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SHORT REPORT

How tool use and arm position affect peripersonal space representation

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Abstract Experiment 1 investigated whether tool use can expand the peripersonal space into the very far extrapersonal space. Healthy participants performed line bisection in peripersonal and extrapersonal space using wooden sticks up to a maximum of 240 cm. Participants misbisected to the left of the true midpoint, both for lines presented in peripersonal and for those presented in extrapersonal space, confirming a peripersonal space expansion up to a distance of 240 cm. Experiment 2 investigated whether arm position could influence the perception of peripersonal and extrapersonal space during tool use. Participants performed line bisection in the peripersonal and in the extrapersonal space (up to a maximum of 120 cm) using wooden sticks in two different conditions: either with the arm bent or with the arm stretched. Results showed stronger pseudoneglect in the stretched arm condition.

Keywords Peripersonal space · Extrapersonal space · Tool use · Arm position · Line bisection · Pseudoneglect

Introduction

Conscious perceptual experience of the surrounding space is unitary and integrated. Neuropsychological and behavioral studies, however, have shown that distinct brain and cognitive mechanisms are implicated in coding peripersonal space (within reaching; near) and extrapersonal space (beyond reaching; far). The peripersonal/extrapersonal distinction has been reported in studies on healthy participants, using the line bisection task. When required to bisect a visual line, healthy participants systematically misbisect to the left of the veridical midpoint in peripersonal space (pseudoneglect; Jewell and McCourt 2000). In contrast, healthy participants misbisect to the right of the midpoint, when they are required to perform line bisection in extrapersonal space (Bjoermont et al. 2002; Varnava et al. 2002). Nonetheless, the peripersonal/extrapersonal distinction may be modulated by tool use that can expand the peripersonal space into the extrapersonal space (Berti and Frassinetti 2000; Maravita et al. 2002). Recent line bisection studies have shown that, both in peripersonal and in extrapersonal space, a leftward shift to the veridical line midpoint is observed when participants perform bisection, by using a tool, which expands peripersonal space (e.g., a stick). In contrast, an overall rightward shift has been observed when participants perform bisection in the extrapersonal space, by using a tool that does not expand the peripersonal space (i.e., a laser pointer; Gamberini et al. 2008; Longo and Lourenco 2006).

In the present study, we conducted two line bisection experiments. Experiment 1 aimed to investigate how far tool use can expand the peripersonal space. Some studies have investigated whether the peripersonal space could be expanded by tool use beyond 120 cm (Neppi-Mòdona et al. 2007; Serino et al. 2007). Our aim was to investigate whether tool use might expand the peripersonal space up to 240 cm. Participants bisected lines using either a wooden stick at the distances of 60 and 240 cm or a laser pointer at the distances of 60, 240, 360, and 480 cm. We expected that participants would misbisect to the left of the midpoint using the laser pointer in the peripersonal space, but to the right of the midpoint in the extrapersonal space. In contrast,

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we expected that participants would constantly misbisect to the left of the midpoint using the sticks, both in the peripersonal and in the extrapersonal.

Experiment 2 investigated whether arm position, while participants were handling a tool, could influence the perception of the peripersonal and the extrapersonal space, as a function of having the participants' arms either stretched or bent during line bisection. We hypothesized that in the 'stretched arm' condition, the error on the left of the midpoint would be greater than that in the bent arm condition. Arms act mainly within functional regions of space to achieve actions. An object placed close to the arm may change its functional implications. Recent studies on healthy adults have shown that different positioning of the limbs may improve the perceptual and attentional processing of certain regions of space (Reed et al. 2006). The existence of bimodal neurons may explain the reason behind this phenomenon, since the perception of target stimuli could be amplified by the increased visual- and tactile-dependent activity of these neurons (Graziano and Gross 1994).

Experiment 1

Participants

Thirty participants with normal or corrected-to-normal vision took part in Experiment 1 (15 males; $M = 24.53$ years, $SD = \pm 3.63$ years, range = 20–34 years).

Materials

There was one viewing distance for the peripersonal space (60 cm) and three viewing distances for the extrapersonal space (240, 360, and 480 cm). Lines measured 8, 16, 32, 64, and 128 cm (height: 2 mm). Except for the 128 cm line that was printed in the center of a plastic panel, the other lines were presented in the center of white sheets of paper. Each sheet of paper was positioned in the center of a wooden panel attached to a mobile apparatus composed of a horizontal wooden base and a vertical bar. Two wooden sticks (lengths: 78.6 and 250 cm) were used for the participants to perform line bisection at the distances of 60 and 240 cm. The laser pointer was positioned in front of the chinrest, and it was mounted on the head of a tripod.

Procedure

Participants were seated in front of a table with their head positioned in a chinrest. They were required to bisect each line displayed at one of the four viewing distances. Participants performed two experimental blocks (stick, laser pointer). Each experimental block comprised 38 trials. The order of stimuli and the order of viewing distances were randomized. Block order was counterbalanced among participants. In the stick condition, participants were asked to put the far extremity of the stick on the bisection point. In the laser pointer condition, participants were asked to orient the laser pointer, which was mounted on the head of a tripod, to the bisection point. After each participant performed bisection, the experimenter marked the line at the point touched with stick or indicated with the laser pointer on each line.

Results

There were two independent variables [device (two levels: stick, laser pointer) and viewing distance (four levels: 60, 240, 360, 480 cm)]. The dependent variable was the mean difference between the observed midpoint and the true midpoint of the line. Positive values indicate shifts to the right of the true midpoint, whereas negative values indicate shifts to the left of the true midpoint. Data for repeated measures analysis, including devices and distances, were available only for the distances of 60 and 240 cm. First, a two-way analysis of variance (ANOVA) for repeated measures was conducted with Device (laser vs. sticks) and Distance (i.e., 60 cm vs. 240 cm) as factors. There was a significant main effect of Device $F(1, 28) = 9.08$, $p = .005$, indicating a mean bisection bias to the left of the midpoint when the stick was used ($M = -0.087$ % error), but a mean bisection bias to the right of the midpoint when the laser pointer was used ($M = 0.169$ % error). The main effect of Distance was also significant, $F(1, 28) = 11.88, p = .002$, showing a left to right shift when the laser pointer was used, during the transition from the peripersonal to the extrapersonal space (60 cm = −0.21 vs. 240 cm = 0.55). The interaction Device by Distance was significant, $F(1, 28) = 11.01, p = .003$. Paired comparisons revealed a significant difference between 60 and 240 cm, for the laser pointer, $t(29) = -4.73$, $p < .001$, whereas this difference was not significant for the sticks.

In the next analysis, only the laser pointer device and all distances (i.e., 60, 240, 360, 480 cm) were considered. A one-way ANOVA for repeated measures revealed a significant effect of Distance $F(3, 84) = 10.33$, $p < .001$. A repeated contrast showed that this effect was significant only between the distances of 60 and 240 cm, $F(1, 29) = 22.373$, $p < .001$ (see Fig. 1).

Experiment 2

Participants

Thirty participants with normal or corrected-to-normal vision took part in Experiment 2 (15 males; $M = 22.83$ years, $SD = \pm 6.65$ years, range = 20–29 years).

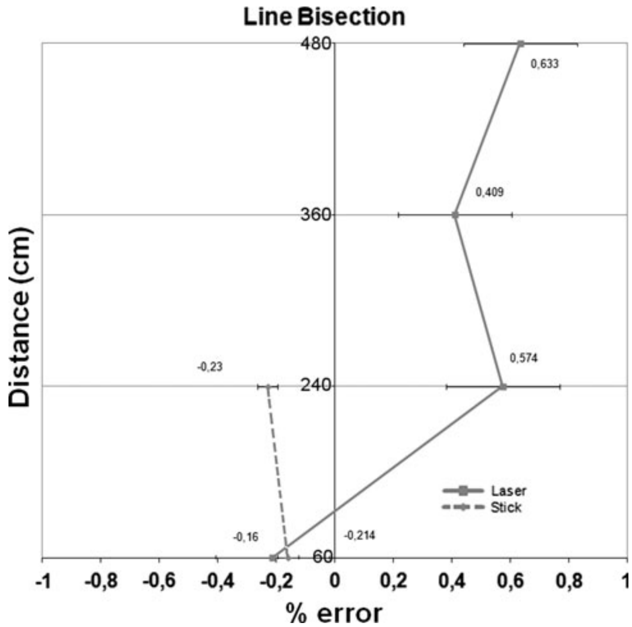

Fig. 1 The graph shows the mean percentage error (*X axis*) along the distances of line presentation, 60-, 240-, 360-, and 480 cm (*Y axis*) for the device used (laser vs. sticks). *Negative values* indicate an error to the left of the lines midpoint; *positive values* indicate an error to the right of the lines midpoint. *Error bars* represent the standard error of the mean (SE)

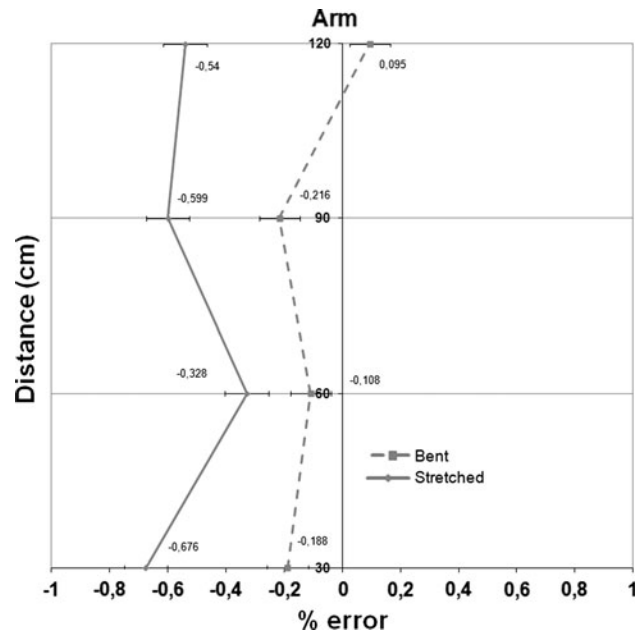

Fig. 2 The graph shows the mean percentage error (*X axis*) along the distances of line presentation (*Y axis*) for the arm condition (stretched vs. bent) in the 'stick' condition. *Negative values* indicate an error to the *left* of the lines midpoint; *positive values* indicate an error to the *right* of the lines midpoint. *Error bars* represent the standard error of the mean (SE)

Materials

There were two viewing distances for peripersonal space (30 and 60 cm) and two viewing distances for extrapersonal space (90 and 120 cm). Lines measured 2, 4, 8, 16, and 32 cm (height: 1 mm). Each line was centered on a white sheet of paper (width: 33 cm; height: 24 cm). Each sheet of paper was positioned in the center of a 50 by 50 cm white panel. For the 'bent' arm condition, participants used four wooden sticks (length: 49.2, 78.6, 104.3, and 121.8 cm) to perform line bisection at the four viewing distances (30, 60, 90, and 120 cm, respectively). For the 'stretched' arm condition, participants used two wooden sticks (length: 30 and 60 cm) to perform line bisection at the four viewing distances (30, 60 and 90 cm with the first one, and 120 cm with the second one).

Procedure

The procedure was the same as that of Experiment 1. There were two main blocks: arm bent block and arm stretched block. Each experimental block comprised 40 trials.

Results

There were two independent variables [arm (two levels: bent, stretched) and viewing distance (four levels: 30, 60, 90, 120 cm)]. The dependent variable was the same as that of Experiment 1. A two-way repeated measures ANOVA was conducted with Arm (bent vs. stretched) and Distance (60, 30, 90, 120 cm) as factors. There was a significant main effect of Arm $F(1,26) = 16.25$, $p < .001$, indicating a mean bias to the left of the midpoint in the 'bent' condition ($M = -0.555$ % error) and in the 'stretched' condition ($M = -0.172$ % error). The main effect of distance and the interaction Arm by Distance were not significant. Paired comparisons revealed a significant difference between 'bent' versus 'stretched' conditions at 30 cm, $t(29) = -2.63$, $p = .013$, and at 120 cm, $t(17) = -2.58$, $p = .015$ (see Fig. 2).

Discussion

Experiment 1 showed that when participants used a pointer laser, a stable shift to the right of the midpoint of the line was observed in extrapersonal space along the three distances used. In contrast, line bisection performance was characterized by a reliable leftward shift when participants performed bisection in the peripersonal space. These findings further corroborate the assumption that our representation of space can be divided into two main sectors: the peripersonal and the extrapersonal one. A tool, however, can modify this distinction, by extending the peripersonal space representation up to the limit of the tool handled. A constant shift to the left of the midpoint was present in peripersonal space and was also observed in the expanded peripersonal space (240 cm), when participants performed bisection using a stick. Thus, we report that peripersonal space can be expanded to extrapersonal space through tool use up to a distance of 240 cm. To the best of our knowledge, only one study has tested bisection in a farther distance than that of our study (300 cm; Neppi-Mòdona et al. 2007); they found a constant rightward bias both in peripersonal and extrapersonal space independently of the tool used (laser pointer vs. wooden sticks). Further research is required to determine the maximum distance up to which the peripersonal space can be expanded.

Experiment 2 showed an influence of arm position in the modulation of space perception, when participants performed bisection. The tool extended peripersonal space representation to the limit of the tool handled, both when the arm was bent and when the arm was stretched, with a constant bias to the left of the midpoint of the line along all the distances, as reported in the previous studies (Gamberini et al. 2008). When the arm was stretched, a larger leftward bias in the very near peripersonal space (30 cm) and in the very far extrapersonal space (120 cm) was present, partially confirming the initial hypothesis. Evidence that arm position can influence the perception of visual stimuli derives from crossmodal extinction studies with brain damaged patients (Làdavas et al. 2000). The registration of the electrical activity of individual neurons in the monkeys' premotor and posterior parietal cortex has shown evidence of visuotactile spatial interactions centered on the hand and relative to the hand position changes in space (Graziano et al. 1997). The combination of tactile stimulation of a body part and of the visual stimulation near that part can improve both visual and tactile perception.

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