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Motor resources in peripersonal space are intrinsic to spatial encoding: Evidence from motor interference

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ABSTRACT

The aim of this study was to explore the role of motor resources in peripersonal space encoding: are they intrinsic to spatial processes or due to action potentiality of objects? To answer this question, we disentangled the effects of motor resources on object manipulability and spatial processing in peripersonal and extrapersonal spaces. Participants had to localize manipulable and non-manipulable 3-D stimuli presented within peripersonal or extrapersonal spaces of an immersive virtual reality scenario. To assess the contribution of motor resources to the spatial task a motor interference paradigm was used. In Experiment 1, localization judgments were provided with the left hand while the right dominant arm could be free or blocked. Results showed that participants were faster and more accurate in localizing both manipulable and non-manipulable stimuli in peripersonal space with their arms free. On the other hand, in extrapersonal space there was no significant effect of motor interference. Experiment 2 replicated these results by using alternatively both hands to give the response and controlling the possible effect of the orientation of object handles. Overall, the pattern of results suggests that the encoding of peripersonal space involves motor processes per se, and not because of the presence of manipulable stimuli. It is argued that this motor grounding reflects the adaptive need of anticipating what may happen near the body and preparing to react in time.

1. Introduction

Humans represent the space near the body and within arm's reach (peripersonal) differently from the space farther away and beyond arm's reach (extrapersonal) (Berti & Frassinetti, 2000; Brain, 1941; Iachini, Ruggiero, Conson, & Trojano, 2009; Previc, 1998; Rizzolatti, Fadiga, Fogassi, & Gallese, 1997). Peripersonal space contains the objects with which one can act in the here and now. At neural level, this portion of space is subserved by a frontal–parietal network that integrates multisensory cues around the body for the guidance of action (Cardinali, Brozzoli, & Farnè, 2009; Cooke & Graziano, 2004; Farnè, Demattè, & Làdavas, 2005; Fogassi & Luppino, 2005; Rizzolatti & Matelli, 2003). Therefore, many authors define peripersonal space as an "action space" that offers a multisensory interface for body–object interactions (Brain, 1941; Brozzoli, Makin, Cardinali, Holmes, & Farnè, 2011; Makin, Holmes, & Ehrsson, 2008; Rizzolatti et al., 1997; Stein & Meredith, 1993). Some authors have highlighted the role of peripersonal space encoding in preserving body integrity (Graziano & Cooke, 2006). This space, defined as "safety buffer", has been conceived of as a protective buffer surrounding the body and prompting defensive behaviors against the intrusion of potentially threatening stimuli (Coello, Bourgeois, & Iachini, 2012; Graziano & Cooke, 2006; Holmes & Spence, 2004; see also Hall, 1966).

Both "action" and "safety" functions of peripersonal space imply motor processes or the simulation of a potential action toward a location (e.g., Coello & Delevoye-Turrell, 2007; Gallese, 2007; Rizzolatti et al., 1997). On the other hand, extrapersonal space has no immediate relevance for action in the here and now since objects located in this space cannot be reached without moving toward them. Extrapersonal space information is predominantly processed through the ventral visual stream and this suggests that the encoding of this space is more linked to visual–spatial mechanisms (Bjoertomt, Cowey, & Walsh, 2002; Coello et al., 2008; Previc, 1998; Weiss et al., 2000). Along this line, Bartolo et al. (2009) found that an object in extrapersonal space activates essentially visual areas such as the cuneus.

Much research has demonstrated that visual features of objects trigger the activation of motor simulation processes even in the absence of any intention to act (Anelli, Nicoletti, & Borghi, 2010; Borghi & Cimatti, 2010; Borghi et al., 2007; Chao & Martin, 2000; Craighero, Fadiga, Rizzolatti, & Umiltà, 1998; Creem-Regehr & Lee, 2005; Ellis & Tucker, 2000; Iachini, Borghi, & Senese, 2008; Jeannerod, Arbib, Rizzolatti, &

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Sakata, 1995; Tucker & Ellis, 1998, 2001, 2004; Umiltà, Brochier, Spinks, & Lemon, 2007). Coherently with the concept of affordance, i.e. the perception of object properties that afford actions such as the presence of a handle (e.g., Gibson, 1979; see also Humphreys, 2001), these findings highlight the power of the environment to provide the viewer with action possibilities (see also Tucker & Ellis, 1998, 2001).

Building on this literature, some studies have investigated the link between motor processes, object affordances and peripersonal space. Usually, in these studies participants have to give a response (e.g., classifying stimuli) by adopting either a power or a precision grip. This grip could be congruent or not with the grip evoked by the stimulus and when congruent facilitated the performance. This motor compatibility effect would demonstrate the involvement of motor processes (Olivier & Velay, 2009). For example, Costantini, Ambrosini, Tieri, Sinigaglia, and Committeri (2010) asked participants to replicate a seen grip, with the right or the left hand, on the presentation of a mug with the handle oriented toward their left/right (thus being congruent or not). The mug could be placed in participants' peripersonal or extrapersonal space and a semi-opaque screen was inserted in the peripersonal space that made the mug reachable or non-reachable. Participants were faster in the congruent condition only when the mug was in the peripersonal reachable space. Cardellicchio, Sinigaglia, and Costantini (2011) in a TMS study found higher motor evoked potentials when participants observed graspable objects in reachable space (with monkeys see Caggiano, Fogassi, Rizzolatti, Thier, & Casile, 2009).

In sum, this literature suggests that perceiving manipulable objects in peripersonal space implies an embodied motor simulation (Cardellicchio et al., 2011; Costantini et al., 2010; Ferri, Riggio, Gallese, & Costantini, 2011). Embodied motor simulation can be defined as a simulation of action possibilities with those objects based on previous bodily experiences (Barsalou, 1999; Gallese, 2005; for a review, see Iachini, 2011). Importantly, the kind of motor acts elicited by the observation of pictures of objects are specific, i.e. the common reaching and grasping actions we typically perform with them (Tucker & Ellis, 1998, 2001). However, the neural literature would suggest that motor resources are prompted as soon as a stimulus enters the crucial margin of peripersonal space (e.g. Rizzolatti & Matelli, 2003; Rizzolatti et al., 1997; Schieber, 2000). Therefore, just seeing non-manipulable stimuli could also activate motor resources, for example we prompt avoidance actions when a dangerous event, such as lightning or splinters of glass (clearly two non-manipulable stimuli), occur near our body (e.g., Huang, Chen, Tran, Holstein, & Sereno, 2012). Considering that objects and their positions are intrinsically linked, the question emerges as to whether the motor encoding of peripersonal space is triggered as soon as *whatever* stimulus enters the peripersonal margin or only when the object is actually manipulable (e.g., easy to grasp and use with one hand, i.e. a cup; Vingerhoets, Vandamme, & Vercammen, 2009). In other words, does peripersonal space encoding require the involvement of motor resources by itself or because it contains manipulable objects? In order to answer this question, we should disentangle the effects of motor resources on object manipulability and on spatial encoding processes in peripersonal and extrapersonal spaces. Consequently, an experimental paradigm with the following characteristics was devised: a spatial task to assess the processing of peripersonal vs extrapersonal space, manipulable and non-manipulable stimuli presented in peripersonal and extrapersonal spaces to discard the role of distance from that of stimuli, and a motor interfering condition to weigh the role of motor resources in those spaces and with those stimuli.

The spatial task consisted of giving right/left localization judgments of stimuli with respect to the body midline. In line with previous literature, the motor interference condition was obtained by comparing a condition with free arm vs a condition with arm blocked in the back. The effectiveness of this kind of motor interference was demonstrated in several studies (e.g., Sirigu & Duhamel, 2001; Stevens, 2005). For example, Stevens (2005) found an increase in motor imagery times when participants had their arm bent. Sirigu and Duhamel (2001) found similar results when participants had to imagine their own hands while holding their real hands in the back (see also Lotze & Halsband, 2006).

In the present study, once immersed in a virtual room participants had to locate manipulable and non-manipulable stimuli in peri-/extrapersonal spaces, with or without motor interference. Several studies have proved the reliability of immersive virtual reality technology as a tool for psychological research (Bailenson, Blascovich, Beall, & Loomis, 2003; Iachini et al., 2012; Ruotolo et al., 2013; Slater, 2009).

Consistent with the double-task paradigm of classic studies on working memory (e.g., Logie, 1995), an interference should occur when the main task shares the same resources with the interfering task. On the basis of the literature two hypotheses can be put forward: 1) if the spatial localization of stimuli in peripersonal space requires motor processes per se, then motor interference should affect the performance in peripersonal but not extrapersonal space, independent of the characteristics of stimuli (e.g., Rizzolatti & Matelli, 2003; Schieber, 2000); and 2) if motor resources are activated only when manipulable stimuli are actually reachable (e.g., Costantini et al., 2010), then motor interference should affect the spatial localization of manipulable (but not non-manipulable) stimuli in peripersonal space.

To verify which hypothesis was true, two experiments were carried out.

2. Experiment 1

In this experiment, participants had to judge if stimuli (manipulable or not) presented in peripersonal and extrapersonal spaces had appeared on their left or right in two conditions: a) arm free: participants responded with the left hand and had the right arm free; and b) arm blocked: participants responded with the left hand and had the right arm blocked. In order to highlight the motor aspects, the study was carried out on the basis of the following criteria: (1) only right-handed subjects were recruited; (2) only the dominant right arm was blocked; and (3) all manipulable stimuli with a handle had the handle oriented toward the right (see Fischer & Zwaan, 2008).

2.1. Material and methods

2.1.1. Participants

Forty right-handed participants (24 females, mean age = 25.35, SD = 3.00, range = 20–36) took part in the experiment. All participants had normal or corrected-to-normal visual acuity. The Edinburgh Handedness Inventory (Oldfield, 1971) was used to measure handedness (mean score = 90.7, SD = 3.2). Participants provided informed consent before taking part in the study.

Recruitment and testing were in conformity with the local Ethics Committee requirements and the 2008 Helsinki Declaration.

2.1.2. Setting and immersive virtual reality equipment

The experiment was carried out in the Laboratory of Cognitive Science and Immersive Virtual Reality (IVR), Department of Psychology, Second University of Naples (Italy). The IVR equipment includes the 3-D Vizard Virtual Reality Toolkit Devices for Integrated VR Setups and Position Tracking System. Virtual stimuli were presented through the nVisor SX (NVIS, USA) head mounted display (HMD) with two displays providing stereoscopic depth (approximately 30 times a second). The stereoscopic images ran at 1280 × 1024 resolution, and were refreshed at 60 Hz. The virtual scenario spanned 60° horizontally by 38° vertically. Graphics card used Vizard software (WorldViz, USA). Head orientation was tracked by a three-axis orientation sensor (InertiaCube3; Intersense, USA) and head position by a passive optical tracking system (Precision Position Tracker, PPT-E4; WorldViz, USA). Graphic modeling was created by 3D Google SketchUp 7.0 free-software. The IVR allowed participants to