Multisensory Conflict yields Adaptation in Peripersonal and Extrapersonal Space

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Abstract. Spatial representations are acquired through active interaction with the environment and are based on a multisensory integration mechanism that combines visual, tactile and proprioceptive information. The weighting of different modalities depends on their reliability and changes from peripersonal to extrapersonal space. In a virtual reality setup we investigated whether conflict between visual and proprioceptive information regarding the hand position yields adaptation of spatial representations. Our results show a stronger bias towards the manipulated visual information for localizations in extrapersonal space. The data is consistent with the assumption that peripersonal space is more strongly grounded in proprioceptive than visual information, compared to extra-personal space.

Keywords: Spatial Perception, Peripersonal Space, Virtual Reality

1 Introduction

Active interaction with the environment shapes the way we perceive the space around us and internal models used to predict action outcomes originate from these interactions [1]. Each motor command provides a variety of visual, tactile, proprioceptive and acoustic sensations, which are integrated into a coherent percept by means of a maximum likelihood integrator [2]. Especially for the immediate space around the body - the so-called peripersonal space - the close relation between motor codes, vision and proprioception has been shown [5]. Hence, the internal representation of peripersonal space is not defined in terms of a Cartesian metric, but in terms of sensorimotor functionality. With increasing distance from the body, the weighting of visual and proprioceptive information in the spatial representation changes. Longo & Lourenco [4] could show that the representation of extrapersonal space is dominated by visual information. This transition in the weighting of visual and proprioceptive information is continuous and scales with arm-length.

To investigate the weighting of information and how the spatial representations are formed during sensorimotor interactions, an active manipulation of the mapping between modalities is required. Classic methods to introduce multisensory conflict - like the rubber hand illusion - require participants to remain motionless. Virtual reality (VR) setups offer a possible solution. We manipulated the mapping between visual and proprioceptive hand position to investigate whether the integration of the conflicting sensory information yields adaptation of spatial representations. Participants had to perform a bimanual task during which the visual hand representation was shifted, resulting in a correction of the actual hands, to maintain the target position in the VR. The mismatch between proprioception and vision should yield an adaptation in the representations of peri- and extrapersonal space, which we measured via localization tasks in near and far space. We expected stronger mislocalizations for the far space since it should be adapted according to the manipulated visual impression. To further explore the role of visual saliency, we hid the virtual hand models during the localization in half of the trials.

2 Method

Participants. 33 students from the University of Tübingen participated in the study (22 males). Their age ranged from 18 to 30 years (M = 21.7, SD = 2.5). Participants were told a cover story to keep them naive to the purpose of the study. After the experiment, participants were debriefed and offered the opportunity to withdraw their data.

Virtual Reality Setup. Participants were equipped with an Oculus Rift © DK2 stereoscopic head-mounted display. Hand motions were captured with a Leap Motion © near-infrared sensor, placed 30cm in front of the participants on a table. The VR scenario put participants in a static mountain scenery, with a basket at the outer right corner of their reachable task space. During the experiment a flower spawned at the center of the scene and participants had to pick the petals and put them into the basket (see Fig. 1, panel A).

Fig. 1. Panel A: Object interaction task. Panel B: Self-Localization, diamonds indicate palm and thumb centroids, respectively. Panel C: External Localization, diamonds indicate palm and index finger centroids, respectively.

Procedure. In each trial, participants had to perform three tasks. First a localization, second the object interaction during which the visual offset was applied to the hand model, finally they repeated the localization task. The experiment consisted of two blocks, each consisting of 12 trials.

Localization. Participants had to locate themselves and an external reference within the scene by pointing to the reference with both hands. For the self-localization, participants were instructed to point with the tip of their thumbs to themselves. In case of the external reference, participants were instructed to point at the basket with their index fingers. The two types of localization are displayed in Fig. 1 (panel B and C). The experiment was divided into two blocks. In one block, the hand model was displayed during the localization, while it was hidden in the other block.

Object Interaction. After the initial localization was accomplished, a flower bloomed in the center of the scene. Participants were instructed to pick as many petals as possible and to put them into the basket. In order to so, they had to grab the stem with the left hand and to pick the petals with the right hand (see Fig. 1, panel A). During task the offset between visual and felt hand position was introduced. The offset was introduced gradually and only while the hands were moving. Participants complied with the task in general, collecting 4.5 petals on average per trial (SD = 1.4).

Design. To test systematic effects on the localization performance, we used a 2 $\times$ 2 design with the factors visibility (hand visible during localization or not) and reference (pointing towards external reference or towards self). We derived three dependent measures for the quantitative analysis. The *palm drift* refers to the difference between the hand centroid in the pre- and post-localization and indicates adaptation of the spatial representations of the hands. A shift in hand position does not necessarily lead to mislocalization, the *angular disparity* quantifies the adaptation of the hand rotation from the the pre- to the post-localization which compensate possible drifts. To assess changes in the actual localization, the *positional discrepancy* is the difference between the positional estimates in the pre- and post-localization.

3 Results

Data were analyzed with 2 (hand visibility) $\times$ 2 (positional reference) repeated measure ANOVAs. Results are displayed in Fig. 2. For all variables, main effects for hand visibility and reference were obtained, the respective interaction was only significant for the *angular disparity.* For all conditions and measures, means differed significantly from zero, the only exception being the positional discrepancy in case of invisible hands and self-localization.

4 Discussion

We dissociated visual and the proprioceptive hand position in a VR setup and tested whether the introduced dissociation affected localization performance. To manipulate the saliency of visual and proprioceptive information, we let the participants perform the localization task either with visible, or invisible virtual hands. The data implies that participants stuck to the shifted center of their

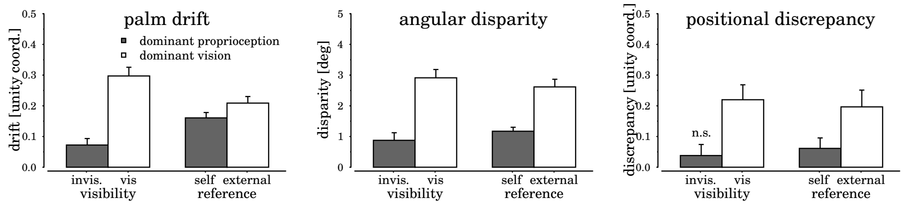

Fig. 2. Main effects for hand visibility (left) and localization reference (right). Both main effects are significant for all measures. Bars with gray background indicate conditions where the localization relied more on proprioceptive information. All means differed significantly from zero, except in case of positional discrepancy and invisible hands (this condition is marked with "n.s."). Please note that the scale for angular disparity indicates angles in degrees, while for the two other measures, the y-axis represents units in Unitys' coordinate system.

hands, but partially compensated this shift by an according rotation of their palms in the localization tasks. Results with respect to the positional discrepancy show how the participants adapted their location estimate in a systematic way, reflecting the introduced visual offset. The only exception was the combination of invisible hands and self-localization - the most proprioceptive condition so to say.

Our results show how multisensory conflict yields adaptation of the spatial representation of far space and, to a smaller degree to an adaption of the self-localization. The results dovetail with earlier work that showed a different weighting of proprioceptive and visual information in peripersonal and extrapersonal space [3]. Furthermore, the results highlight the dynamic nature of spatial representations. Earlier studies have shown the fast remapping of peripersonal space in case of tool-use, our results extend these findings by showing the remapping of ego- and allocentric frames of reference due to sensorimotor interaction.

Active manipulation of spatial representations in VR allows to study aftereffects on spatial reasoning and spatial compatibility effects. This will provide an even deeper understanding how spatial representations are rooted in the sensorimotor system and how they affect higher cognitive functions.

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