated and imagined abilities). Furthermore, when I used a concurrent action dual-task, which inhibited the simulation such that there was no outcome to inform perception, perceivers did not see the world in terms of their abilities to act. These results suggest that simulation may be one process that is involved in relating the perceiver's abilities to perception.

Chapter 5

5. General Discussion

The purpose of this dissertation was twofold. First, I demonstrated that changing the body, via tool use, influences perception. Targets beyond reach of the hand looked closer when reached to with a tool than when reached to without the tool. However, this effect was conditioned by the perceiver's intention to use the tool. When the participants did not intend to reach, the targets looked the same distance away with and without the tool. These results demonstrate that non-visual information influences perception. Second, I demonstrated that one process that is involved in these effects may be a type of motor simulation. The intended action is simulated, and the outcome of the simulation informs perception of the perceiver's abilities to act. For example, when the outcome is that the target is within reach, the target looks closer. If the outcome is that the target will require more energy to throw to it, then it will look farther away. When there is no outcome of the simulation, then perception is based on optical information alone even if the target is within reach or requires more energy to throw to it.

5.1 Implications for Theories of Perception

Especially when combined with similar findings of ability and effort on perception (see Introduction), the current findings have implications for many theories of perception. Few of the major theories of perception have considered sources of information beyond optical and oculomotor information[6]. Thus, many of the theories either need to be abandoned or revised to incorporate these new findings.

5.1.1 Modular Approaches to Perception

Perhaps the most dominant view of perception is that it is an informationally-encapsulated, modular process that only receives inputs from optical and oculomotor information and is not influenced by cognitive and motor factors (e.g. Fodor, 1983; Pylyshyn, 2003). In fact, many sources (e.g. The MIT Encyclopedia of the Cognitive Sciences, Karmiloff-Smith, 1999) use perception as the prototypical example of a modular process. However, results demonstrating that information about the perceiver's ability to act influences perception challenges this view of perception as a modular process. Instead, perception is part of a cyclical relationship combining optical cues with information from motor processes (such as simulation). What we see impacts how we act, the actions we perform influence what we see, and our abilities to act influence what we see. Perception integrates information about the external environment with information about the "internal environment" (see Proffitt, 2006) and with information about the perceiver's ability to act.

Fundamental in many approaches to perception is that the purpose of perception is to create an internal representation of the environment that is as geometrically accurate as

[6] The New Look theory of perception (e.g. Bruner & Goodman, 1947) did incorporate aspects of the perceiver into perception although few if any currently subscribe to the New Look. For a comparison of how the new sets of results relate to the New Look, please see Riener and Proffitt (2006).

possible. Although there exist systematic biases in the perceptual geometry of the environment (e.g. distance: Loomis et al., 1992; slant: Proffitt et al., 1995), these biases tend to be consistent (but see Lappin, Shelton, & Rieser, 2006; Witt, Stefanucci, Riener, & Proffitt, in press). The current results challenge the 'internal model' view of perception on two accounts. First, perception does more than simply represent the environment as it exists. Perception reflects the environment in ways that relate to the perceiver's ability to act. Thus, perception is useful, for example, for planning actions (see Section 5.3). Second, these findings raise the question of what should be considered the gold standard for perception. Why should geometric accuracy be considered veridical rather than a metric that relates the geometry of spatial layout to the perceiver's ability to act? Perception is a biological adaptation. Perception may be most useful when relating the environment to the physiological state and abilities of the organism rather than to an abstract geometric system.

5.1.2 Ecological Approach to Perception

Not all perceptual psychologists prescribe to the "internal representation" account of perception. Notably, J. J. Gibson and ecological psychologists were opposed to this notion, and instead, they argued that the purpose of perception was not to represent the environment but rather to direct action. According to Gibson, this was done by perceiving objects in terms of their affordances, which are the possibilities for action that objects possess (Gibson, 1979). Depending upon its size, shape, and weight, an object may afford grasping, throwing, poking, sitting, and so forth. According to Gibson, affordances exist in the environment, and are picked-up by the perceiver based on the perceiver's body and current intentions to act.

We have expanded on Gibson's work to show that perceiving one affordance, as opposed to another, changes the perceived metric properties of the environment. Since Gibson did not know about these findings prior to his death, we are reluctant to speculate on what he would say about this account. He was, however, adamantly opposed to the idea that perception was augmented by internal knowledge structures and instead argued that perception was direct, meaning that it is influenced only by optical information and not constructed by cognitive processes. These results demonstrate that internal information about the perceiver's ability to act influences perception, so perception is mediated by aspects of the perceiver. Therefore, ecological psychologists may be hesitant to accept our claims as they go against the notion of direct perception, and thus, diverge from Gibson in a seemingly fundamental way.

However, the context in which Gibson made his claim for direct perception is quite different than the context in which we claim internal information influences perception. Gibson's argument for direct perception was in response to theories that claimed that internal information was *necessary* to accurately perceive the environment. Gibson argued that the information available to a moving point of observation was sufficient to adequately specify environmental layout, and therefore, internal inferences were not necessary. We agree that spatial layout is adequately specified by optical variables. However, it is important to make the distinction between sufficient information for perception and information that is actually incorporated into perception. Just because the optical information is sufficient does not mean that internal information about the perceiver cannot also be informative in perception. Moreover, our reasoning for arguing that internal information about the perceiver's ability to act influences perception resonates with Gibson's entire approach to perception, namely that perception is about affordances.

5.1.3 Two Visual Streams

More recently, a different approach to perception has proposed that perception is not unitary but rather there are two perceptions each serving a different purpose (Milner & Goodale, 1995). The "what" pathway, which goes ventrally into the temporal lobe, is responsible for object identification whereas the "how" pathway, which goes dorsally into the parietal lobe, is responsible for visually-guided actions such as reaching or grasping. Among the many distinctions between the two visual streams is that the "what" pathway is responsible for conscious perception while the "how" pathway is unconscious.

Our account applies to conscious perception only. The effects of ability and effort do not influence visual-guided actions that are directed by the "how" perceptual pathway. Perception of slant has been investigated using measures of conscious perception such as verbal reports or visually matching. However, perceived slant has also been measured using a visually-guided action measure (Proffitt et al., 1995, 2001; Witt et al., in press), which might be directed by perceptual representations in the dorsal stream. Bhalla & Proffitt (1999) demonstrated that while manipulations of effort such as fatigue or a heavy load influenced conscious perceptual measures, they did not influence the visually-guided action measure.

One reason that effort and ability may not influence the “how” pathway is that the “how” pathway operates on a different time scale. It is for immediate action and has a memory that last no more than 2 seconds for reaching and grasping (Bridgeman, Peery, & Anand, 1997; Hu & Goodale, 2000; Westwood, McEachern, & Roy, 2001) and only a few minutes for actions on a hill (Creem & Proffitt, 1998). In contrast, the “what” pathway, or conscious perception, operates on a longer-term scale and can be used for planning actions (see section 5.3; see also Proffitt, 2006).

Interestingly, the very action-abilities that are represented in the “how” pathway seem to influence perception. For example, the reachability neurons described in the Introduction are located in the intraparietal sulcus (Iriki et al., 1996), which is part of the dorsal stream. Thus, the current results may be an example of the “how” pathway influencing the “what” pathway.

We know that the “what” pathway influences the “how” pathway. For example, when grasping tools, the user needs to know not only the physical dimensions of the tool in order to form an effective grasp, but the user must also know where to grasp the tool in order to form an appropriate grasp, which would allow the person to be able to use the tool in a functional way. An appropriate grasp requires knowledge about what the tool is and what it does to be integrated with information about how to grasp the tool (Creem & Proffitt, 2001). If the “what” pathway is impaired, either via a lesion (e.g. Sirigu et al., 1995b) or a dual-task interference (Creem & Proffitt, 2001), then the user will be able to effectively grasp the tool without dropping it, so long as the dorsal stream is intact, but will not grasp the tool appropriately so as to be able to use it.

However, there are currently no demonstrations that the “how” pathway influences the “what” pathway. Thus, the current result that reachability influences perception may be an example of this direction of interaction between the two pathways. If so, we need to explain how the different pathways are integrated together into conscious perception. Here, I have proposed that one such process is a type of motor simulation. Through forward and back projections between the parietal lobe and prefrontal cortex, perceivers simulate intended actions and spatial representations are updated according to the outcome of this simulation. Clearly, more research is needed to understand the nature of this interaction.

5.1.4 Embodied Cognition. Embodied Perception?

Increasingly today, there is a sense that a person’s body and ability to act need to be included in accounts of perception and cognition. Supporters of this approach have claimed that the body influences mental processes such as language and metaphors (e.g. Lakoff & Johnson, 1980), categories (e.g. Lakoff, 1990), memory representations (e.g. Glenberg, 1997), the selection of perceptual information (e.g. Ballard, Hayhoe, & Pelz, 1995), and several other cognitive processes (see, e.g. Clark, 1997; Wilson, 1999). Each of these cognitive processes has a long history of being evaluated in isolation of the body and the context within which it operates; however, new research makes it evident that the body plays a significant role in many of the mind’s processes.

The current research demonstrates the informative role of the body in spatial perception. However, these findings also go beyond the embodied cognition approach by expanding on what aspects of the perceiver influence perception. The embodied cognition approach focused mostly on the body. However, other aspects of the perceiver also influence perception. Importantly, the perceiver's intentions influence all of the effects such that only ability for the intended action affects perception (e.g. Witt et al., 2004). Moreover, new research is starting to suggest that emotional states also influence perception. Hills look steeper for participants who are in a sad mood relative to those in a happy mood (Riener, 2006). Riener manipulated mood using sad and happy music as well as having participants write about sad or happy episodes in their lives. After the mood induction, participants viewed hills from the bottom, and in both experiments, the groups that experienced the sad manipulation perceived the hill to be steeper than the groups that experienced the happy mood induction. Fear also seems to modulate perception. Participants who stood on top of a skateboard and viewed hills from the top perceived the hill to be steeper than participants who were not on a skateboard (Stefanucci, Proffitt, & Clore, 2005). Also, heights looked taller when viewed from the top than from the bottom, which may be a result of participants experiencing more fear from the top of a high balcony (Stefanucci, 2006). Thus, the body combined with intentional and emotional states influence perception.

5.2 How Do We Know it is Perception?

Given the long-standing history of conceptualizing visual perception as a process involving only optical and oculomotor information, one can imagine some resistance to the claim that these high-level representations of the self influence perception. A common explanation is that the effects are due to response biases or post-perceptual processes that are involved in generating behavioral responses. In other words, ability, effort, and intention influence processes occurring after perception and not perception itself. However, we have gone to some length to provide strong support that the effects described above are truly perceptual.

The first step is to provide converging measures. If the perceiver's abilities affect the processes involved in generating a specific response, such as a verbal report, then we should see effects only when participants respond verbally but not when they perform other tasks that are driven by conscious perception such as visual matching tasks or visually-directed actions. However, if the effect is perceptual, then all behavioral responses that are directed by perception should be equally affected.

Many of the experiments described above employ converging measures. In the studies on slant perception, participants gave both a verbal report and a visual matching estimate of slant (Bhalla & Proffitt, 1999; Proffitt et al., 1995)[7]. Verbal reports and visual matching tasks were also used in the distance perception studies on effort for throwing (Witt et al., 2004) and reachability (Experiments 1 and 2).

Additionally, in a recent study (Witt, Proffitt, & Epstein, 2006), we used a visually-directed action to measure perceived distance. Unlike visually-guided actions such as reaching and grasping, which are controlled by dorsal stream representations, visually-directed actions such as blindwalking are thought to be controlled by conscious perception (see Philbeck & Loomis, 1997). Participants walked on a treadmill with zero

[7] They also gave a haptic response, which did not show effects of effort. However, the haptic response is likely driven by dorsal stream perceptual representations rather than by conscious perception (Creem & Proffitt, 1998; Proffitt et al., 1995; Witt & Proffitt, in press).

optic flow, thus increasing anticipated effort for walking. Then they viewed a target in a hallway. One group intended to blindwalk to the target while the other group intended to throw a beanbag to the target with their eyes closed. After donning a blindfold, we instructed both groups to walk to the target, so our measure of perceived distance was how far they blindwalked. If the target looked farther away, then they should blindwalk past the target. The group that originally intended to walk blindwalked farther than the group that originally intended to throw. Both groups had experienced the same treadmill adaptation, so if the adaptation had influenced the processes responsible for transforming perceived distance into a blindwalking response, then both groups would have walked equally as far. However, according to our interpretation, the group that intended to walk perceived the target as being farther away because walking on a treadmill had increased their anticipated effort for walking, and they intended to walk. In contrast, the group that intended to throw did not perceive the target to be farther away because even though anticipated effort for walking increased for this group as well, they intended to throw to the target, and effort for throwing had not increased, so the target did not look farther away. Thus, the two groups perceived the target to be at different distances and therefore walked different distances.

A second step that previous studies have employed to ensure that the effects are truly perceptual is to decrease the transparency of the effects. For example, while it may be obvious to the participants that wearing a backpack should influence their perception of distance and they may adjust their estimates correspondingly, it is not obvious how walking on a treadmill should impact one's perception of distance.

Furthermore, we have also used designs where we have not gotten the expected results if cognitive correction had been driving our effects. For example, in the experiment where participants simply held the baton but never reached with it, if participants figured out that targets should look closer as a result of the baton, we would have likely seen the same effects when they did not intend to reach as when they did intend to reach. Similarly, if participants had anticipated that throwing a heavy ball should make targets look farther away, then the targets would have looked farther even for people who intended to walk. Instead, we found that targets do not look as far if participants intend to walk than if they intend to throw a heavy ball (Witt et al., 2004). Thus, it is unlikely that our effects are due to cognitive correction.

At this point, there are several studies all converging on the same conclusion: perception is influenced by the perceiver's ability to perform the intended action. Neither we, our colleagues, nor our critics have presented an alternative explanation that fits the data as well as this conclusion.

5.3 Adaptive Illusions versus an Error in Perception

In one sense, these effects on perception demonstrate an error in perception. Most researchers implicitly assume that the purpose of perception is to recover the geometric layout of the environment, so when a target is the same distance away but looks different depending on the state of the perceiver, this is considered an error or an illusion. However, although perception is not geometrically veridical, it is veridical relative to the perceiver. Perception does not just capture the physical relationships in the environment.

Rather, perception recovers the properties of the environment in a way that relates to the perceiver and the ability to act.

There are reasons to believe that a perceptual system such as the one proposed here is adaptive. One purpose of perception is to guide actions, especially those that are necessary for survival. The information that is necessary to do this is not a complete representation of the environment as is but rather information about aspects of the environment that relate to the perceiver's abilities. Animals with different behavior abilities such as the ability to fly or the ability to breathe under water have different types of perceptual systems that are adapted for both their abilities and their environments (see, e.g., Hughes, 1999). For example, many aquatic animals have a keen perception of sound and less acute visual perception. This is adaptive because sound carries well through water while light is hazy and provides less information. Similarly, bats use sonar radar, which is adaptive because they are active at night when there is much less light to perceive. Animals occupy a niche in their environment, and perceptual systems evolved to pick up information from the environment that relates to their needs. For example, frogs see randomly moving dots as food. Their visual system has evolved to processes typical fly movements as food. Frogs do not process a stationary fly as being food because the fly does not move and therefore goes undetected by the visual system (Lettvin, Maturana, McCulloch, & Pitts, 1959). Similarly, by exaggerating the perception of spatial layout, people see hills that are not climbable as being much steeper relative to slightly more shallow hills that are climbable (Proffitt et al., 1995). Just as the frog's perception (or lack there of) of a stationary fly will not lead the frog, even if it is starving, to eat the fly, a person's perception of an extremely steep hill will likely lead the person to avoid having to traverse it.

Given a perceptual system that is sensitive to the energetic costs of an action, people can make quick and rapid decisions of what behavior to perform because they see what actions are possible, allowing for appropriate actions in time-pressured situations. Also, because perception reveals the energetic costs for each action, this will affect a perceiver's decision of what action to perform and the way to perform it, such as selecting an energy-appropriate walking speed in a way that maximizes energy-efficiency. In this way, perception, whose purpose is guiding behavior, helps the perceiver preserve energy and prevent exhaustion.

5.4 SUMMARY

Perception is one of many processes dedicated to the survival of the organism. Through mutual interactions with motor processes such as simulation, perception relays a description of the environment that is tuned to the perceiver's abilities and the costs associated with intended actions. Thus, the perceiver has information readily available about a beneficial yet costly environment with which the perceiver can choose which actions to make, the path along which to make them, and the pace at which to make them. By incorporating several aspects of the perceiver's abilities and intentions into perception, the perceiver need only to look at the environment and decide what to do rather than try to use cognitive processing to figure out what the best course of action.

We are now beginning to understand the neurological underpinnings of these effects. Previously, research has shown that different aspects of the environment are coded by different perceptual systems. For example, orientation is coded by the dorsal pathway in the parietal cortex whereas object identification is coded by the ventral stream (Valyear, Culham, Sharif, Westwood, & Goodale, 2006). Yet, somewhere this information is integrated together in conscious perception. Although we are not sure of what processes bring the "what" and the "how" pathways together, one possibility may be a type of motor simulation. Perceivers implicitly simulate the intended action, and the outcome of the simulation is informative for perception. Future research will lead to a better understanding of how these processes are integrated as well as what other sources of non-visual information are incorporated into perception.

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