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SHORT REPORT

Embodied perception of reachable space: how do we manage threatening objects?

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Abstract This study aimed at determining whether the size of reachable space is affected by the level of danger of some everyday manipulable objects. Two possibilities are examined: Dangerous objects affect the size of reachable space because of long-term semantic knowledge of their potential hurtful value or the on-line relation between objects' dangerous attributes and the body. The experimental paradigm combined the danger value (dangerous/not dangerous) and the orientation of objects (e.g. pointing away from/towards the perceiver). Reachability judgments measured the size of peripersonal space, and perception of objects' danger was estimated through questionnaires. Results revealed that, whatever the estimated level of objects' danger, the extent of peripersonal space was reduced when the threatening part of dangerous objects was oriented towards participants, not when oriented away. This suggests that the characteristics of the here and now body-objects interaction are crucial in affecting the boundary of peripersonal space.

Keywords Visual perception · Reachability · Dangerous objects · Embodiment

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Introduction

Peripersonal space is the portion of space that surrounds the body and is within arm reaching (Rizzolatti et al. 1997; Stein and Meredith 1993). Being able to perceptually delimiting peripersonal space is critical since peripersonal space contains the objects with which one can interact in the here and now, specifies our private area during social interactions and encompasses the obstacles or dangers to which the organism must pay attention in order to preserve its integrity (Holmes and Spence 2004; Graziano and Cooke 2006). Peripersonal space is differentiated from extra-personal space at both a conceptual and neurophysiological level (Bartolo et al. 2009; Coello and Delevoye-Turrell 2007; Previc 1998). When looking at a target-object in the environment, near-space information is predominantly processed through the dorsal visual stream, whereas far-space information is predominantly processed through the ventral visual stream (Milner and Goodale 1995).

In the past, several studies have shown that people are quite accurate in visually delimiting their peripersonal space. Reachability estimates were found to correlate with actual action possibilities, though depending on the environmental context, the emotional state, the postural constraints and even the presence of mental or neurological illness (for a review Delevoye-Turrell et al. 2010). The perception of reachable space was thought to involve a motor-based perceptual system combining visual variables with motor-related information. Conceptually, motor-related information may enable the anticipation of action consequences and, in turn, this capacity might represent the mechanism underlying the evaluation of action feasibility and the distinction between reachable and non-reachable objects (Coello and Delevoye-Turrell 2007; Jeannerod 2006; Witt and Proffitt 2008). Although the perception of reachable space is mainly determined by properties of the body and action system (Coello and Delevoye-Turrell 2007), objects' characteristics such as their level of danger may also have an influence (Dosey and Meisels 1969; Felipe and Sommer 1966). Indeed, when you have to grasp a sharp knife, you are careful because of the potentially dangerous blade, but this does not happen with a rubber globe. Can the different danger value and alleged action requirements of objects modify the perception of what is reachable?

Here, we compare two possibilities. Dangerous objects may affect the size of reachable space because of long-term semantic knowledge of their potential hurtful value. This would be in line with the literature showing that the vision of objects automatically activates their relevant sensorimotor information (for a review Fischer and Zwaan 2008). The other possibility is that the on-line relation between objects' dangerous attributes and the subject makes a difference.

The experimental paradigm proposed here manipulates the danger value (dangerous and not dangerous) and the orientation (pointing away from or towards the participant) of objects. The comparison of these conditions would allow us to verify the following hypotheses: (1) If semantic knowledge of objects' characteristics is dominant, then a main effect dangerous/not dangerous should appear; (2) if the on-line relation between the object and the participant is dominant, then an interaction dangerous/not dangerous and orientation towards/away should appear.

Method

Participants

A total of 13 right-handed participants (6 females, mean age: 22.30 years, mean score at the Edinburgh Inventory Test: 0.89, mean arm length: 72.30 cm which corresponded to an actual maximum reachable distance with the right hand of 61.5 cm) were self-declared volunteers and gave their informed consent prior to their inclusion in the experiment. This research was performed in agreement with the local ethical committee guidelines and in accordance with the principles of Helsinki declaration.

Apparatus and stimuli

Eight manipulable real-world objects were selected for the experiment: 4 had a potential threatening side (dangerous objects: syringe, scissors, box cutter, cork screw) and 4 had no threatening side (not-dangerous objects: bottle of spices, torch light, highlighter, remote control, see Fig. 1b). Top-view coloured pictures of these objects were taken by means of a professional camera on a white background and were then used as stimuli. All objects had the same physical size (17 cm long) while projected by a video projector (Hitachi LCD, with a 60" projection size and a 1,400 × 1,050 pixels resolution) on the top surface of the experimental apparatus. The latter consisted of a rectangular box (58 cm high, 200 cm wide and 150 cm deep) with the inside divided horizontally by a (80 × 120 cm) mirror (see Fig. 1a). Due to the convex mirror projection system, the video projector placed above the rear side of the experimental apparatus allows the projection of a (150 × 180 cm) image on the top surface consisting of a translucent Procolor projection screen (150 × 200 cm). The image was thus reflected by the mirror and participants could see a projected image of the stimuli on the table in front of them. The experimental room was dark so that to avoid irrelevant environmental visual information.

Procedure and data analysis

The objects were presented in two orientations: with the non-dangerous functional side (e.g. the bulb of a torch) and the dangerous side (e.g. the needle of a syringe) pointing towards or away from the subject's body. All objects were presented along 29 distances (range 29–75 cm from the front side of the experimental box, at 1.64 cm steps). After a training session, subjects were presented with the stimuli, one at a time. Stimuli remained on the screen until participants decided whether they were reachable or not by pressing with their left-hand one of two computer keyboard keys (see Fig. 1a). The right hand was kept stationary on the lower surface of the apparatus, at a distance of 17 cm from the body. After the response, a blank appeared (1.5 s) and the next stimulus was presented. The order of presentation was completely randomised. We used a repeated-measure design. The combination of all factors gave rise to 464 trials for each participant (8 objects × 2 orientations × 29 locations). At the ending of the experimental session (lasting about 30 min), there was a post-experimental debriefing. Participants had to rate the degree of caution and danger associated with objects on a 10-point scale (1: not caution/not dangerous at all to 10: much caution/very dangerous). The questions were as follows: 1–2) Imagine somebody passing you an object like this (dangerous part oriented towards or away). How much caution do you need? (3) Look at the object while presented horizontally. How much dangerous does it look? (4) Imagine you are using the object. How much caution do you need?

Perceived boundary of reachable space was determined from reachability judgments, using a maximum-likelihood fit procedure based on the second-order derivatives (quasi-Newton method) to obtain the logit regression model that

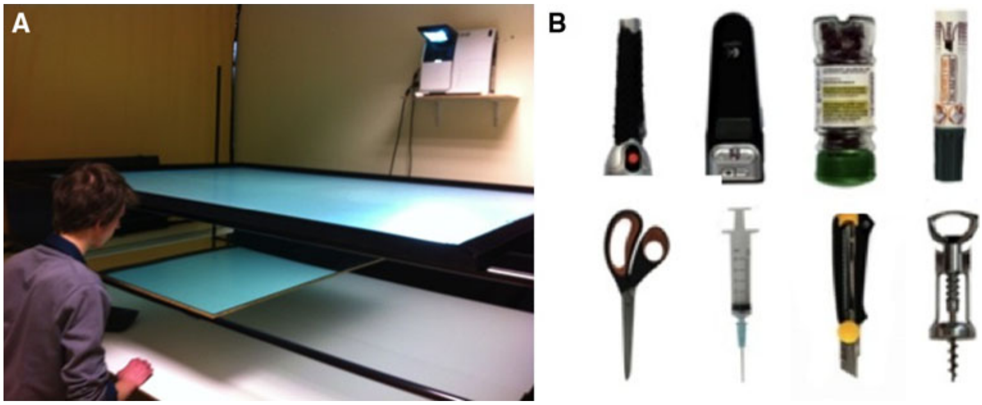

Fig. 1 **a** Experimental apparatus and (**b**) objects used in the experiment. Participants sat in front of the apparatus with their forehead resting on the *top level* of the apparatus (screen) and looked at the mirror the image coming from the screen and projected through it at the *bottom level* of the apparatus. The *right hand* remained still while performing the reachability judgment task and reachability estimates were provided on the computer keyboard using the *left hand*. Objects were displayed on the screen one at a time and at 29 different distances ranging from 29 up to 75 cm from the *front side* of the experimental box

best fitted the reachable/unreachable responses of the participants for the 29 positions of the target, using the equation: $y = e\ (\alpha + \beta\ x)/(1 + e\ (\alpha + \beta\ x))$, in which y was the participant's response, x corresponded to the distance, $(-\alpha/\beta)$ was the critical value of x at which the transition from one type of response (reachable) to the other type of response (unreachable) occurred, thus expressing the perceived maximum reachable distance.

Results

Perception of the degree of required caution and danger Figure 2 presents the averaged value obtained during the post-experiment interview. Data were analysed using a parametric bootstrap method (Efron and Tibshirani 1993) to obtain the 95 % confidence intervals of the cumulative Gaussian functions after running 2,000 simulations. Analysis revealed that among dangerous objects, two were considered as really dangerous (syringe and box cutter) and two were considered as less dangerous (scissors and cork screw). Dangerous objects were perceived as more dangerous when oriented towards participants (mean: 6.42), though scissors and cork screw (mid-dangerous objects, mean: 4.65, 95 % CI [3.65/5.57]) less than syringe and cutter (dangerous objects, mean: 8.19, 95 % CI [7.3/9.03]), than when oriented away from participants (mean: 2.67, with 95 % CI [1.57/2.46] and [2.57/4.15], respectively, for mid-dangerous and dangerous objects, see Questions 1 & 2). Not-dangerous objects were not affected by their orientation (respective means: 1.36 (towards) and 1.17 (away), with 95 % CI [1.13/1.65] and [1.00/1.40]). Finally, the level of danger for dangerous and mid-dangerous objects was not different when evaluating an interactive situation (Question 1, mean: 6.42, 95 % CI [5.57/7.21]), the intrinsic danger (Question 3, mean: 5.90, 95 % CI [4.90/6.88]) or the required caution (Question 4, mean: 5.29, 95 % CI [4.40/6.13], see Fig. 2a).

Perception of reachability Reachability judgements were analysed using a 3 (dangerous, mid-dangerous, not-dangerous objects) X 2 (threatening part oriented towards or away) repeated-measure ANOVA, and standard Student's *t* test for post hoc pairwise comparisons. Data for dangerous, mid-dangerous and not-dangerous objects were pooled for statistical analysis (see Fig. 2b). Average boundary of reachable space was located at 51.28 cm (SD: 9.97 cm) away from the location of the right hand, which corresponded to an overestimation of on average 9.9 % of the actual limit of reachability. We found an interaction between the two factors ($F(2,24) = 5.24$, $p <= .01$). It was due to the fact that orienting the threatening part towards participants produced a reduction in perceived reachable space for both dangerous (50.74 cm, SD: 10.25 cm) and mid-dangerous (50.18 cm, SD: 9.74 cm) objects as compared to not-dangerous objects (51.77 cm, SD: 10.11 cm, with $t(24) = 2.50$, $p = .01$ and $t(24) = 3.86$, $p < .01$). This difference was not observed when comparing the objects categories with the threatening part away from the participant (respectively, 51.53 cm (SD: 11.07 cm), 51.89 cm (SD: 10.07 cm) and 51.60 cm (SD: 10.49 cm), with $t(24) = 0.16$ and $t(24) = 0.71$, both $p > .05$).

Discussion and conclusion

The aim of this study was to determine whether the size of reachable space is affected by the level of danger of some

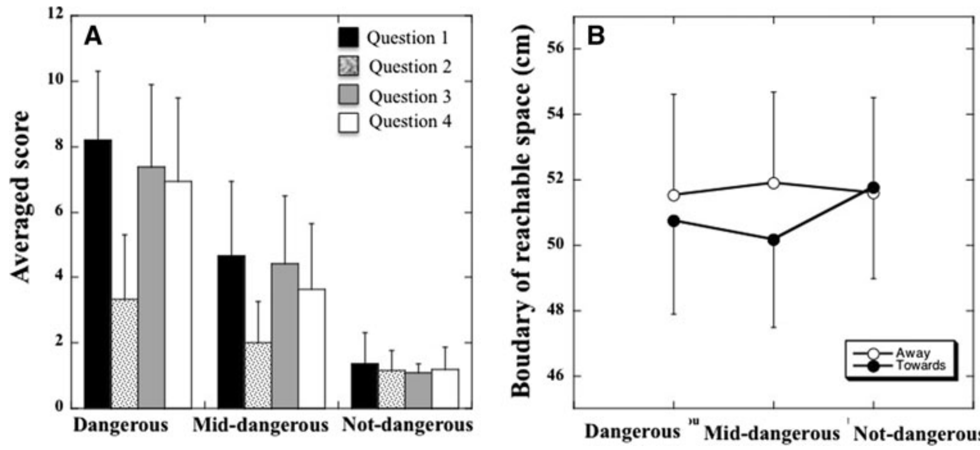

Fig. 2 **a** Averaged scores obtained in Questions 1–4 during the post-experiment interview and **b** averaged perceived boundary of reachable space as a function of the objects category (dangerous, mid-dangerous, not dangerous) and the orientation of the objects (towards, away)

everyday manipulable objects. An influence could be expected since the perception of reachable space seems to be linked to a simulation of action possibilities (see Coello and Delevoye-Turrell 2007; Costantini et al. 2012), and actions are shaped by the anticipation of their consequences (see Hommel 2009; for a review Iachini 2011). By combining the dangers value and the orientation of objects in relation to the perceiver, we tried to understand at which level the simulation processes are triggered: at an abstract level of semantic knowledge or at a more basic level based on the on-line relation between body and object.

Results revealed that the extent of peripersonal space was reduced by 1.25 cm on average when the threatening part of dangerous objects was oriented towards the participants, not when oriented away. Furthermore, perceived boundary of peripersonal space was located at the same distance when comparing dangerous objects with the threatening part oriented away from the participants with not-dangerous objects. This suggests that the characteristics of the here and now body-objects interaction is crucial in affecting the boundary of peripersonal space and, from a more theoretical perspective, highlights the situated and embodied character of encoding of space (see Barsalou 2008).

However, as suggested by post-experiment Questionnaires, the level of danger was dependent on the object considered. Indeed, when oriented towards the participant, some objects were perceived as highly dangerous (syringe and box cutter), whereas some others were perceived as less dangerous (scissors and cork screw) or minimally dangerous (all not-dangerous objects). Thus, objects with a threatening side are viewed as a potential danger for the organism along a continuous scale. Interestingly, danger assessment was not influenced by whether the object was evaluated in an interaction context (Questions 1–2), or according to pure semantic knowledge (Questions 3 and 4). Thus, it seems that, when questioned about objects' danger value, participants referred mainly on knowledge of objects' semantic.

By contrast, reachability estimates of dangerous objects varied in a similar way, whatever the danger score attributed to them. This suggests that the effect of dangerous objects on the extent of reachable space is due more to the implicit reproduction of hurtful consequences of acting with objects than to abstract knowledge of their characteristics. Therefore, the results seem to imply that the simulation processes underlying perception of reachable space involve a simulation of the consequences of action for the safety of the individual, whereas pure semantic knowledge about how to use an object seems not sufficient to alter the boundary of peripersonal space, though useful for categorising dangerous and not-dangerous objects. This evidence is in line with the idea that peripersonal space has both a safety value and an action value (Làdavas and Serino 2008).

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