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Processing of peripersonal and extrapersonal space using tools: Evidence from visual line bisection in real and virtual environments

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Abstract

The dissociation between peripersonal space (within reaching) and extrapersonal space (beyond reaching) has been reported in studies using the line bisection task in left neglect patients and in healthy participants. Furthermore, this dissociation can be modulated by tool use. We conducted two experiments to compare line bisection in peripersonal (i.e., 30, 60 cm) and extrapersonal space (i.e., 90, 120 cm). Healthy participants bisected visual lines using sticks and a laser pointer, according to the experimental paradigm of Longo and Lourenco [On the nature of near space: Effects of tool use and the transition to far space. *Neuropsychologia*, 44, 977–981, 2006]. In Experiment 1 participants performed line bisection in a real environment, whereas in Experiment 2 participants performed line bisection in a virtual environment. Results from both experiments revealed an abrupt midpoint shift from the peripersonal to the extrapersonal space but only when a laser pointer was used. In addition, we confirmed that peripersonal space can be extended to extrapersonal space when participants used a stick. Notably, virtual reality can be a useful technique for studying the dissociation between peripersonal and extrapersonal space and their interaction by means of tool use.
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1. Introduction

Spatial neglect (SN) is a general term referred to a variety of acquired neuropsychological disorders, affecting explicit processing of contralesional spatial information (or of the contralesional sector of a single object) following unilateral brain damage (see review in Halligan, Fink, Marshall, & Vallar, 2003). For instance, SN patients following right hemisphere damage fail to respond, report, or orient to stimuli in the left hemispace (Heilman, Watson, & Valenstein, 1979). The aforementioned signs of defective contralesional spatial processing are not due to elementary sensory or motor disorders since double dissociations between SN and hemianopia, hemianestesia, or hemiplegia have been reported (Bisiach & Vallar, 2000).

In clinical practice the assessment of left SN is of fundamental importance in order to measure its severity, to monitor its evolution in time and to plan effective rehabilitation and treatment. One of the most diffused assessment tests for left SN is line bisection. In this test, left SN patients are presented with a horizontal line segment. The midpoint of the line segment is aligned with the patient's body midline. The patient is asked to bisect (i.e., mark the midpoint) of the presented visual line segment. Typically, a rightward bias of the line midpoint is observed as if the leftmost portion of the line was missing or compressed. Halligan and Marshall (1988) observed that line bisection in left SN patients could be systematically influenced by the length of the presented line. More precisely, there was a positive correlation between line length, on the one hand, and the displacement of the subjective midpoint, on the other hand. Hence, the longer the line the larger the rightward displacement of the midpoint of the line. Nonetheless, for the shortest line length (i.e., 25 mm) a leftward displacement of the midpoint was observed. This paradoxical phenomenon is termed the "cross-over effect".

What defines the contralesional → ipsilesional continuum along which SN is observed (i.e., left → right in case of left SN)? In fact, SN can be based on distinct coordinate frames of references for the definition of spatial information. For instance, the contralesional → ipsilesional continuum could be described on the basis of various dimensions, along the radial meridian which,

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in turn, can be defined by personal coordinates (i.e., space occupied by the body), peripersonal coordinates (i.e., space that can be reached using the limbs), or extrapersonal coordinates (i.e., space beyond the peripersonal one, that can be described verbally or can be telecontrolled). Double dissociations have been reported between the processing of contralesional personal and peripersonal hemispace (Cocchini, Beschin, & Jehkonen, 2001; Guariglia & Antonucci, 1992) and between the contralesional peripersonal and extrapersonal hemispace (Barrett, Schwartz, Crucian, Kim, & Heilman, 2000; Cowey, Small, & Ellis, 1994; Halligan & Marshall, 1991; Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998). Finally, the study of Rizzolatti, Matelli, and Pavesi (1983) on monkeys showed that lesions to the postarcuate cortex (area 6) can cause neglect for the peripersonal space, whereas lesions to the prearcuate cortex (area 8) can cause neglect for the extrapersonal space.

Recent studies have suggested that tool use can modulate the borders between peripersonal and extrapersonal space. For example, Iriki, Tanaka, and Iwamura (1996) showed that the receptive fields of neurons that represent peripersonal space can be expanded to encode the space surrounding a tool held by a monkey. Similar findings have been reported in studies with brain damaged patients. For example, the peripersonal space can be extended around a tool when the tool is actively manipulated by patients with crossmodal extinction (Farnè & Làdavas, 2000). Furthermore, Berti and Frassinetti (2000) described a patient with SN (PP) who, using a laser pointer, misplaced the midpoint of the line to the right of the true midpoint, when line bisection took place in the peripersonal space. By contrast, the patient was more accurate when the same task took place in the extrapersonal space. However, when a stick was used, instead of the laser pointer, PP showed effects of neglect both in the peripersonal and in the extrapersonal space. These findings suggest that tool use can extend neglect from the peripersonal space to the extrapersonal one (see also Neppi-Mòdona et al., 2007).

The dissociation between peripersonal and extrapersonal space has been also investigated by means of the line bisection task in studies on healthy participants. When presented with lines located in the peripersonal space, healthy participants show a systematic displacement of the midpoint to the left, a phenomenon known as pseudoneglect (for a comprehensive review see Jewell & McCourt, 2000). Although some studies did not report an effect of distance (i.e., peripersonal vs. extrapersonal space) on pseudoneglect (Cowey, Small, & Ellis, 1999; Weiss et al., 2000), other studies reported a significant left-to-right shift of bisection, in the transition from the peripersonal space (i.e., mean shift to the left of the true midpont) to the extrapersonal space (i.e., mean shift to the right of the true midpont) (Bjoermont, Cowey, & Walsh, 2002; Longo & Lourenco, 2006; McCourt & Garlinghouse, 2000; Varnava, McCarthy, & Beaumont, 2002). The question whether the left-to-right shift is abrupt or gradual has been addressed by Longo and Lourenco (2006) and Varnava et al. (2002) who reported a gradual left-to-right shift of the bisection point in the transition from the peripersonal to the extrapersonal space.

The present study had two aims. First, we aimed to replicate the study of Longo and Lourenco (2006) in order to test whether peripersonal space can be extended to extrapersonal space either abruptly or gradually. Second, we implemented the study of Longo and Lourenco (2006) in a virtual reality environment to investigate whether virtual reality (VR) constitutes a valuable means for testing the dissociation between peripersonal and extrapersonal space. In the last 10 years VR confirmed to be a useful tool for the assessment and rehabilitation of motor disability and cognitive impairment due to central nervous system dysfunctions (Rizzo, 2006; Rose, Brooks, & Rizzo, 2005). Continuous decrease in costs along with strong effort on usability (Gamberini & Spagnoli, 2002; Rizzo, 2006), have contributed to the adoption of virtual reality in a wide spectrum of interventions in the domains of executive dysfunction (McGeorge et al., 2001), memory impairments (Brooks, Rose, Potter, Jayawardena, & Morling, 2004), learning disabilities (Brooks, Rose, Attree, & Elliot-Square, 2002), attention deficits (Rizzo et al., 2000), spatial neglect (Baheux, Yoshizawa, Seki, & Handa, 2006; Baheux, Yoshizawa, & Yoshida, 2007; Castiello, Lusher, Burton, Glover, & Disler, 2004; Glover & Castiello, 2006; Katz et al., 2005; Kim et al., 2007; Myers & Bierig, 2000), spatial learning in traumatic brain injury (Skelton, Bukach, Laurance, Thomas, & Jacobs, 2000), and neurodegenerative disease (Gamberini et al., 2006). VR offers the possibility to simulate interactive, three-dimensional environments and to precisely record and manipulate behavioural responses. Indeed, behaviour measurement in the virtual environment can be more precise and consistent. With reference to line bisection, for example, in real-word settings all measures are collected with a manual procedure and expressed in mm, whereas in the virtual setting measurements can be automatically collected and described on a more detailed scale (1/4 mm). Furthermore, VR provides a safe and ecological clinical setting in which patients can practice their skills with the support of computer systems (Standen & Brown, 2005). One of the many advantages of VR is the possibility to simulate complex settings that can be similar to those of everyday life. For example, extensive assessment and rehabilitation of neuropsychological patients can take place in an environment that is similar to that of their home, school, or working place.

2. Experiment 1: line bisection in a real environment

2.1. Methods

2.1.1. Participants

Sixteen participants with normal or corrected-to-normal vision took part in Experiment 1 (eight males and eight females; $M = 26.18$ years, S.D. = ±2.88 years, range = 21–30 years). All participants gave their informed consent to participate in the study. According to the Edinburgh Handedness Inventory (Oldfield, 1971), all but one of the participants were right-handed ($M = 69.90$, S.D. = ±42.78).

2.1.2. Apparatus and stimuli

The same stimuli and viewing distances were used as in Longo and Lourenco (2006). Single lines measuring 2, 4, 8, 16, or 32 cm (height: 1 mm) were displayed. Each line was centred on a white sheet of paper (width: 33 cm; height: 24 cm). Each sheet of paper was positioned in the centre of a 50 by 50 cm white panel.

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