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Note

On the nature of near space: Effects of tool use and the transition to far space

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Abstract

Many researchers have proposed that the near space immediately surrounding the body is represented differently than more distant space. Indeed, it has often been suggested that near space encompasses that within arm's reach. The present study used a line bisection task in healthy adults to investigate the effects of tool use on space perception, and the nature of the transition between near and far space. Subjects bisected lines at four distances controlled for both veridical and angular size using a laser pointer and a set of sticks. When the laser pointer was used, a left to right shift in bias was observed as stimuli were moved from near to far space. When a tool was used, however, a leftward bias was observed at all distances, similar to that observed with the laser pointer in near space. These results suggest that the tool expanded the range of near space. Additionally, the transition from near to far space was gradual, with no abrupt shift at arm's length (or at any other distance). In contrast to theories describing near space as that within arm's reach, these findings suggest that the representation of near space is less rigid, extending with tool use and gradually transitioning into far space.

Keywords: Near space; Peripersonal space; Line bisection; Pseudoneglect; Tool use

1. Introduction

Perceiving the space around us is crucial for successful action. Given that we cannot act at indefinite distance, it is of primary importance to represent the space closest to us. Accordingly, many researchers in diverse fields have differentiated the near space immediately surrounding the body from that farther away (e.g., Brain, 1941; Hall, 1966; Sommer, 1969). Brain, for example, described two patients with opposite localization deficits, one unable to locate "objects within arm's reach" (p. 255), the other unable to localize objects farther than a yard from his body. Subsequent research has replicated this double-dissociation (Cowey, Small, & Ellis, 1994; Halligan & Marshall, 1991). Brain distinguished the *grasping distance* within arm's reach from the *walking distance* beyond. Following Brain, others have described near space as that within arm's reach (e.g., Berti et al., 2002; Cowey et al., 1994; Halligan, Fink, Marshall, & Vallar, 2003; Rizzolatti, Matelli, & Pavesi, 1983; Weiss, Marshall, Zilles, & Fink, 2003). The distinction between near and far space, however, may be less rigid (cf. Berti & Rizzolatti, 2002). For example, near space may be extended through the use of tools, and the transition from near to far space may be more gradual than abrupt. The present study examined these issues in neurologically healthy individuals.

1.1. Effects of tool use

Recent neurophysiological and neuropsychological findings have demonstrated that tool use affects space perception. Rizzolatti, Scandolara, Matelli, and Gentilucci (1981) described neurons in the monkey with visual RFs consisting of the space either immediately adjacent to tactile RFs (*pericutaneous*), or within arm's reach (*distant peripersonal*). Iriki, Tanaka, and Iwamura (1996) found that these RFs extend to include the space around a rake wielded by a monkey. Similarly, visual-tactile interference around the hand in human patients with cross-modal extinction extended to incorporate the space surrounding a wielded tool (Farnè & Làdavas, 2000).

Case studies of patients with neglect have also investigated effects of tool use on perception of near and far space. Berti and

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Frassinetti (2000) described a patient who showed left neglect (i.e., rightward bias) when bisecting lines with a laser pointer in near, but not far, space. However, when responding with a stick, neglect appeared in both near and far space. Berti and Frassinetti suggested that tool use, by extending the range of effective action, remapped near space, projecting neglect into far space. In contrast, Pegna et al.'s (2001) patient showed a rightward bias using a tool, but not a laser pointer, regardless of distance. These authors suggested that differential motor requirements, rather than extension of near space, might account for effects of tool use. Humphreys, Riddoch, Forti, and Ackroyd (2004) proposed, alternatively, that tools affect performance by drawing attention to neglected regions of space. Thus, while it is clear that tool use affects performance, it is less clear whether this represents extension of near space.

1.2. Transition from near to far space

Another sense in which near space may differ from Brain's (1941) conception is that the transition to far space may be more gradual than abrupt. The extent of peripersonal RFs from the skin varies widely. Fogassi et al. (1996), for example, found visual RFs ranging in extent from 5 to 35 cm from tactile RFs. Nevertheless, these visual RFs always remain within the monkey's reaching distance (Fogassi & Gallese, 2004). Thus, while there appears to be a gradient of neuronal responses coding (at a population level) the location of objects within reach, near space itself may terminate rather abruptly at the periphery of arm's reach.

Most studies of near and far space in human patients have presented stimuli at only two distances, making inferences about the transition between near and far space impossible. Two exceptions are studies by Berti et al. (2002) and Cowey, Small, and Ellis (1999). Berti et al. used three distances, finding more severe neglect beyond (1.5 and 3 m) than within arm's reach (.5 m). There was no difference in performance at 1.5 and 3 m, consistent with an abrupt shift between near and far space. In contrast, Cowey et al. (1999) studied five patients with greater neglect in near than far space at six distances, failing to find any abrupt shift at the distance of arm's reach. These results are difficult to interpret, however, since only one patient displayed what could be characterized as a continuous shift (Berti & Rizzolatti, 2002). The others displayed patterns consistent with abrupt shifts, but at different distances. When averaged, these data appear to indicate a gradual shift, potentially masking individual differences. Another interpretive problem with studies such as Cowey et al. (1999) is that, in controlling visual angle, progressively longer lines were presented at farther distances. Consequently, any effects of distance may actually be effects of line length. Indeed, neglect patients often bisect longer lines farther to the right than shorter lines (Marshall & Halligan, 1989; Tegnér, Caneman, & Levander, 1990).

The distinction between near and far space has also been examined in healthy adults using line bisection tasks. On standard versions, presented in near space, subjects demonstrate a slight leftward bias, known as *pseudoneglect* (Bowers & Heilman, 1980; see Jewell & McCourt, 2000 for review). While several studies have either failed to find effects of distance on pseudoneglect (e.g., Cowey et al., 1999; Weiss et al., 2000) or found only inconsistent effects (e.g., Cowey et al., 1994; Wilkinson & Halligan, 2003), three recent studies reported consistent rightward shifts in bias from near to far space (Bjoertomt, Cowey, & Walsh, 2002; McCourt & Garlinghouse, 2000; Varnava, McCarthy, & Beaumont, 2002). Varnava et al., unlike the other studies, presented lines at more than two distances, finding an apparent gradual shift. As with Cowey et al.'s (1999) study, however, these studies controlled visual angle, presenting longer lines at farther distances. Given that line length has been found to modulate pseudoneglect (McCourt & Jewell, 1999; Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990), these effects of distance are ambiguous. Indeed, Wilkinson and Halligan found less consistent distance effects when veridical size was controlled.

1.3. The present study

As described above, existing studies are ambiguous about two important issues: whether effects of tool use actually represent extension of near space and about the nature of the transition between near and far space (i.e., abrupt versus gradual). To examine these issues, healthy subjects in the present study bisected lines at four distances (controlled for both veridical and angular size) using either a laser pointer or a set of sticks. If modulation of bisection performance observed in previous studies reflects effects of near versus far space, a rightward shift in bias with distance was predicted on laser pointer trials. In contrast, if tool use extends the range of near space, no such shift was expected with the sticks; rather, a constant leftward bias was anticipated, comparable to that obtained with the laser pointer in near space. Alternate interpretations of the effects of tool use (e.g., Humphreys et al., 2004; Pegna et al., 2001) would not predict such an interaction. Furthermore, since more than two distances were used, abrupt versus gradual models of the transition from near to far space can be distinguished controlling both veridical and angular size.

2. Methods

2.1. Participants

Sixty students (35 female, 25 male), between 18 and 30 years, participated. All but one were right-handed as determined by the Edinburgh Handedness Inventory (Oldfield, 1971), *M*: 68.93; range: −26.3 to 100.

2.2. Stimuli

Lines of 2, 4, 8, 16, and 32 cm (1 mm in height) were used, centered on legal-sized paper attached horizontally to a wall, 156 cm above the floor. A subset of lengths was selected from three of the four distances – at 30 cm (2, 4 and 8 cm), 60 cm (4, 8 and 16 cm), and 120 cm (8, 16 and 32 cm) – such that the visual angle subtended by lines (3.82°, 7.54°, and 15.27°) was constant across distances.[1]

[1] Because of the line lengths used, no pairs of lengths allowed comparison between the 90 cm distance and any of the others when visual angle was controlled.

There were four sticks, one appropriate for each distance (49.2, 78.6, 104.3, and 121.8 cm). One end of each tapered to a point.

2.3. Procedure

Forty participants completed two blocks of 40 trials. In each block, participants used either the laser pointer or sticks to bisect lines at four distances (30, 60, 90, 120 cm). Order of distances and line lengths was randomized, and order of blocks was counterbalanced between participants.

The laser pointer was attached to the head of a tripod. Participants activated the laser pointer with their right hand and moved the head of the tripod with their left. Participants held the sticks in their right hand, which rested on the tripod. The tripod's height was adjusted for the participant's comfort. When participants determined their response, an experimenter (who, until then, remained behind the participant) marked it in pencil.

One concern about these procedures was that responses were right-handed with the sticks, but bimanual with the laser pointer. To control for this difference, an additional 20 participants were run in a unimanual condition using only their right hand to respond with the laser pointer (which was attached to the tripod such that it was always activated). These subjects completed 80 laser pointer trials; five lines of each length[2] were bisected at each distance.

For the last 44 participants, arm-length (right acromion to tip of middle finger) was measured after the experiment. Two coders measured bisection responses off-line, never disagreeing by more than .25 mm. Mean percent deviations were calculated for each subject for each combination of distance, and device-type (laser pointer and sticks).

3. Results

Analysis of variance revealed effects of distance, $F(3, 117) = 4.40$, $p < .01$, and device-type, $F(1, 39) = 12.91$, $p < .001$, and an interaction between distance and device-type, $F(3, 117) = 5.83$, $p < .001$. When the laser pointer was used – but not the sticks – a clear left to right shift in bias was observed with increasing distance (see Fig. 1, top panel). Planned contrasts revealed bias to be significantly farther to the right on laser pointer than stick trials at 60 cm, $t(39) = 1.90$, $p < .05$, 90 cm, $t(39) = 2.59$, $p < .01$, and 120 cm, $t(39) = 4.91$, $p < .0001$; but not at 30 cm, $t(39) = 1.14$, n.s. Analysis of a subset of line lengths controlling visual angle revealed similar effects of distance, $F(2, 78) = 2.64$, $p = .08$, device-type, $F(1, 39) = 7.88$, $p < .01$, and their interaction, $F(2, 78) = 5.21$, $p < .01$. A similar right to left shift in bias with increasing distance was also found for the unimanual control group, $F(3, 57) = 46.51$, $p < .0001$ (see Fig. 1, bottom panel). Bias in the two laser pointer conditions did not differ significantly at any distance, all $p > .05$, suggesting that the differences observed between the laser pointer and the tools were not due to differences in hand use.

Because similar effects of distance were observed in the bimanual and unimanual laser pointer conditions, they were collapsed for subsequent analyses. Arm length for every subject in which it was measured (44 of 60) fell between 60 and 90 cm (*M*: 69.8 cm, range: 60–80 cm). While the 30 and 60 cm distances are within arm's reach (since every subject's arm was longer than 60 cm), the 90 and 120 cm distances are outside arm's reach (since every subject's arm was shorter than 90 cm). Accordingly, an abrupt shift between mechanisms coding space within and outside arm's reach, would predict a shift only between 60 and 90 cm. While planned contrasts on laser pointer trials indicated such an effect, $t(59) = 2.97$, $p < .02$, rightward shifts were also observed from 30 to 60 cm, $t(59) = 3.24$, and 90 to 120 cm, $t(59) = 3.00$, both $p < .01$. Thus, distance modulated bisection performance between distances entirely within and entirely outside of arm's reach, as well as across this threshold. There were no significant shifts between any of these distances on stick trials.

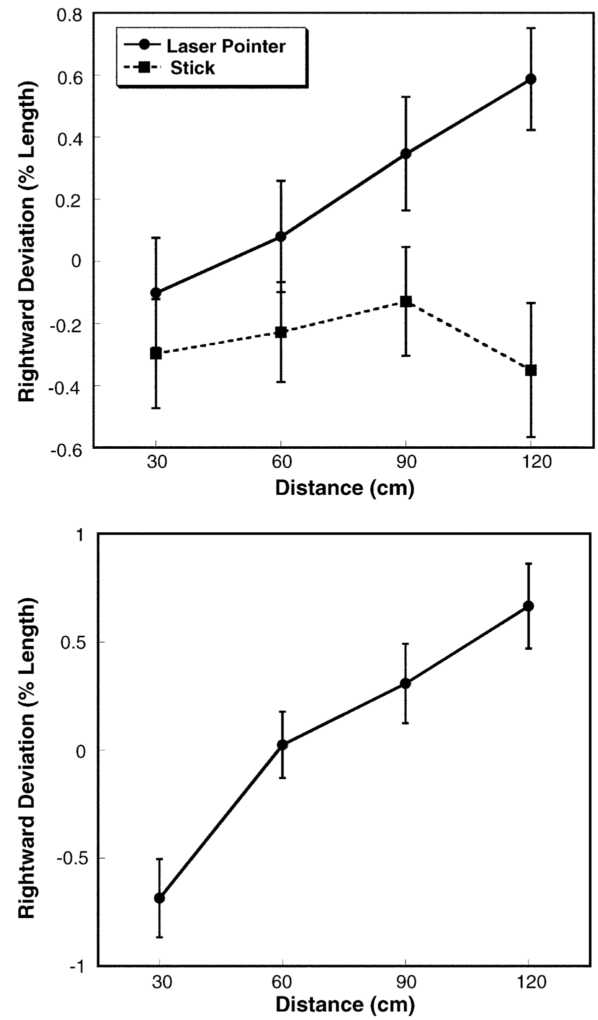

Fig. 1. Top panel. Mean rightward bias (percent of line length) on stick and bimanual laser pointer trials as a function of distance. Bottom panel. Mean rightward bias (percent of line length) on unimanual laser pointer trials. Error bars represent one S.E.M.

Effects of distance were further examined using contrast analysis. A contrast representing a linear shift with increasing distance (−3, −1, 1, 3) was compared with contrasts representing abrupt shifts between 30 and 60 cm (−3, 1, 1, 1), 60 and 90 cm (−1, −1, 1, 1), and 90 and 120 cm (−1, −1, −1, 3). The linear model provided the best fit, accounting for 99.6% of between-conditions variance, compared with 65.9%, 78.5%, and 55.1% for the abrupt models, respectively.[3] In contrast, the

[2] Lines of 2 cm were not used, as responses on these lines in the bimanual laser and stick conditions were found to be more variable than on longer lengths.

[3] The variance accounted for by the abrupt models is similar to what would be expected with a linear shift, as the linear model shares 60%, 80%, and 60% of the variance with the three abrupt models, respectively.

linear model accounted for less than 1% of variance on stick trials. Even when fit to individual subjects' data, difference contrasts indicated that the linear model provided a better fit than all three abrupt models, $t(59) = 2.44$, 2,72, and 3.28, respectively, all $p < .01$, ruling out the possibility that near space ends abruptly for each subject, but at different distances (cf. Berti & Rizzolatti, 2002).

4. Discussion

The present study examined two important issues concerning the nature of near space: whether wielding a tool expands the range of near space, and whether the transition to far space is abrupt or gradual. When subjects bisected lines with a laser pointer, a left to right shift in bias with increasing distance was observed, consistent with previous findings. Importantly, this shift occurred whether controlling for visual angle or veridical size, suggesting a modulating effect of distance per se. The shift was gradual, occurring within, beyond, and across the extent of arm's reach.

In contrast, there was no effect of distance when subjects responded with sticks. Rather, a constant leftward bias was observed, as if the lines were perceived as being in near space at all distances, consistent with Berti and Frassinetti's (2000) interpretation that tool use expands the range of near space. These data are inconsistent with two alternative explanations of effects of tool use. Pegna et al. (2001) suggested that differential motor requirements of the laser pointer and tools could account for performance differences. While a plausible explanation for their patient who manifested neglect when using a tool (but not a laser pointer) regardless of distance, it cannot account for an interaction between device-type and distance. Humphreys et al. (2004) showed that tool use improved neglect patients' performance in detection tasks by drawing attention to otherwise neglected spatial regions. It seems unlikely, however, that a similar benefit would occur in individuals without attentional deficits or with bisection tasks generally. Indeed, Berti and Frassinetti's patient performed worse in far space when using a tool than a laser pointer.

4.1. Why does distance modulate bisection performance?

Activation of each cerebral hemisphere, particularly regions in and around the intraparietal sulcus, biases attention contralaterally (Corbetta, Shulman, Miezen, & Petersen, 1995), a tendency stronger in the left than the right hemisphere (Kinsbourne, 1987; Làdavas, Del Pesce, & Provinciali, 1989). Coding of near space has been found to activate similar areas, particularly in the right parietal cortex (Bjoertomt et al., 2002; Fink et al., 2000). Thus, presentation of stimuli in near space may activate right parietal mechanisms for directed attention, biasing attention leftward and leading to pseudoneglect. On this interpretation, the relative leftward bias on bisection tasks indexes the degree to which representations of near space in the right posterior parietal cortex are activated. When a laser pointer is used, near space representations become gradually less active as the subject moves away from the stimulus, leading to a gradual left to right shift in bias since the orienting tendency of the left hemisphere (rightward) is stronger at baseline than that of the right hemisphere (leftward). When a tool is used, in contrast, near space representations are strongly activated at each distance and a constant leftward bias is observed.

As mentioned above, several studies failed to find effects of distance in healthy adults. Several factors may have contributed to these null results. Many of these studies tested a small number of age-matched control subjects, mostly in their 60 s, as part of clinical studies of neglect patients. Pseudoneglect has been found to decrease with increasing age (Jewell & McCourt, 2000), and it is unclear how this might influence changes with distance. Studies using young adults have generally found rightward shifts in bias with increasing distance (this study; Bjoertomt et al., 2002; McCourt & Garlinghouse, 2000; Varnava et al., 2002), the one exception being that of Weiss et al. (2000). This latter study, however, was conducted while subjects were undergoing PET scanning, which may have affected performance on the behavioral task.

4.2. On the nature of near space

The present results are inconsistent with the conceptualization of near space as consisting of the space within arm's reach. No abrupt shift was observed at or about arm's length; rather, there was a generally continuous shift as stimuli were moved farther away. These results make a great deal of sense given that the range of our arms does not place a categorical limit on our ability to act. Through movements of the torso or via locomotion, we can easily act at farther distances, though such actions are more effortful. Thus, the relatively abrupt shifts between near and far space observed in many neurophysiological studies may be due, in part, to monkeys being restrained in their seats during testing and, consequently, unable to act beyond arm's reach regardless of amount of effort (e.g., Fogassi et al., 1996; Rizzolatti et al., 1981). In these studies, arm's length places a discrete limit on the ability to act that does not exist when movement is not restricted. One intriguing possibility is that the strength of representations of near space may be in inverse proportion to the degree of effort required to act, and rather than being coded as the space within arm's reach, near space may be scaled as a ratio of arm's length.

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