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The role of visual similarity and memory in body model distortions

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ABSTRACT

Several studies have shown that the perception of one's own hand size is distorted in proprioceptive localization tasks. It has been suggested that those distortions mirror somatosensory anisotropies. Recent research suggests that non-corporeal items also show some spatial distortions. In order to investigate the psychological processes underlying the localization task, we investigated the influences of visual similarity and memory on distortions observed on corporeal and non-corporeal items. In experiment 1, participants indicated the location of landmarks on: their own hand, a rubber hand (rated as most similar to the real hand), and a rake (rated as least similar to the real hand). Results show no significant differences between rake and rubber hand distortions but both items were significantly less distorted than the hand. Experiments 2 and 3 explored the role of memory in spatial distance judgments of the hand, the rake and the rubber hand. Spatial representations of items measured in experiments 2 and 3 were also distorted but showed the tendency to be smaller than in localization tasks. While memory and visual similarity seem to contribute to explain qualitative similarities in distortions between the hand and non-corporeal items, those factors cannot explain the larger magnitude observed in hand distortions.

1. Introduction

There is probably no more familiar object to us than our own body. This might give rise to the impression that we know our body better than anything else. This impression partly comes from the fact that we receive constant and immediate sensory information about our body. A single glance at one's hand and we know its location in space as well as its relative proportions with other limbs (e.g., the hand is smaller than the arm). Consequently, it seems natural to assume that we have an accurate perception of the size and shape of our body and its parts. However, multiple studies indicate the presence of systematic distortions in the perception of bodily proportions (Linkenauger et al., 2015; Longo & Haggard, 2010, 2011, 2012; Saulton, Dodds, Bülthoff, & de la Rosa, 2015). Those distortions were demonstrated in visual estimations tasks (Linkenauger et al., 2015; Longo & Haggard, 2012) as well as in tactile and localization tasks (Longo & Haggard, 2010, 2011). In this study, we are particularly interested in better understanding the origin of the distortions measured in localization tasks (Longo & Haggard, 2010).

Localizing one's body in space is important for perception and action (Frith, Blakemore, & Wolpert, 2000). For instance, one needs to know the location of one's hand in order to grasp objects (Frith et al., 2000). Research suggests that localization judgments related to our body parts are based on the combination of proprioceptive signals (e.g. joint angles) and stored representation of body size and shape (van Beers, Sittig, & van der Gon, 1998; Longo & Haggard, 2010; Soechting, 1982). This stored representation of the body metric properties, referred to as the body model, was measured in a localization task for the hand (Longo & Haggard, 2010). Participants were asked to point towards the felt location of their occluded finger tips and knuckles. By analyzing the spatial configuration of the felt locations of the finger tips and knuckles, implicit maps of hand shape were created. Those maps showed large distortions of hand shape. This pattern of distortion was characterized by an overestimation of hand width and an underestimation of finger length.

Interestingly, distortions of hand shape measured in localization tasks matched those found in tactile size perception of the hand (Linkenauger et al., 2015; Longo & Haggard, 2011; Weber, 1996). Hand distortions measured in localization tasks were consistent with anisotropies characterizing the hand's tactile acuity and receptive field geometry (Longo & Haggard, 2010, 2011). Hand distortions were therefore interpreted as retaining "vestigial traces of the primary somatosensory homunculus of Penfield" (p. 11729, Longo & Haggard, 2010).

However, there is no direct evidence that hand distortions in the localization task are due to somatosensation. Particularly, the localization

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task does not involve tactile perception, as the hand is not touched during the experimentation (see method in, Longo & Haggard, 2010; Saulton et al., 2015). As such, there may be no direct link between anisotropic tactile sensitivity of the hand and hand shape distortions measured in localization tasks.

Indeed, localization tasks distortions were not limited to the hand and appeared to generalize onto certain types of objects, particularly in the case of a rake (Saulton et al., 2015) Distortions measured on the rake item were more similar to the one found on the participant's hand than on other objects depicting square and rectangular shapes. Although the amount of distortion was significantly smaller on the rake than on the hand, it was also characterized by an overestimation of the width axis compared to a large underestimation of the length. The purpose of the present paper is to better understand why distortions would be more similar across a rake and a hand than across a hand and other geometrical objects. We will explore both body and non-body related factors that might account for these results.

We explored whether an item's visual similarity to a real hand was behind the greater performance similarity between the hand and the rake. Due to structural similitudes between the hand and the rake (e.g. five fingers/five tines), it could be that participants partly matched the representation of their hand onto the stored spatial representation of the rake. Hand shapes are more familiar to participants than tools. Hence, matching strategies could be used in localization task as an attempt to improve one's performance in the localization task. If this is the case, an object with greater visual similarity to a real hand (e.g. a rubber hand) might depict distortions that are closer to the hand than the rake. This idea would be in line with research on embodiment showing that objects can be experienced as part of one's body (i.e. as embodied) when they share important structural and visual information about the body part (Bertamini & O'Sullivan, 2014; Holmes, Snijders, & Spence, 2006; Tsakiris, Carpenter, James, & Fotopoulou, 2010; Tsakiris & Haggard, 2005). Studies on the rubber hand illusion suggest that the degree to which fake body parts (rubber hand and non-biological mechanical hand) can be embodied depends on the similarity between the actual body part and the tested stimulus. For instance, embodiment of a rubber hand is facilitated and obtained to a larger degree compared to a non-biological hand made of wires (Bertamini & O'Sullivan, 2014). Although embodiment mechanisms are unlikely to occur in the localization task (no visuo-tactile stimulation applied onto the participant's hand and the tested stimulus), one cannot exclude the possibility that greater visual similarity between an item and a real hand contribute to an increase in localization task distortions. This aspect was investigated in experiment 1 by comparing participants' estimates of landmarks located on a rubber hand, a rake and the participants' hand in a localization task.

Alternatively, the similarity in localization task distortions between the hand and rake might be explained by non-body specific factors. Previous work suggests the presence of viewer-centered biases and immediate vision on hand distortions in localization tasks (Longo, 2014; Saulton et al., 2015). In line with these ideas, people might also partially rely on a general form of memory (e.g. spatial memory) that is not directly related to proprioception. Overall, memory distortions have been observed in multiple studies, from tasks involving the recollection of stories or experienced events (Bartlett, 1932; Nourkova, Bernstein, & Loftus, 2004) to psychophysical experiments measuring object size perception, localization and distance estimations on maps and figures (Cooper, Sterling, Bacon, & Bridgeman, 2012; Huttenlocher, Hedges, Corrigan, & Crawford, 2004; Tversky, 1981, 1992; Tversky & Schiano, 1989). For instance, distances stored in memory between entities of the same categories (cities on map) are perceived relatively smaller compared to distances between entities of different categories (Tversky, 1992). Semantically, fingers often constitute a separate body part category (Enfield, Majid, & Van Staden, 2006). Hence, memory biases related to finger categorization could explain why underestimation of finger length compared to hand width were found in localization tasks (Longo, Mancini, & Haggard, 2015; Mattioni & Longo, 2014). To assess whether memory of distances between landmarks can create the distortions measured on items in the localization task, we ran a second experiment. In experiment 2, we asked participants to indicate on a line, the memorized distance between landmarks marking the finger/branches length and width of the hand, the rake and the rubber hand. We compared the ratio of length over width distortions obtained in this distance memory task (experiment 2) with the same length to width ratio calculated in localization task (experiment 1) for the same items.

In order to investigate whether the distortions measured on the participant's hand in the distance memory task can be behaviorally dissociated from distortions coming from the somatosensory feeling associated with one's own hand, we ran a third experiment. In experiment 3 participants indicated on a line, both the memorized and the felt distance between landmarks on their hand. Different results between the felt and memorized distance conditions of experiment 3 would favor the hypothesis that memory information about hand parts can be dissociated from information related to the somatosensory feelings associated to the hand.

2. Experiment 1

In experiment 1, we investigated the extent to which the similarities between the item and the participant's hand modulate the distortion measured in the localization task. In order to measure the contribution of visual similarity on the items' distortions, it is important to choose stimuli that gradually increase in visual similarity with a hand: a rake which only had a similar structure to a real hand; a rubber hand which had the structure and the visual configuration/form of a real hand and the participant's own hand. We used typical localization task methods (Longo, 2014; Longo & Haggard, 2010, 2012; Saulton et al., 2015) to estimate the relative distance between 10 predefined landmarks on the hand, the rubber hand and the rake. We then compared the aspect ratio of the hand with the ones from hand-like items (rake and rubber hand). If the magnitude of the distortions increases with the items visual similarity to a real hand, the difference in distortions between the participant's hand and the rubber hand should be smaller than the one obtained with the rake. In other words, the estimated shape of the rubber hand should be more distorted than the rake.

Before starting the main experiment, we ran a pilot study to assess whether individuals ($N = 16$; age $M = 28.8$) judged the rubber hand to be perceptually more similar to the real hand compared to the rake. Participants were seated at a table and items were presented separately in front of them in a random order, for 30 s each. After each item presentation (the rake, the rubber hand and their own hand) participants had to rate how similar the item was to a real hand on a continuous interval scale from 0 to 10. Participants had to answer the question: How similar is this item to a real hand in terms of visual appearance? 0 corresponded to "the item is not at all similar to a real hand" and 10 corresponded to "the item is exactly like a real hand". Both the rubber hand [$M = 8$; $SD = .77$; $t(15) = -10.32$; $p < .001$; $r = .93$] and the rake [$M = 3.81$; $SD = 1.98$; $t(15) = -12.48$; $p < .001$; $r = .95$] were rated as differing from a real hand [$M = 10$; $SD = 0$] in terms of visual similarity. More importantly, participants considered the rubber hand to look significantly more like a real hand than the rake [$t(15) = 7.78$; $p < .001$; $r = .89$]. Thus, the visual similarity to the hand significantly increased from the rake to the rubber hand.

2.1. Method

2.1.1. Participants

Sixteen right handed individuals (5 males) between 20 and 34 years of age ($M = 24.5$) participated in the localization task. Participants gave written informed consent prior to the study. The research was approved by the ethics committee of the University of Tübingen.