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Cooperative tool-use reveals peripersonal and interpersonal spaces are dissociable

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ABSTRACT

The space surrounding people is often termed Interpersonal (IPS) in social psychology and Peripersonal (PPS) in neuroscience. In the current debate about their origin, the prevalent opinion is they share common functional characteristics. Bucking the trend, here we report a dissociation between PPS, operationalized as reachable space, and IPS, operationalized as comfort space. To probe their plasticity we introduced a novel type of cooperative long-tool-use that would modify both spaces. Results showed the estimated IPS referred to another individual was reduced, as expected following a positive social interaction. In sharp contrast, the estimated PPS toward the very same cooperative person was actually extended after use of the same long-tool. Control short-tool-use selectively reduced IPS, but not PPS, when performed in the same cooperative set or had no effect on either space estimation, when performed in a neutral set where the other person is not interacting cooperatively, but simply observing. The use of tools to perform actions in social settings allows us to report the first strong evidence that PPS and IPS underlie dissociable plastic representations: the former representation is sensitive to long-tool-dependent plasticity, whereas the latter representation, independently of use of a short or long tool, is sensitive to cooperation-dependent plasticity.

1. Introduction

Our sensorimotor and social interactions mostly occur within a limited area around the body. Although scholars from different fields had various visions about how this space is coded, the area surrounding our bodies is framed around two main representations: peripersonal space (PPS) and interpersonal space (IPS). PPS arises from the activity of multimodal neurons encoding the space surrounding different body-parts (Rizzolatti, Scandolara, Matelli, & Gentilucci, 1981; Brozzoli et al., 2014). Crucial for sensorimotor guidance of actions (Avenanti, Anella & Serino, 2012; Makin, Holmes, Brozzoli, Rossetti, & Farnè, 2009; Serino, Annella, & Avenanti, 2009), PPS is a plastic space, which may be extended by tool-use to the point where an individual is able to act (Berti & Frassinetti, 2000; Cardinali et al., 2009; Cardinali et al., 2012; Farnè & Làdavas, 2000; Maravita, Husain, Clarke, & Driver, 2001), also referred to as the reachable space (Maravita & Iriki, 2004; Occelli, Spence, & Zampini, 2011). However, human beings commonly perform actions in social contexts, where others are present and interacting to various degrees. Individuals reliably regulate a socially appropriate distance between each other, termed IPS, which typically extends to a point that, if crossed, causes discomfort (Hall, 1966; Sommer, 2002).

Several recent studies revealed that PPS is not only modified by using a long-tool, but also by social factors (Heed, Habets, Sebanz, & Knoblich, 2010; Teneggi, Canzoneri, di Pellegrino, & Serino, 2013), supporting the idea that PPS and IPS are tightly interwoven. Adopting an embodied perspective (Ferguson & Bargh, 2004), some scholars suggested these systems share common mechanisms regulating space around the body (Iachini, Pagliaro, & Ruggiero, 2015; Lloyd, 2009). Within this debate, we previously hinted at the possibility that there may not be full overlap between action and social space: the tool-use-dependent changes of the peer-referred PPS, as indexed by a Reaching-distance task, do not modify the IPS toward the same peer, as indexed by a Comfort-distance task

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(Patané, Iachini, Farnè, & Frassinetti, 2016). Yet, one may argue that IPS modulation was not observable because the classical tool-use manipulation was not "social" enough, since participants were left alone and required to reach for objects by themselves (Farnè, Iriki, & Ladavas, 2005). Stressing the sensorimotor body-objects interaction might have thus endorsed only PPS plasticity, whereas IPS plasticity may require a more social context to emerge.

Here we have overcome this limitation to more directly address the question of whether PPS and IPS may be considered as the two faces of the same coin, or not. As we frequently engage in cooperative behavior to coordinate our actions in space with those of conspecifics, we introduced a "social" tool-use setting, in which tools are not only bodily extensions, but become instruments for social cooperation. If PPS and IPS represent the same psychological entity, then cooperative tool-use should similarly impact reachable (PPS) and comfort space representations (IPS). More specifically, if a social dimension is necessary to unveil IPS changes, adding a social context to a conventional long-tool-use manipulation known to extend PPS could increase not only the reachable, but also the comfort space. The finding of a similar tool-use dependent remapping of both spatial representations would thus support the idea that PPS and IPS share common functional mechanisms. Alternatively, if the social dimension of long-tool-use triggers plasticity of two functionally distinct representations, a different scenario would be predicted: PPS estimates should increase because of tool-use-dependent sensorimotor plasticity, whereas IPS estimates should decrease because of tool-use-dependent social plasticity. This finding would instead support the alternative hypothesis that the two spatial representations are independent from each other. We tested these predictions in Experiment 1. Participants were engaged in a Reaching-distance and a Comfort-distance task to estimate respectively their PPS and IPS toward a male confederate, before and after having used a 70 cm-long tool to cooperate with the confederate. After finding evidence for differential changes of PPS and IPS following the use of a long tool in a social context, in Experiment 2 we investigated the effects induced by the use of a short tool in the same cooperative set. We predicted that plasticity due to the cooperative use of a short tool, which does not expand one's action capability, should affect perceived IPS, but not perceived PPS. Finally, to further assess the selectivity of social-tool-use effects, we also ran a control experiment. The question we addressed in Experiment 3 was whether cooperative interaction with another person is critical for any sensorimotor or social modulations of both spatial representations. In particular, neither PPS nor IPS changes were expected to occur when short tool-use is not cooperative.

A final goal of the present study was to explore the relationships between PPS and IPS and a series of factors potentially involved in the sensorimotor and social regulation of the space surrounding the body. The parallel reading of cognitive neuroscience and social psychology literature led us to select two variables of interest: actual length of the arm (Linkenauger, Bülthoff, & Mohler, 2015; Longo & Lourenco, 2007) and familiarity with the other individuals (Hayduk, 1983; Pedersen & Shears, 1974). Based on this literature, we hypothesized the perception of PPS to be influenced by actual arm's reach, whereas the perception of IPS should be influenced by the degree of perceived familiarity of the interacting person.

2. Experiment 1

The first experiment was conducted to assess the plastic effects of a novel version of a long-tool-use paradigm from a more social perspective. To this aim, we adopted two tasks to measure the individual-to-individual spatial relationships before and after a cooperative long-tool-use session. Participants were therefore engaged in a Reaching-distance and a Comfort-distance task, administered in two separate blocks, to estimate respectively their PPS and IPS toward a male confederate, before and after having used a 70 cm-long tool to cooperate with the confederate.

2.1. Method

2.1.1. Participants

Twenty healthy volunteers (9 women) were recruited for this study (mean age = 23 years, SD = 2.03 years, education = 15.90, SD = 1.17, see supplemental material for sample size estimation). They were all right-handed but three ambidextrous as assessed by the Edinburgh Handedness Inventory (mean = 58.72, SD = 20.24; Oldfield, 1971), and provided written informed consent before participating. The protocol was approved by the institutional ethics review board and conformed to the principles of the Declaration of Helsinki.

2.1.2. Procedure

All participants were tested individually in the same room. They performed a Reaching- and a Comfort-distance task to measure the estimated PPS and IPS between the participant and a male confederate actor. Next, participants underwent a cooperative tool-use session by using a 70-cm long rake, hereafter *long-tool,* to perform a task with the confederate. Then, the Reaching- and the Comfort-distance tasks were repeated with the same confederate. After completing the experimental post tool-use tasks, participants were asked to rate their perception of the tool-use session on several dimensions (i.e., easiness, pleasantness, positivity, cooperation, competition) and the perceived familiarity with the confederate. Moreover, the experimenter recorded the participant's length of the right arm (acromion to middle fingertip, with both arms outstretched at shoulder height). At the very end of the experiment, subjects were debriefed and thanked. None of the participants was suspicious about the real goal of the study.

A standardized appearance of the confederate was ensured across all sessions and all participants: the confederate had to wear the same neutral casual clothes and to maintain a neutral expression. Subjects and the confederate were not allowed to speak to each other for the whole experiment.

2.1.3. Experimental tasks

At the beginning of each trial, participants were positioned at a starting position with their toes on a line that was marked on the floor, while the confederate was located in front of them. The confederate looked straight at the participant's chin, avoiding any direct eye contact. Through the experimental tasks, participants stood with their arms extended along their trunk and were instructed to close their eyes between each trial. In the Reaching-distance task, participants were required to move at a natural gait speed toward the confederate and stop themselves at the distance they thought they could reach the other person by extending their arm. Instead, in the Comfort-distance task they were asked to move toward the confederate and to stop themselves at the shortest distance they would feel comfortable with the other's proximity. In either task, subjects could fine-tune the distance by moving slightly further backward or forward. Finally, they closed their eyes and the chest-to-chest distance at the sternum level was measured with a digital laser meter (Agatec, model DM100, error ±0.3 cm). Then participants opened their eyes and came back to their initial position for the following trial. The Reaching- and Comfort-distance tasks were administered in separate blocks of 10 trials per task. The order of blocks was counterbalanced between participants. Within each task, the initial distance between the two partners varied randomly across trials. In half of the trials the confederate was located at a distance of 3.5 m from participant,