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RESEARCH NOTE

Space perception and body morphology: extent of near space scales with arm length

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Abstract Numerous studies have found that the near space immediately surrounding the body is represented differently than more distant space. In a previous study, we found a gradual shift in attentional bias (on a line bisection task) between near and far space (Longo and Lourenco in Neuropsychologia 44:977–981, 2006). The present study concerns the possibility that arm length relates systematically to the rate at which this gradual shift between near and far space occurs. Participants bisected lines using a laser pointer at eight distances (within and beyond arm's reach), and the rate of shift was estimated by the slope of the least-squares regression line. A negative correlation was found between the slopes and arm length; participants with longer arms showed a more gradual shift in bias with increasing distance than those with shorter arms. These results suggest that, while near space cannot be considered categorically as that within arm's reach, there is a systematic relation between the extent ("size") of near space and arm length. Arm length may constitute an intrinsic metric for the representation of near space.

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Introduction

Numerous researchers in various fields have differentiated the near space immediately surrounding the body from the space farther away (e.g., Brain 1941; Cutting and Vishton 1995; Hall 1966; Sommer 1969). Following Brain's (1941) proposal of specialized neural mechanisms representing *grasping distance*, many researchers have suggested that near space consists of that within arm's reach (e.g., Berti et al. 2002; Halligan et al. 2003; Rizzolatti et al. 1981; Witt et al. 2005). Other studies, in contrast, have found a continuous transition between near and far space, with no apparent bifurcation at or about arm's reach (e.g., Cowey et al. 1999; Longo and Lourenco 2006; Varnava et al. 2002). In the present study, we attempt to reconcile these apparently contradictory conclusions. Specifically, we examine the possibility that even if there is a continuous transition between near and far space, arm length may relate systematically to the rate at which this transition occurs.

In the present study we measured lateral biases in attention at different distances in near and far space. While each cerebral hemisphere directs attention contralaterally (Corbetta et al. 1995), the rightward orienting tendency of the left hemisphere is stronger than the leftward orienting tendency of the right hemisphere (e.g., Làdavas et al. 1989). This asymmetry results in an overall rightward attentional bias (for review, see

Kinsbourne 1987).[1] Paper-and-pencil line bisection tasks administered to healthy adults, however, have generally revealed a slight *leftward* bias, known as *pseudoneglect* (Jewell and McCourt 2000). This apparently paradoxical result can be explained by the finding that representation of near space preferentially involves the right parietal lobe (e.g., Bjoertomt et al. 2002; Fierro et al. 2000; Previc 1998). Bisecting lines presented in near space (as in paper-and-pencil tasks), then, should preferentially activate the right parietal lobe and bias attention leftward, relative to lines presented in far space. Indeed, studies have found that bias in line bisection shifts rightward with increasing distance (e.g., Longo and Lourenco 2006; Varnava et al. 2002).

In an earlier study (Longo and Lourenco 2006), we used this shift in bias to examine whether there is an abrupt transition between near and far space at or about arm's length. Using a laser pointer, participants bisected lines presented at various distances (i.e., 30, 60, 90, and 120 cm) from the body. As the length of everyone's arm was between 60 and 90 cm, the two nearer distances (30 and 60 cm) were within arm's reach, whereas the two farther distances (90 and 120 cm) were outside of arm's reach. If near space consisted only of the space within arm's reach, an abrupt shift (i.e., a step function) should have been observed, with bias farther to the left at the two nearest distances compared to the two farthest distances. Instead, we found a gradual left–right shift in bias as distance increased. Indeed, significant rightward shifts were observed between distances entirely within (30 vs. 60 cm), and entirely outside of (90 vs. 120 cm) arm's reach, as well as across this threshold (60 vs. 90 cm). There was no hint of any transition at or about arm's length. Rather, near space appeared to grade off from the body in a generally continuous manner.

The present study examines the relation between near space and arm length. Given that near space is not categorically restricted to the space within arm's length, one possibility is that near space bears no relation to arm length, grading off independently from the body. Alternatively, even if near space grades off from the body continuously, the extent (i.e., "size") of near space can still be conceptualized in terms of the *rate* at which this shift occurs. That is, a more gradual transition between near and far space can be thought of as a "larger" near space than a more abrupt transition. It may be in this sense that the size of near space relates to arm length.

In the present study, participants used a laser pointer to bisect lines at eight distances ranging from 30 to 240 cm. The size of near space was determined for each participant by computing the slope of the best-fitting line, regressing rightward bias on distance. If there is no relation between the size of near space and arm length, these slopes should be unrelated to the length of participants' arms. In contrast, if near space is systematically related to arm length, these slopes should be inversely related to arm length. That is, people with longer arms should have a correspondingly larger near space and, hence, a more gradual shift in bias, than people with shorter arms.

Method

Participants

Twenty-three students (15 female), between 18 and 38 years, participated. All but one were right-handed as determined by the Edinburgh inventory (Oldfield 1971), $M = 77.2$, range: −20.0 to 100.

Stimuli

Lines of 7.5, 15, 22.5, and 30 cm (1 mm in height) were used, centered on legal-sized sheets of paper attached horizontally to a wall, 156 cm above the floor. As line length was held constant, across distances, angular size varied across distances. Note that in an earlier study (Longo and Lourenco 2006) we found similar rightward shifts with increasing distance when veridical size was held constant, as well as when a subset of lines controlling visual angle were analyzed.

Procedure

Participants completed two experimental sessions, on separate days, each lasting about an hour. They used a laser pointer to bisect lines at eight distances (30, 60, 90, 120, 150, 180, 210, and 240 cm), marked on the floor with tape. The laser pointer was attached to the head of a tripod such that the beam was always activated. The height of the tripod was adjusted for each participant's comfort. The tripod was located to the right of the participant, and as far from the wall as his/her feet. Participants used their right hand to move the head of

[1] Some authors (e.g., Mesulam 1981) have suggested, in contrast, that while both hemispheres direct attention primarily contralaterally, the right hemisphere has an additional (weaker) tendency to direct attention ipsilaterally. Since the vector sum of the right hemisphere's contra- and ipsilateral orienting tendencies yield a leftward tendency weaker than the rightward orienting tendency of the left hemisphere, the two theories make identical behavioral predictions.

the tripod, bisecting the line with the laser beam. Responses were marked by an experimenter (who, until then, remained behind the participant). Two coders measured bisection responses off-line, never disagreeing by more than 0.25 mm. Mean percent deviations were calculated for each participant for each distance in each session.

Trials were presented in blocks of 32, formed by crossing the four line lengths and the eight distances. Order of trials was randomized within blocks. In each hour-long session, participants completed as many whole blocks as possible (first session: $M = 3.57$, SD = 0.59; second session: $M = 3.96$, SD = 0.47). At the end of the second session, arm length (right acromion to tip of right middle finger), arm span (distance between laterally outstretched middle fingers), and height[2] were measured for each participant.

In our previous study and in pilot studies, we found that while the majority of participants showed a clear rightward shift in bias with increasing distance, a smaller subset (approximately 10%) showed either no apparent shift or a leftward shift. While the reason for these individual differences is unclear, it would not make sense to compare the rate of the rightward shift to arm length for those not showing a clear rightward shift in bias. Thus, participants not showing a rightward shift accounting for at least 20% of the between-conditions variance (3 of 23) were excluded from comparisons involving arm length.

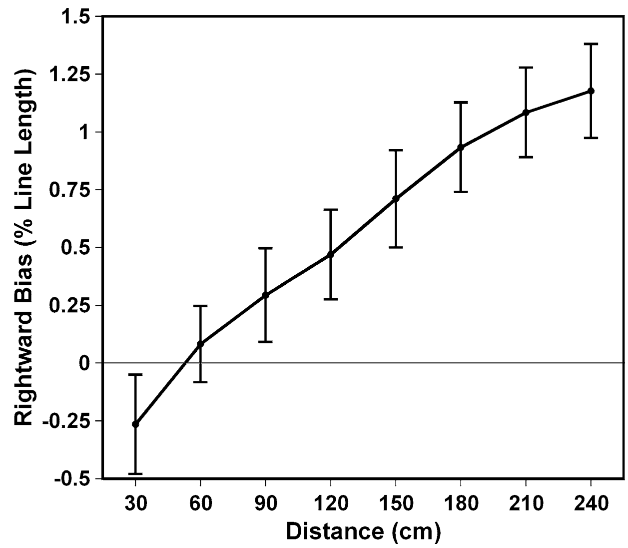

Fig. 1 Bias as a function of distance. *Error bars* are 1 SEM

Table 1 Comparisons of rightward bias (% line length) between adjacent distances

Comparison (cm)	Mean difference (SD)	Test statistic
60–30	0.348 (0.561)	$t(22) = 2.97$**
90–60	0.212 (0.431)	$t(22) = 2.35$*
120–90	0.176 (0.370)	$t(22) = 2.28$*
150–120	0.241 (0.280)	$t(22) = 4.12$**
180–150	0.223 (0.331)	$t(22) = 3.23$**
210–180	0.151 (0.355)	$t(22) = 2.04$*
240–210	0.093 (0.391)	$t(22) = 1.14$

*$P < 0.05$, uncorrected; **$P < 0.05$, Bonferroni corrected

Results

An 8 × 2 factorial analysis of variance (ANOVA) with distance (30–240 cm) and session (first or second) as within-subjects factors, revealed a significant main effect of distance, $F(7, 154) = 33.58$, $P < 0.0001$. As in our previous study, there was a clear rightward shift in bias with increasing distance (see Fig. 1). Bias did not differ significantly between the two sessions, $F(1, 22) = 1.99$, nor was there a significant interaction between session and distance, $F(7, 154) = 1.07$. Arm length for all participants was between 60 and 90 cm, $M = 71.4$ cm, range: 63.5–85.0 cm. Thus, the 30 and 60 cm distances are within arm's reach, whereas the 90–240 cm distances are outside of arm's reach. Significant rightward shifts were observed between distances entirely within arm's reach (30 vs. 60 cm), across this threshold (60 vs. 90 cm), and entirely outside of arm's reach (all other contrasts), providing further evidence for a gradual transition between near and far space (see Table 1).

To quantify the rate at which bias shifted with distance, least-squares regression was computed for each participant (i.e., the slope of the best-fit line to the function shown in Fig. 1). Congruent with the ANOVA results above, the overall slope was positive (0.685% line length/m), $t(22) = 7.50$, $P < 0.0001$, indicating a rightward shift with distance. Further, 22 of the 23 participants showed an overall positive slope ($P < 0.0001$, binomial test). Similar rightward shifts were observed in the first (0.699% line length/m), $t(22) = 8.33$, $P < 0.0001$, and second (0.671% line length/m), $t(22) = 6.24$, $P < 0.0001$, sessions. Across sessions, these slopes accounted, on average, for 69.9% of the between-conditions variance. Slopes in the first and second sessions were significantly correlated, $r(22) = 0.818$, $P < 0.0001$, indicating that there are consistent individual differences in the size of near space.

[2] Height was measured both with and without shoes. As these measures were almost perfectly correlated, $r(22) = 0.995$, $P < 0.0001$, only height without shoes was used in analyses.

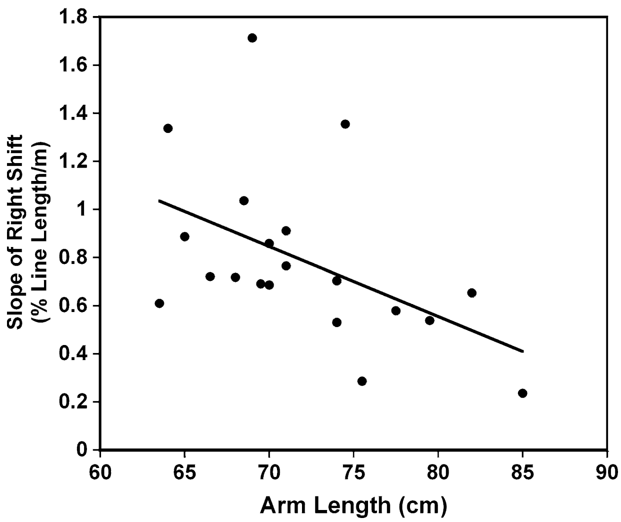

Fig. 2 Scatterplot relating slopes of regression equations measuring the rate at which bias shifts with distance (i.e., the "size" of near space) and arm length

The central question of interest is whether these individual differences in the size of near space relate to arm length. Across sessions, there was a significant negative correlation between slope and arm length, $r(19) = -0.480$, $P < 0.05$ (see Fig. 2). Similar negative correlations were found when first, $r(19) = -0.554$, $P < 0.01$, and second, $r(19) = -0.369$, $P < 0.05$ (one-tailed), sessions were examined separately. To make sure these correlations were not inflated by one or two unduly influential points, a Spearman's rank-order correlation was conducted, revealing the same negative relation between arm length and the size of near space, $r(19) = -0.536$, $P < 0.05$.

Discussion

There are two main findings of the present study. First, as in our previous study, we found a gradual shift in lateral attention from near to far space; significant rightward shifts in bias were observed between distances entirely within, and entirely outside of, arm's reach, as well as across that threshold. Second, and most importantly, consistent individual differences were observed in the rate at which this shift occurred, indicating a systematic relation to arm length. People with longer arms showed a more gradual shift in bias and hence, a larger near space than those with shorter arms.

While near space cannot be conceptualized categorically as that within arm's reach, there is nevertheless a systematic relation between the size of near space and one's body. Our findings suggest that the distance of objects may be scaled as a proportion of one's arm length. This suggestion is reminiscent of Gibson's (1979) concept of *affordances*, those opportunities for action furnished by the environment around us. Warren (1984) found that judgments of maximum climbable height of stairs scaled as a constant function of leg length, arguing that such affordances are scaled in *intrinsic*, or body-centered, coordinates (e.g., leg-length, eye-height, or arm-length), rather than in coordinates *extrinsic* to the observer (e.g., feet, meters). Similarly, Mark (1987) manipulated eye-height by having participants wear blocks under their feet, effectively lengthening the leg, which rescaled judgments of sitability and climbability. Warren and Whang (1987), furthermore, demonstrated that body-scaled information can be used as a metric for perceptual judgments of affordances; manipulating apparent eye-height altered judgments of the passability of apertures, without affecting their perceived distance or size.

While distance is not an affordance in a literal sense, it can certainly modify the availability of affordances; while two chairs may equally afford sitting, the nearer chair affords it more readily. The present results suggest that just as affordances such as sitting and stepping are scaled in intrinsic coordinates, near space may be similarly scaled in terms of arm length. Consistent with this interpretation, Witt et al. (2005) found that when participants used a baton to point to objects-effectively lengthening the arm-they perceived objects as closer than after having pointed with their finger. Witt et al. (2005) proposed that reachability serves as a perceptual metric of perceived distance. However, on the basis of the present results, we would suggest that it is not reachability in a binary sense, but arm-length in a continuous sense in which near space is scaled.

While clear rightward shifts in bias were observed well beyond arm's reach in the present study, this trend appears to be decelerating at the farther distances (see Fig. 1). Indeed, of all the adjacent pairwise comparisons (see Table 1), only the one between the two farthest distances is not significant (at least before multiple-comparison correction). This suggests that near space may grade off entirely somewhere around 2 m from the body. This interpretation is consistent with Previc's (1998) model which proposes that the peripersonal space within about 2 m of the body is mediated primarily by the right cerebral hemisphere, whereas more distant space is mediated primarily by the left hemisphere. Cutting and Vishton (1995) similarly (though for different reasons) proposed that *personal space* extends about 2 m from the body.

One potential concern about the present findings is that they are essentially correlational; natural variability in arm length was found to relate to the size of near space, but arm length was not experimentally manipulated. Adult humans are approximately isomorphic (Schmidt-Nielsen 1984), meaning that linear bodily dimensions (e.g., arm length, height) increase in direct proportion to each other (McMahon and Bonner 1983). Indeed, in the present study, arm length was strongly correlated with arm span, $r(22) = 0.937$, $P < 0.0001$, and height, $r(22) = 0.898$, $P < 0.0001$. This makes it impossible to conclude definitively that the size of near space does not scale with some other bodily dimension, such as height. Nevertheless, there is reason to believe that it is arm length, per se, that functions as the metric of near space. In our earlier study, we showed that when people used sticks (instead of a laser pointer) to bisect lines, the rightward shift in bias over distance was eliminated; rather, there was a constant leftward bias, suggesting that near space had expanded to incorporate the tip of the tool, consistent with previous findings (for review, see Maravita and Iriki 2004). The use of a tool can be considered an experimental manipulation of arm length. The present results complement those of our earlier study; near space is expanded when arm length is explicitly manipulated (Longo and Lourenco 2006), and the size of near space is related systematically to natural variability in arm length (the present study).

While modern weights and measures are almost invariably defined by extrinsic metrics, many cultures around the world have used arm length (and other intrinsic metrics) as an explicit measure of length or distance (Nicholson 1912). The cubit used in the ancient near east was the distance from the elbow to the tip of the middle finger; the fathom of the Norse was the distance between the tips of the middle fingers of the outstretched arms (Ritchie-Calder 1970). This was true even though differences in the length of people's arms severely limited the utility of such measures. The implicit use of arm length in the perception of near space suggests a reason why such explicit measures may have seemed intuitive, indeed providing a potential cognitive basis for this cultural regularity.

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