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Manipulating time and space: Collision prediction in peripersonal and extrapersonal space

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ABSTRACT

Being able to predict potential collisions is a necessary survival prerequisite for all moving species. Temporal and spatial information is fundamental for this purpose. However, it is not clear yet if the peripersonal (i.e. near) and extrapersonal (i.e. far) distance between our body and the moving objects affects the way in which we can predict possible collisions. In order to assess this, we manipulated independently velocity and path of two balls moving one towards the other in such a way as to collide or not in peripersonal and extrapersonal space. In two experiments, participants had to judge if these balls were to collide or not. The results consistently showed a lower discrimination capacity and a more liberal tendency to predict collisions when the moving balls were in peripersonal space and their velocity was different rather than equal. This did not happen in extrapersonal space. Therefore, peripersonal space was particularly affected by temporal information. The possible link between the motor and anticipatory adaptive function of peripersonal space and collision prediction mechanisms is discussed.

1. Introduction

In everyday life we interact with moving objects and plan dynamic actions such as crossing a crowded road, catching a ball, avoiding a sliding rock, braking before crashing and so forth. These activities require the ability of locating and predicting the future course of moving objects to prompt avoidance or approaching actions at the appropriate time (Enns & Lleras, 2008; Senot, Prévost, & McIntyre, 2003; on time-pressure constraints see Wilson, 2002). From an adaptive point of view, this capacity is a fundamental survival prerequisite for all moving species and the ability to process spatio-temporal information is one of the earliest developing cues underlying this capacity (Flombaum, Kundey, Santos, & Scholl, 2004; O'Reilly, Mesulam, & Nobre, 2008; Xu, 1999).

Much research has explored the nature of perceptual information enabling to anticipate a possible collision between moving objects (Gray & Thornton, 2001; Zago & Lacquaniti, 2005). Behavioural studies have shown that this capacity is based on the processing of various types of information that physically describe the event (Eilan, Brewer, & McCarthy, 1993; for a review see Berthoz, 1997). The simplest parameter concerns the position over time of the object (Flombaum et al., 2004; Gilden & Proffitt, 1989; O'Reilly et al., 2008; Proffitt & Gilden, 1989). This parameter involves two kinds of information: the path covered in space and the velocity with which the object moves. The kind of information which is mainly used in collision judgments, spatial and/or temporal (Coull, Vidal, Goulon, Nazarian, & Craig, 2008; O'Reilly et al., 2008; Senot et al., 2003) or the ratio between the two (e.g. time-to-collision: Bootsma & Craig, 2003; Bootsma & Oudejans, 1993; Cavallo & Laurent, 1988; Lee, 1976; Regan & Hamstra, 1993; Schiff & Detwiler, 1979) has been widely investigated and is still debated (e.g. Andersen & Sauer, 2007; Li, Mo, & Chen, 2015; Tresilian, 1999).

Collision events may happen near or far from our body. However it has not been explored yet if the distance, peripersonal or extrapersonal, between our body and the moving objects affects the way in which we process information in order to predict possible collisions. Peripersonal space refers to the space surrounding our body where we can act in the here and now, whereas extrapersonal space refers to the far area beyond the reach of our limbs (e.g., Berti & Frassinetti, 2000; Brain, 1941; Previc, 1998; Ruggiero, Frassinetti, Iavarone, & Iachini, 2014). Behavioural evidence has shown that objects presented in peripersonal space, but not in extrapersonal space, automatically trigger action plans

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(e.g., Cardellicchio, Sinigaglia, & Costantini, 2011; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010; Iachini, Ruggiero, Ruotolo, & Vinciguerra, 2014). For this reason, many authors define peripersonal space as "action space" (Rizzolatti, Fadiga, Fogassi, & Gallese, 1997; Stein & Meredith, 1993).

At neural level, the representation of peripersonal space exhibits a high degree of multisensory integration in fronto-parietal areas (Cardinali, Brozzoli, & Farnè, 2009; di Pellegrino & Làdavas, 2015; Farnè, Dematté, & Làdavas, 2005). This sensorimotor integration has likely evolved for a better guidance of goal-directed and defensive actions towards objects (e.g., Cooke & Graziano, 2004; Fogassi & Luppino, 2005; Rizzolatti et al., 1987; for reviews Cléry, Guipponi, Wardak, & Ben Hamed, 2015; Coello & Iachini, 2015).

Some authors have highlighted the role of peripersonal space, as "safety buffer", in preserving body integrity (Graziano & Cooke, 2006). It would correspond to a protective buffer surrounding the body and prompting defensive behaviors against the intrusion of potentially threatening stimuli (de Vignemont & Iannetti, 2015; Graziano & Cooke, 2006; Hall, 1966; Holmes & Spence, 2004; Sommer, 1959). In line with this, Vagnoni, Lourenco, and Longo (2012) have shown that collision judgments of looming stimuli approaching observers were affected by their semantic content: threatening stimuli were judged as colliding sooner than non-threatening stimuli.

Therefore, organisms must pay particular attention to stimuli within their peripersonal boundary in order to act in time with positive stimuli or avoid in time negative stimuli (see Brozzoli, Makin, Cardinali, Holmes, & Farnè, 2011; Graziano & Cooke, 2006). This adaptive function would require the pre-activation of motor resources (e.g., Anderson, Yamagishi, & Karavia, 2002; Coello, Bourgeois, & Iachini, 2012; Phillips & Ward, 2002; Symes, Ellisa, & Tuckera, 2005). The majority of studies about peripersonal space have taken into account static stimuli whereas in everyday life we very often deal with moving stimuli. Therefore, the question arises: are the mechanisms underlying collision prediction ability affected by the peripersonal vs extrapersonal distance from the observer's body?

Aiming at exploring the nature of peripersonal space, in a previous study (Iachini et al., 2014) we have shown that participants were faster and more accurate in localizing both manipulable and non-manipulable stimuli in peripersonal, not extrapersonal, space with their arms free. This suggests that the encoding of peripersonal space, being necessary to react as more effectively as possible to near body events, has an intrinsic motor and anticipatory function (Coello & Iachini, 2015; Iachini et al., 2014). In other words, this function was elicited simply because the event was occurring near the body and not because of the characteristics of stimuli.

However, in that study we only used static stimuli. Here our aim was to investigate if and how the capacity to predict possible collisions is influenced by the space, peripersonal or extrapersonal, where the dynamic event occurs. We chose a collision judgment task because the capacity to predict possible collisions is fundamental to act appropriately with dynamic stimuli.

Usually, in collision studies experimental stimuli can move in depth towards the observer (e.g., Cavallo & Laurent, 1988) or in the fronto-parallel plane towards an external location (e.g., Rosenbaum, 1975; Tresilian, 1995). To compare events occurring in peripersonal vs extrapersonal space in relation to the observer, we chose the latter condition. Thus, we devised possible collision and non-collision events by varying the velocity and/or the path of two balls moving one towards the other in participant's frontal plane at two predetermined distances: 30 cm and 120 cm. The concept of path refers to the line in the space covered by a moving object and it is more linked to spatial aspects, whereas the velocity implies position changes according to "temporal" coordinates.

In two Immersive Virtual Reality (IVR) experiments, participants had to judge if two balls appearing in their peripersonal or extrapersonal space were to collide or not (Andersen & Kim, 2001; for a review on collision judgment tasks, Andersen & Sauer, 2007). If we assume that peripersonal space works like an anticipatory buffer to prepare timely reactions (Brozzoli et al., 2011; Coello & Iachini, 2015; Graziano & Cooke, 2006; Iachini et al., 2014; Ruggiero et al., 2016), then in some circumstances participants should be more prone to predict that collision events may occur in peripersonal than extrapersonal space. It has been shown that is more difficult to track the movements of two or more objects when they have different instead of same velocity (e.g., Fencsik, Klieger, & Horowitz, 2007; Pylyshyn, 2004). We may expect that when the spatio-temporal parameters that physically describe the event are more difficult to process, participants should be more prone to predict collisions. More specifically, we may expect a lower sensitivity to detect collisions and a more liberal response strategy in the peripersonal space when the two balls have different velocity. Indeed, in these cases predicting that a collision event will occur can help to prepare on time an adequate motor reaction.

2. Experiment 1

In this experiment, participants were presented with two balls that were left to drop at the exact same moment and the same height from the ground. The ball on the left moved downwards and to the right, whereas the ball on the right moved downwards and to the left. The balls could gain three velocities under three angles of fall that were combined in such a way as to generate four conditions: symmetric incident paths with the same velocity (Same-Velocity Same-Path), symmetric incident paths with different velocities (Different-Velocity Same-Path), non-symmetric incident paths with same velocity (Same-Velocity Different-Path), non-symmetric incident paths with different velocities (Different-Velocity Different-Path). Within each condition, the three velocities and the three angles determining the paths appeared the same number of times. We chose to combine only these physical parameters to control potential spurious factors due to unwanted covariance (Tresilian, 1995).

2.1. Method

2.1.1. Participants

Thirty-eight healthy right-handed participants (26 females, mean age = 25.05, SD = 3.25, range = 19–37) took part in the experiment. All participants had normal or corrected-to-normal visual acuity. The Edinburgh Handedness Inventory (Oldfield, 1971) was used to assess the handedness (mean score = 92.3, SD = 2.1). Participants were naïve to the purpose of the experiment and gave their informed consent. Recruitment and testing were in conformity with the local Ethics Committee requirements and the 2008 Helsinki Declaration.

2.1.2. Materials

The experiment was carried out by means of Immersive Virtual Reality devices (IVR; Laboratory of Cognitive Science and Immersive Virtual Reality of the University of Campania "Luigi Vanvitelli"). The IVR technology allows for keeping under control the parameters of the physical situation while reproducing the depth perspective of natural perception (see Iachini et al., 2012, 2016; for a review Zaal & Bootsma, 2011). The virtual environment was displayed through an nVisor SX (NVIS; Reston, VA) head mounted display (HMD). The HMD presented stereoscopic images at 1280×1024 resolution, refreshed at 60 Hz. The virtual scenario