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Big people, little world: The body influences size perception

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Abstract. Previous research has shown that changes to the body can influence the perception of distances in near space (Witt et al, 2005 *Journal of Experimental Psychology: Human Perception and Performance* **31** 880 – 888). In this paper, we question whether changes to the body can also influence the perception of extents in extrapersonal space, namely the perception of aperture widths. In experiment 1, broad-shouldered participants visually estimated the size of apertures to be smaller than narrow-shouldered participants. In experiment 2, we questioned whether changes to the body, which included holding a large object, wearing a large object, or simply holding out the arms would influence perceived width. Surprisingly, we found that only when participants' hands were widened was extrapersonal space rescaled. In experiment 3, we explored the boundaries of the effect observed in experiment 2 by asking participants to hold their arms at four different positions in order to determine the arm width at which apertures appeared smaller. We found that arm positions that were larger than the shoulder width made apertures appear smaller. The results suggest that dimensions of the body play a role in the scaling of environmental parameters in extrapersonal space.

1 Introduction

Driving into a parking space in an SUV (sport utility vehicle) can be a somewhat complicated and daunting task when compared to parking a small sports car. Anecdotally, we have experienced situations in which driving a vehicle larger than we are accustomed to makes parking spaces appear much smaller. This paper provides experimental evidence that suggests that this anecdotal experience is a perceptual reality. Instead of manipulating the width of the observers by placing them in a large or small vehicle, we had them hold objects of different sizes or simply hold out their arms to be wider than normal. We then asked them to estimate a series of aperture widths. We believe that, when the body is widened (by holding a large object or by holding out the arms), observers adaptively rescale the perceived size of the environment to be smaller.

1.1 *The body and the perception of near space*

Previous research has shown that the ability to act on or perform actions within an environment contributes to the perception of the body. This perception of the body can be altered by changing the action abilities of the observer, like giving her/him a rake to retrieve food or a baton to reach a target (Iriki et al 1996; Kinsbourne 1995; Reed and Farah 1995; Witt et al 2005). These alterations, among others, can result in a change in the perceived space surrounding the observer, known as peripersonal or near space (Cutting and Vishton 1995; Rizzolatti et al 1997). These claims are supported by both behavioral and neuroscience studies.

Recent research shows that pre-existing differences in perceived body size can influence the perception of size and length. Linkenauger et al (in press) found that right-handed observers perceived their right hands to be larger than their left, and therefore estimated that they could grasp larger objects with their right hand. Also, right-handers perceived their right arms to be longer than their left, which translated

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to increases in the extent to which they believed they could reach to objects with their right arm as opposed to their left. The authors argued that asymmetries in the sizes of the sensory cortices for the right and left hand (right-handers have a larger representation in their sensory cortices for their right hand than their left) could underlie the perceptual differences observed in their studies.

Other work has shown that overt changes to the size of the body can also influence the perception of space. For example, when arm length is extended by asking an observer to hold a baton, near space is rescaled in order to take this extension into account when planning or performing actions. Specifically, Witt et al (2005) showed that, when participants held a baton (which extended their reach), the distance to an object was perceived as shorter than when they did not hold a baton. Also, this decrease in distance estimation occurred only when the observer *intended* to use the baton to reach towards the object. Their research suggests that the perception of near space is influenced by changes in the actions a body can perform, but only when the observer intends to use an object that changes the dimensions of the body.

Similarly, neurological and electrophysiological research supports the claim that a change in the body's ability to act can result in a change in the spatial representations that may underlie the perception of near space (Imamizu et al 2000; Inoue et al 2001). Iriki et al (1996) conducted an electrophysiological study with monkeys, and found evidence for changes in spatial representations in the brain when the body was altered. Certain neurons within the intraparietal lobe fired only when a specific target (in their study, a raisin) was in reach. After training monkeys to use a rake to reach for the raisin (which now put former out-of-reach raisins in reach) they found that the same neurons fired when the raisin was placed within reach of the rake. This research suggests that the brain may be able to quickly integrate changes in body size in order to act in reachable space [but see Holmes et al (2004) for an argument that neurons may be remapping space, rather than integrating a tool]. Evidence from research on human patients also suggests that holding a tool remaps the perception of far-to-near space in cases of visuospatial neglect, a disorder that results in a tendency to ignore part of the visual field (Berti and Frassinetti 2000).

1.2 *The body and the perception of apertures*

The aforementioned studies suggest that changing the abilities of the observer rescales the perception of near or peripersonal space. Is there evidence to suggest that the same holds true for objects or dimensions in *extrapersonal* space? The work of Proffitt and colleagues that pertains to body scaling of space perception has been done with near space distances only. Gibson (1979) stated that perception is the pick-up of information about opportunities for action. Perceiving what the environment *affords* the observer necessarily involves perceiving complementary environmental and body characteristics (Gibson 1979; Warren 1984). The organism must be capable of perceiving the action opportunities that the environment affords to adjust its behavior and actions accordingly (Oudejans et al 1996). This should hold true for far distances as well as near.

A number of studies examining passability judgments for aperture widths (specifically, doorways of various sizes) have suggested that the size of one's body can influence judgments of passage through the aperture. One such study by Warren and Whang (1987) recorded different-sized men walking through a variety of aperture widths. They found that broad-shouldered men needed to rotate their shoulders at larger aperture widths than narrow-shouldered men. However, both broad- and narrow-shouldered men began to rotate their shoulders when walking through an aperture that was 1.3 times the size of their shoulders, which suggests that both groups scaled their actions to the fit between their shoulder width and the aperture width. This rotation also suggests that individuals allow for a margin of safety appropriate to their body size when acting on an aperture.

Similarly, Wagman and Taylor (2005) investigated judgments of passage through an aperture when observers held wide objects. They asked participants to either hold T-shaped objects of varying size or to view the objects (without holding them) and to judge whether they could pass through an aperture when holding the objects. They found that participants were sensitive to the object width (indicating they could not pass through when they wielded large objects) when judging locomotion through an aperture in both the vision and touch conditions. The results suggest that judgments of passage through extrapersonal space (apertures) are scaled to the widest dimension of the participants (when holding or anticipating holding an object).

Collectively, these results suggest that the perception of the environment, specifically decisions about action, can be influenced by a change in the width of the body. However, these observed changes in action may be due, in part, to a rescaling of perceived layout. For example, Warren and Whang (1987) found broad-shouldered men turned more when walking through a doorway than smaller men. In addition to acting as if the aperture was smaller, did these larger men actually *see* the aperture as smaller?

1.3 *Overview of current studies*

The studies reported here address several open questions derived from the previous research on the perception of affordances for apertures in extrapersonal space. First, the research on perceiving affordances for aperture crossing is rich, but none of the studies measured participants' visual perception of the width of the aperture outside of a motor decision or judgment of affordance for passage. Therefore, we examined whether participants of different widths and participants who experienced a change in body size would perceive the aperture widths to be different sizes. We used a visual-matching task to obtain participants' perceptions of the size of aperture widths across multiple trials. We hypothesized that people with larger bodies would estimate apertures to be smaller than those with smaller bodies. Similarly, increasing the size of the body may result in a decrease in the perceived size of the aperture. If the body is used to rescale the perception of the environment, then we suspect it will be used for all situations in which the body is altered. We believe this is important to test, because the perception of the aperture width could influence later motor decisions as measured in the experiments on the affordances of apertures. Therefore, our work makes an important contribution to the literature because it tests whether body scaling may be used to scale sizes at farther distances instead of near distances. In addition, our findings add to our understanding of aperture perception, which has almost exclusively been measured with affordance judgments.

2 Experiment 1

In this experiment, we tested whether broad- and narrow-shouldered participants would estimate the size of apertures to be different given their different sizes. Warren and Whang (1987) found that broad- and narrow-shouldered participants scaled their judgments of passage from a static viewing position to the sizes of their bodies. We sought to confirm that the perceived size of apertures, as assessed with a visual matching task, would also be affected by the size of the observer's body. We hypothesized that broad-shouldered observers would visually match the size of apertures to be smaller than narrow-shouldered observers.

2.1 *Method*

2.1.1 *Participants.* Thirty-six (twenty-one female, fifteen male) College of William & Mary students participated in the experiment for credit in an introductory psychology course. All participants were naive to the purpose of the experiment and gave written, informed consent to participate. All participants were randomly selected; we did not screen for broad- and narrow-shouldered participants.

2.1.2 *Apparatus.* Participants judged aperture widths in a 3.05 m × 3.05 m room with a solid-colored carpet. Two wooden poles, each 2.54 cm thick and 159 cm tall, were moved to display different aperture widths for the participants who stood 95 cm from the poles (home position). The aperture was adjusted to different widths around a center point, which was directly in front of home position. The aperture was placed in front of a cinder block wall. We do not believe that the grooves in the cinder block wall influenced the results because they were present in all conditions. However, to allay concerns that participants may have used the grooves, the experimenter extended the tape measure for the matching task in front of a solid-colored wall to reduce the possibility that participants could use the blocks as a strategy for making their estimates. Participants were asked to stand at the home position for the duration of the experiment.

2.1.3 *Design.* Aperture widths were shown at 5.08 cm intervals ranging from 30.48 cm to 60.96 cm. Aperture widths were randomly presented. Each participant made a total of seven judgments of aperture width (one for each aperture size).

2.1.4 *Procedure.* Participants were asked to imagine walking through the aperture without rotating their shoulders prior to making size estimates, because previous research has shown that the perceived distance to an object was affected only when the participant intended to act on the distance (Witt et al 2005). Then, participants completed a visual matching task to estimate the perceived size of the aperture. For the visual matching task, the experimenter stood to the side of the participant. The experimenter told the participants to adjust the length of a tape measure (that the experimenter pulled open) to be the same as the width of the aperture (see figure 1). The participants were instructed to continuously adjust the length of the tape until it was the most accurate representation of the aperture width. The experimenter always asked if the width was correct when participants seemed satisfied, and would keep his gaze focused on the participants rather than the tape measure in order to provide no feedback about accuracy. After making their estimates, participants turned 180° away from the aperture so that a new test width could be set. Upon completion of the experiment, participants' shoulder widths were recorded. The total experiment took about 10 min to complete.

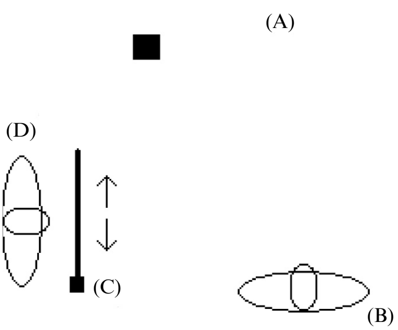

Figure 1. A top–down view of the experimental setup: (A) location of the aperture; (B) location of the observer (95 cm from the center of the aperture in experiment 1; 152.4 cm from the center of the aperture in experiments 2 and 3); (D) location of the experimenter relative to the observer and aperture; (C) the tape measure that was adjusted in either direction to match the size of the aperture (A).

2.2 *Results and discussion*

2.2.1 *Participant selection.* Eighteen participants (ten female, eight male) were selected for analysis from the sample of thirty-six. They were selected for analysis because they represented the largest 25% and smallest 25% of the thirty-six participants who participated. There were nine (one female, eight male) broad-shouldered participants (mean, $M = 48$ cm, SD = 4.01 cm) and nine (all female) narrow-shouldered participants ($M = 39.09$ cm, SD = 1.56 cm).

2.2.2 *Size estimates.* A 2 (shoulder width: broad, narrow) × 7 (aperture width) repeated-measures ANOVA revealed a significant main effect of body width ($F_{1,16} = 4.64$, $\mathrm{MSE} = 71.31$, $p = 0.047$, $\eta_p^2 = 0.23$). Broad-shouldered participants estimated the aperture widths to be, on average, significantly smaller ($M = 44.07$ cm, $\mathrm{SE} = 1.06$ cm) than narrow-shouldered participants ($M = 47.31$ cm, $\mathrm{SE} = 1.06$ cm). There was also a main effect of aperture width ($F_{1,16} = 824.07$, $\mathrm{MSE} = 11.87$, $p < 0.0001$, $\eta_p^2 = 0.98$).

Because of recent findings that gender influences judgments of passage through an aperture, one might be concerned that any differences between the groups in this experiment, especially because the broad- and narrow-shouldered group membership covaried with gender, reflect a difference between genders (Lopresti-Goodman et al 2009). To test this possibility we ran a 2 (gender) × 7 (aperture width) analysis of covariance where aperture width was a within-participants factor and shoulder width was the covariate. The analyses revealed no main effect of gender ($F_{1,15} = 0.67$, $p = 0.43$). Therefore, we tentatively conclude that the differences seen between broad- and narrow-shouldered participants may not be due to gender; however, we cannot strongly conclude that gender is not a factor, given the obvious covariation between group membership and gender.

The results of this experiment indicate that larger individuals saw the aperture as smaller in addition to acting as if the aperture was smaller (see Warren and Whang 1987). Warren and Whang found that both broad- and narrow-shouldered males required apertures to be at least 1.3 times their own shoulder width in order to walk through without rotating their shoulders. However, this also suggests that larger individuals may have required a larger margin of error, the space on either side of their shoulders, when walking through. As a result of the findings of the current experiment, we believe that the larger men in Warren and Whang's study may have required a larger margin of error than narrow-shouldered men because, in part, they *saw* the apertures as smaller.

3 Experiment 2

The purpose of this experiment was to test participants' perception of aperture width when the width of their body was widened, by holding an object or by holding out their arms. Participants in the 'wear' group wore a rod that extended their width but their hands were at their sides. Those in the 'hands only' group positioned their hands as wide as the rod was in the 'wear' group but did not hold any object. In the third condition, the 'hold' group, participants held the rod with their hands placed at its widest extent. The fourth group ('control'), acted as a control; participants did not hold an object or reposition their hands to widen their side-to-side extent. Multiple aperture sizes were presented. All participants viewed all aperture widths, imagined walking through the aperture, and completed a visual matching task to provide an estimate of the width of the aperture. We hypothesized that when participants' width was widened they would estimate the aperture to be smaller. However, we had no specific predictions whether the manner in which participants were made wider would impact their judgments of aperture width.

3.1 *Method*

3.1.1 *Participants.* Forty (twenty-three female, seventeen male) College of William & Mary students participated in the experiment for credit in an introductory psychology course. All participants were naive to the purpose of the experiment and gave written, informed consent to participate.

3.1.2 *Apparatus.* All apparati were the same as in experiment 1, except that only one pole moved parallel to the wall to create the different aperture sizes; the other pole remained stationary. The participants stood 152.4 cm from the center-point of the aperture at the home position. Once again, for the visual matching task the tape measure was extended in front of an adjacent wall perpendicularly to the aperture, which was covered by a solid-colored curtain (see figure 1 for diagram). A light-weight, 114.3 cm long curtain rod was used to extend the participants' body sizes in the two-object conditions.

3.1.3 *Design.* Participants were randomly assigned to condition. For each condition, the aperture width was adjusted to seven target sizes: 76.2, 88.9, 101.6, 114.3, 127, 139.7, and 152.4 cm, and one of pair of distractor distances: 63.5 and 165.1, 81.28 and 144.78, or 93.98 and 134.62 cm. Both target and distractor aperture widths were randomly presented. Distractor widths were included, because each of the target distances was equidistant from each other and there was concern that participants would scale their responses accordingly (eg in regular, rounded intervals). The distractors made it seem like the distances were not regularized. The pair of distractor widths kept the mean of all target distances the same. For each distance, participants imagined walking through the poles and visually matched the length of a tape measure to the aperture width.

3.1.4 *Procedure.* All procedures were the same as in experiment 1. However, in this experiment participants donned an object or adjusted their arm width depending upon the condition to which they were randomly assigned.

If they were randomly assigned to the 'hold' condition, participants were asked to hold the rod in front of their body with their hands clenched around the ends of the rod, but not extending past the ends (see figure 2a). If they were assigned to the 'hands only' condition, participants were asked to hold their hands in a fist (like they were holding an object) at the same extent as the rod (see figure 2b). The rod was used by the experimenter to place the hands of the participants in the correct location before each aperture width was presented. Participants in the 'wear' condition donned a back-pack that was light-weight (empty), with the rod attached to it through loops on a carabiner so that the rod extended equally out to the right and left of the participant (see figure 2c). The participants' arms remained at their sides, but their body sizes were enlarged by wearing the rod. Finally, in the 'control' condition, participants simply made judgments of the size of the aperture with their arms at their sides.

(a) (b) (c)

Figure 2. [In color online, see http://dx.doi.org/10.1068/p6437] Participants in experiment 2 either held the rod (a), placed their hands out to be the same distance when holding the rod (b), or wore the rod (c).

Each participant was then given approximately 15 s to get comfortable and walk around with the rod before any judgments were made. Participants tended to walk around, approach the doorway into the room, or bump the extent of the object into a wall. They did not get experience walking through the test aperture as it was only set up after this familiarization phase. The rod was held throughout the experiment and participants kept it close to their torsos and did not extend it out in front of them. After estimating all widths, participants' shoulder widths were recorded. Participants showed no signs of fatigue. The experiment lasted no longer than 10 min.

3.2 *Results and discussion*

3.2.1 *Perceptual estimates.* We ran a 2 (object: rod or no rod) × 2 (arm position: in or out) × 7 (aperture size) repeated-measures ANOVA with estimates of the size of the apertures as the within-participants dependent variables. The object and arm-position factors were between-participants. There was a main effect of arm position ($F_{1,36} = 8.70$, MSE = 637.04, $p = 0.006$, $\eta_p^2 = 0.20$). Participants who had their arms out (whether holding a rod or not) estimated the aperture to be on average smaller ($M = 103.41$ cm, SE = 2.10 cm) than participants who did not hold the rod or their arms out ($M = 112.42$ cm, SE = 2.22 cm) (see figure 3). However, there was no main effect of object ($F_{1,36} = 0.02$, $p = 0.90$) and no object × arm position interaction ($F_{1,36} = 0.06$, $p = 0.84$). Finally, there was a main effect of aperture size ($F_{6,126} = 462.31$, MSE = 49.63, $p < 0.0001$, $\eta_p^2 = 0.93$), suggesting that participants did perceive the apertures as different across trials.

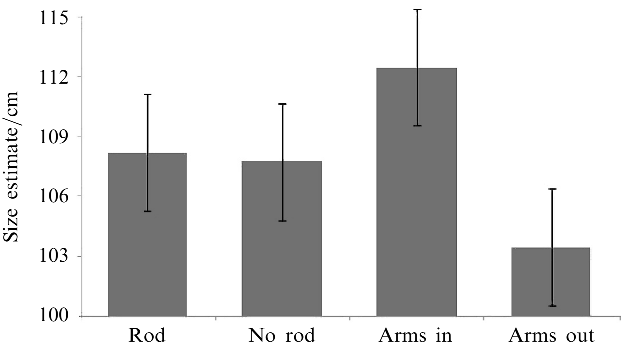

Figure 3. Average size estimates for each experimental factor in experiment 2. Participants estimated the aperture to be significantly smaller when their hands were outstretched (either holding a rod or not). Bars represent ±1 SE.

The results showed that altering the width of participants' bodies changed the perception of aperture width, but only when the hands of the participants were at the widest point. When participants were holding a 114.3 cm rod ('hold' condition) or when they simply stood with their hands 114.3 cm apart ('hands only' condition), they judged the aperture to be smaller than participants whose arms were not far apart ('wear' and 'control' conditions). All depth cues were constant between viewing conditions; therefore the differences in perceived aperture width are likely due to the arm and/or hand positions of participants in the 'hold' and 'hands only' conditions. However, it is possible that wearing the rod produced a confound that was not present in the other conditions, because of the way that the rod was attached to the body. Specifically, for the 'wear' condition, the rod was attached to the backpack and the hands were positioned at the sides of the observer. However, in the 'hold' condition, the observers held the rod at each end with their hands, which produced a covariation of hand position with these two conditions. An alternative for future studies would be to have participants hold the rod in the middle (as done by Wagman and Taylor 2005).

Finally, the weight of the rod was low (0.18 kg, or 0.4 lb), so there could be concern that participants did not accurately perceive the length of the rod in the 'wear' condition, which could lead to the null-effect observed for that condition. There are two pieces of evidence that suggest that the weight of the rod was perceptible to the participants. First, the research on dynamic touch suggests that the rod length could have been revealed to participants when they turned around between each trial. Participants wore the backpack with the rod attached for the duration of the experiment. Between each perceptual estimate, they were asked to turn around while the experimenter set up the next aperture width. This twisting should have been sufficient to reveal the length of the rod to participants (Carello 2004; Carello et al 2006; Carello and Turvey 2004; Wagman and Malek 2007; Wagman and Taylor 2005). We also have data from a pilot study that suggest that the perceived length of the rod is not different between the 'wear' and 'hold' conditions. When participants are asked to visually match or draw the length of the rod when holding or wearing it, they do not differ in their estimates of the rod's length. These two pieces of evidence make us less concerned that the participants in the 'wear' condition did not perceive the change in their width when wearing the rod.

This experiment gives good support to our hypothesis that participants who are wider will see apertures as smaller. Previous work by Higuchi et al (2006) has shown that when the body is widened by holding a rod or sitting in a wheelchair, participants were more cautious when approaching a doorway that they had to pass through when they were not allowed to rotate their shoulders or the chair. Therefore, our results may suggest that, as Higuchi et al's participants were approaching the door, they may have slowed down because they perceived the width of the aperture to be smaller. Our results also suggest that the manner in which the body is widened is important for realizing this potential change in perception. Wearing an object that was large did not alter the perception of apertures in this experiment. Thus, the position of the arms and hands seems important for a change in the body to influence perception. We decided to investigate this further by having participants hold their arms at different locations to see if we could replicate the results of this experiment, but also to pinpoint the locus at which perception begins to be altered by arm position.

4 Experiment 3

The purpose of this experiment was to further explore the effects observed in experiment 2. Specifically, we decided to test the boundaries of the effect of arm and hand location on the perception of aperture width by asking participants to vary the location of the arms during the course of the experiment. Participants held their arms at four widths, one that was as close together as the hands could go, one with their hands 38.1 cm apart, one with their hands 76.2 cm apart, and one with their hands 114.3 cm apart as in the previous experiment (see figure 4). These arm positions were chosen because they divided the widest arm length used in experiment 2 into four equal parts, allowing for a more precise examination of the locus of the effect. However, no objects were held in this experiment. For each arm/hand location, the participants judged the same aperture widths as in experiment 2. Therefore, we could also assess whether changes in perception due to arm location could occur within-participants.

4.1 *Method*

4.1.1 *Participants.* Ten (eight female, two male) College of William & Mary students participated in the experiment for credit in an introductory psychology course. All participants were naive to the purpose of the experiment and gave written, informed consent to participate.

4.1.2 *Apparatus.* All apparati used were the same as in experiment 2. However, no object was held.

4.1.3 *Design.* A within-participants design was used; therefore all participants completed all four arm/hand positions (0 cm, 38.1 cm, 76.2 cm, and 114.3 cm apart). The hand positions were four equally incremented extents that were chosen to more precisely test the relative influence of body width on perceived aperture width. Hand positions were blocked and randomized between participants. For each condition, the aperture width was randomly adjusted to the same seven target sizes used in experiment 2.

4.1.4 *Procedure.* As in experiment 2, participants imagined walking through the aperture and then visually matched the length of a tape measure to the aperture width. Participants' arms and hands were positioned appropriately by the experimenter.

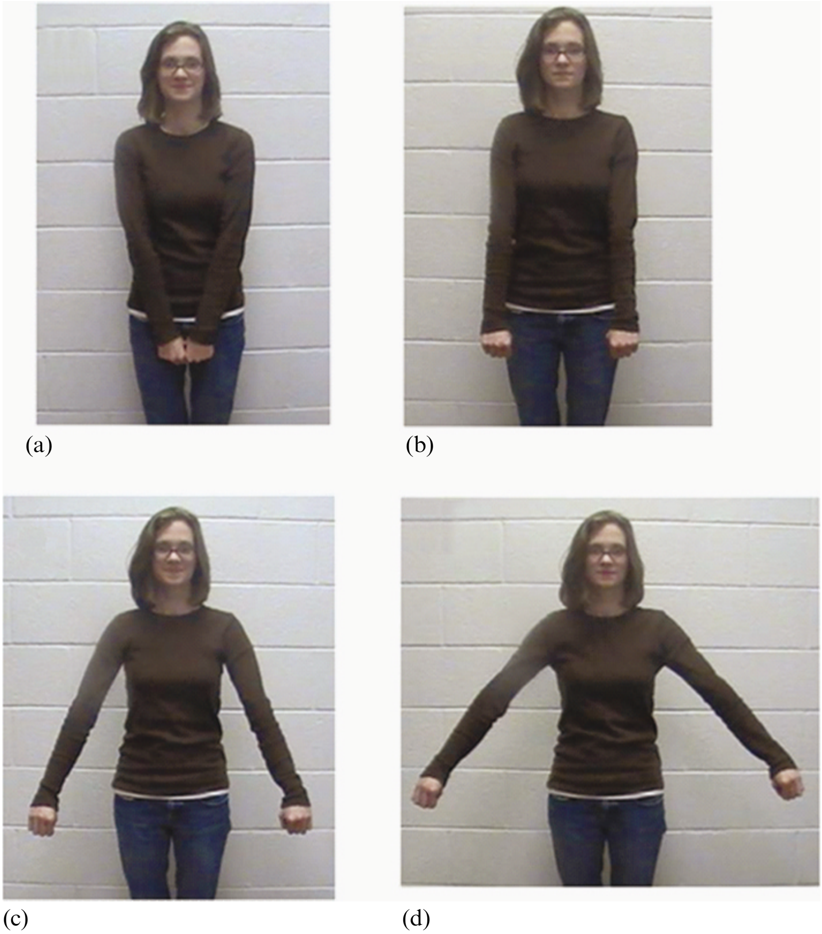

Figure 4. [In color online.] Participants in experiment 3 held their hands (a) as close as possible; (b) 38.1 cm apart; (c) 76.2 cm apart; and (d) 114.3 cm apart.

The distance between participants' hands was checked before each trial and participants kept their elbows extended. After all distances were judged for one position, the experimenter asked the participants to position their hands and arms in the next position, and so forth, until participants completed judgments for each position. Participant shoulder width was recorded at the end of all blocks.

4.2 *Results and discussion*

4.2.1 *Size estimates.* A 3 (order) $\times$ 4 (arm position) $\times$ 7 (aperture width) repeated-measures ANOVA was run; all factors except order were within-participants. The analyses revealed a main effect of aperture width ($F_{6,42} = 222.22$, MSE $= 88.39$, $p < 0.0001$, $\eta_p^2 = 0.97$) and hand position ($F_{3,21} = 5.14$, MSE $= 134.43$, $p = 0.01$, $\eta_p^2 = 0.42$) (see figure 5). There was no main effect of order ($F_{2,7} = 2.4$, $p = 0.16$).

We ran three planned contrasts in order to further assess the influence of hand position on the perception of apertures. First, we tested whether participants estimated the aperture widths to be of different sizes when their hands were not the widest part of their body (0 cm, 38.1 cm) as compared to when their hands were the widest part of their bodies (76.2 cm and 114.3 cm).(1) The analysis revealed a main effect of hand position

(1) Participants' shoulder widths ($M = 41.73$ cm, SD $= 2.97$ cm), ranged from 37.85 cm to 47.63 cm. Only one participant's shoulder width was less than 38.1 cm.

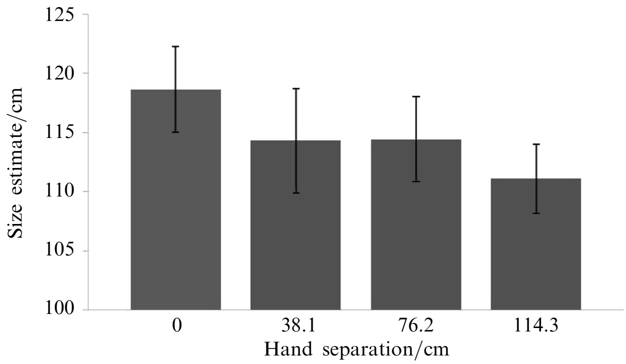

Figure 5. Average size estimate for each arm position. Generally, participants estimated the aperture to be smaller as their hands moved farther apart. Specifically, participants estimated the aperture to be significantly smaller when their hands were the widest part of their body (76.2 cm and 114.3 cm) than when their hands were not the widest part of their bodies (0 cm and 38.1 cm). Bars represent ±1 SE.

($F_{1,9} = 11.81$, MSE $= 81.99$, $p = 0.007$, $\eta_p^2 = 0.57$). On average, participants judged the aperture to be smaller when their hands were the widest part of their bodies ($M = 112.77$ cm, SE $= 3.3$ cm) than when their hands were not the widest part of their bodies ($M = 116.48$ cm, SE $= 3.93$ cm). A second planned contrast revealed that participants judged the apertures, on average, to be significantly smaller when their hands were positioned 114.3 cm apart ($M = 111.1$ cm, SE $= 3.06$ cm) than when their hands were positioned 76.2 cm apart ($M = 114.44$ cm, SE $= 3.57$ cm) ($F_{1,9} = 8.39$, MSE $= 46.516$, $p = 0.02$, $\eta_p^2 = 0.48$). A final planned contrast revealed that participants judged the aperture to be no different when their hands were positioned 0 cm apart ($M = 118.64$ cm, SE $= 3.75$ cm) as compared to when their hands were positioned 38.1 cm apart ($M = 114.33$ cm, SE $= 4.5$ cm) ($F_{1,9} = 2.74$, $p = 0.13$). However, we concede that there was a trend for participants to see the aperture as wider when the hands were moved closer together.

The results indicate that participants began to see the aperture as smaller when their hands were positioned at least 114.3 cm apart. We believe this may be due, in part, to the fact that the hands may normally operate within 76.2 cm of one another. For example, people tend to swing their arms when walking or to gesture when talking. If this is true, it wold suggest that changes to perception in this normal range of operation may be negligible.

5 General discussion

In a series of experiments, we showed that the perception of spatial layout, specifically the size of apertures in extrapersonal space, is affected by observers' body size and their abilities to act within the space. In other words, we believe that observers use the size of their bodies as perceptual metrics for estimating the size of apertures. Our results suggest that participants who are large may perceive the environment to be different than participants who are small. Furthermore, when the body is larger than normal, participants rescale their perception of the environment, possibly to inform their actions.

In experiment 1, we compared broad- and narrow-shouldered participants' estimates of aperture width. As hypothesized, participants who were broad-shouldered visually matched the size of the apertures to be smaller than participants who were narrow-shouldered. In experiment 2, we found that participants who held a large object or held their arms out wide perceived aperture widths to be smaller than those who did not hold an object or whose hands were at their sides when wearing an object.

These findings are novel and interesting, given that previous work has shown that wielding an object provides enough information to discover its length, even when it may be out of view (Burton and Turvey 1990; Kingma et al 2004; Turvey 1996) or when the limb that wielded the object was numb due to peripheral neuropathy (Carello et al 2006). Our findings suggest that, at least for the rescaling of perceived aperture width, the locations of the hands and arms are important in predicting alterations in perception. Furthermore, as observed in experiment 3, these alterations in perception are different depending on the location of the arms and hands. When the body was enlarged by holding the arms out, apertures appeared smaller, but when the arms and hands were held close together, the apertures tended to appear wider.

These studies add to the literature on aperture perception, in that they show that observers use their bodies to visually match the size of apertures. Previous researchers clearly found that the body is used as a metric for making affordance judgments about passage (Wagman and Taylor 2005; Warren and Whang 1987). Our work replicates these findings with a different measure of perception. Furthermore, this measure is influenced by a change to the observer's body, which results in a perceptual rescaling of apertures in extrapersonal space. Witt et al (2005) showed that increasing observers' reaches (by having them hold a baton) resulted in a rescaling of the perception of distance in near space. Linkenauger et al (in press) found that differences in perceived arm length influence estimates of reachable extents. Likewise, differences in perceived hand size altered the perception of what was considered graspable. Our paper adds to this growing body of literature, which suggests that the body is used to scale the perception of space, by extending the previous findings to the perception of extrapersonal space, specifically to the perception of aperture widths. Furthermore, the position of the hands and arms seems to be particularly important in producing these effects.

Recent research on visual attention reveals a plausible reason why the position of the hands and arms may have resulted in a change in perception that was different from wearing the object. Abrams et al (2008) found that, in three experiments, participants were slower to disengage attention when their hands were near the visual display (holding the sides of the screen) rather than far from the display (in their laps). These results suggest that visual perception was enhanced when participants' hands were closer to the objects being processed. Similarly, Reed et al (2006) have found that participants who had one hand on the side of a display were faster to detect targets closer to the hand, even though the location of the targets was randomized across trials. This bias in attention towards areas or objects close to the hands could result from neurons that code for hand-centered space in the parietal cortex (see Graziano 2001; Makin et al 2007). Furthermore, Davoli and Abrams (2009) showed that the hands do not need to be physically near the display to produce an enhancement. They found that imagining the hands being near the display resulted in the same search enhancements as that observed by Abrams et al (2008). We tentatively suggest that a similar mechanism could underlie the current findings. Again, participants may have attended more to the area around their hands, which influenced perceived aperture size when the hands were wide because this awareness provided useful information with which to scale the size of the aperture. Abrams et al (2008) mention that enhanced visual awareness near the hands would be important when wielding or carrying objects to avoid collisions. When participants held the objects in our experiments or held out their arms, they may have had an enhanced awareness of the extent, which resulted in reduced perception of aperture width.

Thus, our findings suggest that adding a large object to the body may result in a decreased perception of aperture width only when participants have salient information about the size of the object from the position of their arms or hands. In our experiments, perceived aperture width was reduced when holding a wide object or holding the arms out, but not when wearing the object or when the hands were at the sides of the body. These findings may also be related to claims that touch can reveal the length and width of objects to observers who are wielding, or even just holding those objects (Carello 2004; Carello et al 2006; Carello and Turvey 2004; Wagman and Malek 2007; Wagman and Taylor 2005). If our participants had better knowledge about the length of the rod when holding it as opposed to wearing it, then this could have affected their perceptual estimates. Holding the arms open may have also provided more reliable proprioceptive cues for the length and extent of participants, such that participants were better able to perceive the size of their body in order to use it to scale aperture width.

Future research should test the influence of the body on other parameters of extrapersonal space. One could imagine that changes to the body could influence the perception of farther distances (holding a long rake could make leaves on the ground appear closer), sizes (wearing a large glove or holding a large object could make an aperture appear smaller for reaching—see Ishak et al 2008), and heights (wearing high heels could make steps look shorter, or holding an umbrella could make heights look smaller—see Stefanucci and Geuss, in preparation). Recent work by Wagman and Malek (2008) showed that affordance judgments for walking under a horizontal barrier were affected by the point of observation of the observer. Participants rescaled their judgments of passage under a barrier when they were sitting on the floor or standing on a stool. Moreover, the effect of the body on space perception may extend to sensitivity around other limbs, like the legs and feet. Hajnal et al (2007) showed that when participants wielded rods with their feet, their perception of the length of the rod was comparable to that of their hands.

Also, changes to the body may not be necessary to alter space perception. Anorexics who exhibit distorted body schemas may show similar distortions of perceived environmental layout as in the current studies. Given that anorexics perceive themselves to be larger than the average person (Sands et al 1997; Zellner et al 1989) they may estimate apertures to be smaller when considering acting on them. In fact, recent research showed that anorexics required a larger margin of error when estimating if they would fit through an aperture than normal, size-matched controls (Luyat et al 2009). Another population that could be affected is people who have claustrophobia (fear of enclosed or small spaces). Previous work has shown that claustrophobics exhibit fears of restriction and suffocation, especially in small, enclosed spaces (Rachman and Taylor 1993). However, they are usually bothered by bodily restrictions as well, especially restriction of the hands. Therefore, they could perceive apertures to be even smaller than normal when their body is restricted or the aperture is in an enclosed space. By studying these populations, methodological issues that arise when adding an object to a person, such as whether the object is seen or touched, could also be avoided.

When approaching an aperture, the visual system dynamically updates the perceived size of the aperture in reference to the size of the body and the actions that body can perform. The system then uses the information about the size of the aperture and the person plus any object he/she is holding or the position of his/her body to make one of three decisions: to walk through without rotating the body, to walk through and rotate the body, or to find an alternative route (Warren and Whang 1987). Often, when dynamically updating the size of the physical constraints, the visual system indicates that another route is required, or, as shown previously by Higuchi et al (2006), to slow down when approaching the aperture if biomechanical constraints are present. Obviously, deciding on an alternative route or to slow down earlier is important so that the observer does not walk into an area, get stuck, and then has to find an alternative route. If the observer sees the aperture as smaller when approaching, then it would facilitate caution.

In contrast, people may decide to change the size of their body in response to their perception of the physical environment. Informally, we have observed people in crowds making their bodies smaller in order to fit through tight spaces. This work suggests that this bodily adjustment might not only serve to create more space in which to maneuver, but it may also enlarge the space perceptually, thus providing possible reprieve from the crowding.

The purpose of these studies was to measure the information on which the system bases these action decisions before the action is imminent. The results suggest that the body is an important source of information for action decisions, and that the position of the hands, in particular, may be privileged in informing the final decision to act.

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