RUNNING HEAD: Seeing the Body Distorts Tactile Size Perception

Seeing the Body Distorts Tactile Size Perception

Matthew R. Longo and Renata Sadibolova

Department of Psychological Sciences, Birkbeck, University of London

Address Correspondence to:

Matthew R. Longo

Department of Psychological Sciences

Birkbeck, University of London

Malet Street

London WC1E 7HX

m.longo@bbk.ac.uk

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Abstract

Vision of the body modulates somatosensation, even when entirely non-informative about stimulation. For example, seeing the body increases tactile spatial acuity, but reduces acute pain. While previous results demonstrate that vision of the body modulates somatosensory sensitivity, it is unknown whether vision also affects metric properties of touch, and if so how. This study investigated how non-informative vision of the body modulates tactile size perception. We used the mirror box illusion to induce the illusion that participants were directly seeing their stimulated left hand, though they actually saw their reflected right hand. We manipulated whether participants: (a) had the illusion of directly seeing their stimulated left hand, (b) had the illusion of seeing a non-body object at the same location, or (c) looked directly at their non-stimulated right-hand. Participants made verbal estimates of the perceived distance between two tactile stimuli presented simultaneously to the dorsum of the left hand, either 20, 30, or 40 mm apart. Vision of the body significantly reduced the perceived size of touch, compared to vision of the object or of the contralateral hand. In contrast, no apparent changes of perceived hand size were found. These results show that seeing the body distorts tactile size perception.

Both vision and somatosensation provide important sources of information about our body. Therefore, combining multisensory inputs is critical to perceiving the properties and current state of the body. Recent results have demonstrated widespread effects of vision of the body on somatosensation, even when entirely non-informative about stimulation, for example by enhancing tactile spatial acuity (Kennett, Taylor-Clarke, & Haggard, 2001) and reducing pain (Longo, Betti, Aglioti, & Haggard, 2009). Such results show that seeing the body can increase the sensitivity of somatosensory processing, or alter perceived intensity of somatosensory stimuli. But does vision also *distort* touch, altering its perceived metric properties? Here, we addressed this question, investigating how vision of the body affects the perceived size of tactile stimuli applied to the seen body part.

How might vision of the body distort tactile size perception? Intriguingly, two sets of considerations lead to opposite predictions. Weber (1834/1996) originally noted that the perceived distance between two tactile stimuli is larger on skin regions with relatively high sensitivity compared to those with lower sensitivity, an effect now known as *Weber's illusion* (Taylor-Clarke et al., 2004). Since seeing the body increases tactile sensitivity (Kennett et al., 2001), it is thus natural to hypothesize that this should lead to a corresponding increase in the perceived size of tactile stimuli. Indeed, this was our initial hypothesis. There is, however, another set of considerations which point in the opposite direction, suggesting that reduced tactile sensitivity can be associated with increased perceived size of the body and of touch. For example, cutting off afferent signals from a body part with local anesthesia increases the perceived size of that body part (Gandevia & Phegan, 1999; Türker, Yeo, & Gandevia, 2005) as well as the perceived size of objects held in the affected body part (Berryman, Yau, & Hsiao, 2006). Similarly, chronic pain often produces both reduced tactile sensitivity on the affected body part (Pleger et al., 2006; Moseley, 2008), as well as perceived swelling (Moseley, 2005, 2008; Pelz et al., 2011). In the case of both anesthesia and pain, *reduced* tactile sensitivity is associated with *increased* perceived body part size. Vision of the body, then, could be expected to produce exactly opposite effects: since seeing the body enhances tactile sensitivity it should reduce the perceived size of the body and also shrink the perceived size of tactile stimuli

We investigated this question using the mirror box illusion (Ramachandran, Rogers-Ramachandran, & Cobb, 1995) to induce the subjective experience of direct vision of the stimulated left hand, while simultaneously keeping vision non-informative about stimulation. In Experiment 1, participants made verbal judgments of the distance between two touches applied to the dorsum of their left hand, while looking into a mirror aligned with their body midline, with their hands symmetrically on either size of the mirror. The reflection of their right hand, thus appeared to be a direct view of their left hand, yet provided no information about the size of touch. In control conditions, participants looked at the mirror reflection of a non-hand object or at their non-stimulated right hand. To anticipate our results, we found that seeing the body reduces the perceived size of touch. In Experiment 2 we replicated this finding and additionally added a measure of perceived hand size before and after each block, finding no apparent change in any condition.

Methods

Participants

Fifty-eight individuals (37 females) between 18 and 72 years of age participated, 30 in Experiment 1 and 28 in Experiment 2. Participants were right-handed as assessed by the Edinburgh Inventory (Oldfield, 1971; *M*: 91.3).

Materials and Procedure

Participants sat at a table in front of a mirror aligned with their body midline (see Figure 1). Velcro disks on the table (20 cm on either side of the mirror) indicated where the index finger of each hand should be placed. There were three visual contexts: (1) in the *View Stimulated Hand* condition, participants looked into the mirror at the reflection of their right hand, which appeared to be a direct view of their stimulated left hand; (2) in the *View Object* condition, participants looked into the mirror at the reflection of a black box (13x7x7 cm) appearing at the same location; and (3) in the *View Other Hand* conditions, participants looked directly at their right hand. Participants wore a black smock preventing peripheral vision of their left arm. A black board across the table from the participant occluded their view of the experimenter's movements.

Figure 1

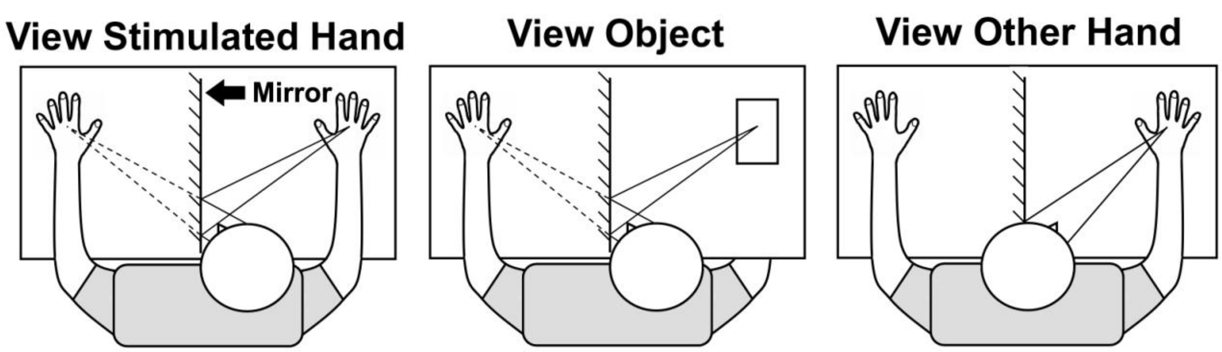

Figure 1: Schematic depictions of the three experimental conditions. The task-relevant tactile stimuli were always delivered to the left hand behind the mirror. In the View Stimulated Hand and View Object conditions, participants looked into the mirror, seeing the reflection of their right hand or a non-hand object. In the View Other Hand condition, participants looked directly at their right hand.

Tactile stimuli were pairs of wooden posts mounted in foamboard, separated by 20, 30, or 40 mm, as in our previous study (Longo & Haggard, 2011). Each post tapered to a blunt point

(~1 mm width). Stimuli were applied to the dorsum of the left hand for approximately one second. Participants made verbal estimates (in mm) of the perceived distance between the two touches. Participants were told that they were free to give a response of 0 mm if they perceived only one touch. Seven participants (two in Exp 1, five in Exp 2) preferred to respond in inches, which were converted to mm offline. Stimuli were oriented either medio-laterally (*across* the hand) or proximo-distally (*along* the hand). There were six experimental blocks. The first three blocks included one block of each context, counterbalanced according to a Latin square. The last three blocks were performed in the reverse order. Each block consisted of six repetitions of each combination of size (20, 30, 40 mm) and orientation (along, across) in random order, yielding 36 trials per block and 216 overall. Z-scores were calculated for each trial, separately for each of the three stimulus sizes. Trials with Z-scores greater than +/-3 were excluded as outliers (0.39% and 0.30% of trials in the two experiments).

Because participants felt the stimuli, but did not see them applied to the left hand, this could produce perceptual conflict in the View Stimulated Hand condition. To avoid this, a white cube (13x5x5 cm) was applied by the experimenter to the dorsum of the right hand (in the View Stimulated Hand and View Other Hand conditions) or object (in the View Object) condition, approximately time-locked to the application of the task-relevant stimulus on the left hand. Though the bottom of the cube was smooth, participants could not see this, making the visual stimulus equally consistent with any of the tactile stimuli applied to the left hand.

After each block, a questionnaire concerning subjective experiences of the mirror box illusion was given verbally (see Figure 2), similar to the ones we have used in previous studies (Longo et al., 2009; Mancini et al., 2011). For Items 1 and 2, participants rated their agreement using a 7-point Likert scale (+3 = strongly agree, -3 = strongly disagree, 0 = neither agree nor disagree), though they could give any intermediate value. Positive values indicated overall agreement, and negative values overall disagreement. Item 3 asked participants to rate the intensity of their percept using a scale, in which 0 indicated a strong left hand percept, 100 a strong right hand percept, and 50 ambivalence. Items 2 and 3 were not administered following the View Object condition, because they would not have made sense.

In Experiment 2 we obtained measures of perceived hand length and width using a slider apparatus similar to that used by Mancini and colleagues (2011). A thin dowel was attached to a 30 cm ruler with a blue pin at one end and a disc that slid along the length of the dowel. The experimenter moved the disc at a constant speed and the participant indicated when the distance between the disc and the blue pin matched the felt length (distance between centre of wrist and knuckle of middle finger) or width (distance between knuckles of index and little fingers) of their unseen left hand. Eight responses were collected immediately before and after each block, consisting of two repetitions of each combination of judgment of hand width or length and of increasing (disc started at pin) and decreasing (disc started at opposite side of dowel) judgments. A photograph was taken of each participant's left hand next to a ruler to allow coding of actual hand dimensions[1].

Results

Illusion Questionnaire

Questionnaire results are shown in Figure 2. Participants reported agreement with item 1 in both the View Stimulated Hand (Exp 1: $t(29) = 2.37$, $p < .05$; Exp 2: $t(27) = 5.85$, $p < .0001$), and View Other Hand (Exp 1: $t(29) = 30.54$, $p < .0001$; Exp 2: $t(27) = 26.70$, $p < .0001$), conditions, but significant disagreement in the View Object condition (Exp 1: $t(29) = -13.26$, $p <$

.0001; Exp 2: $t(27) = -16.81$, $p < .0001$). Participants reported agreement with item 2 in both the View Stimulated Hand (Exp 1: $t(29) = 11.03$, $p < .0001$; Exp 2: $t(27) = 14.65$, $p < .0001$), and View Other Hand (Exp 1: $t(29) = 30.87$, $p < .0001$; Exp 2: $t(27) = 43.43$, $p < .0001$) conditions. Finally, participants reported experiencing seeing a left hand in the View Stimulated Hand condition (Exp 1: $t(29) = 4.02$, $p < .0005$; Exp 2: $t(27) = -3.76$, $p < .001$), but seeing a right hand in the View Other Hand condition (Exp 1: $t(29) = 23.07$, $p < .0001$; Exp 2: $t(27) = 27.30$, $p < .0001$). Thus, the mirror box successfully created the experience of direct vision of the stimulated left hand.

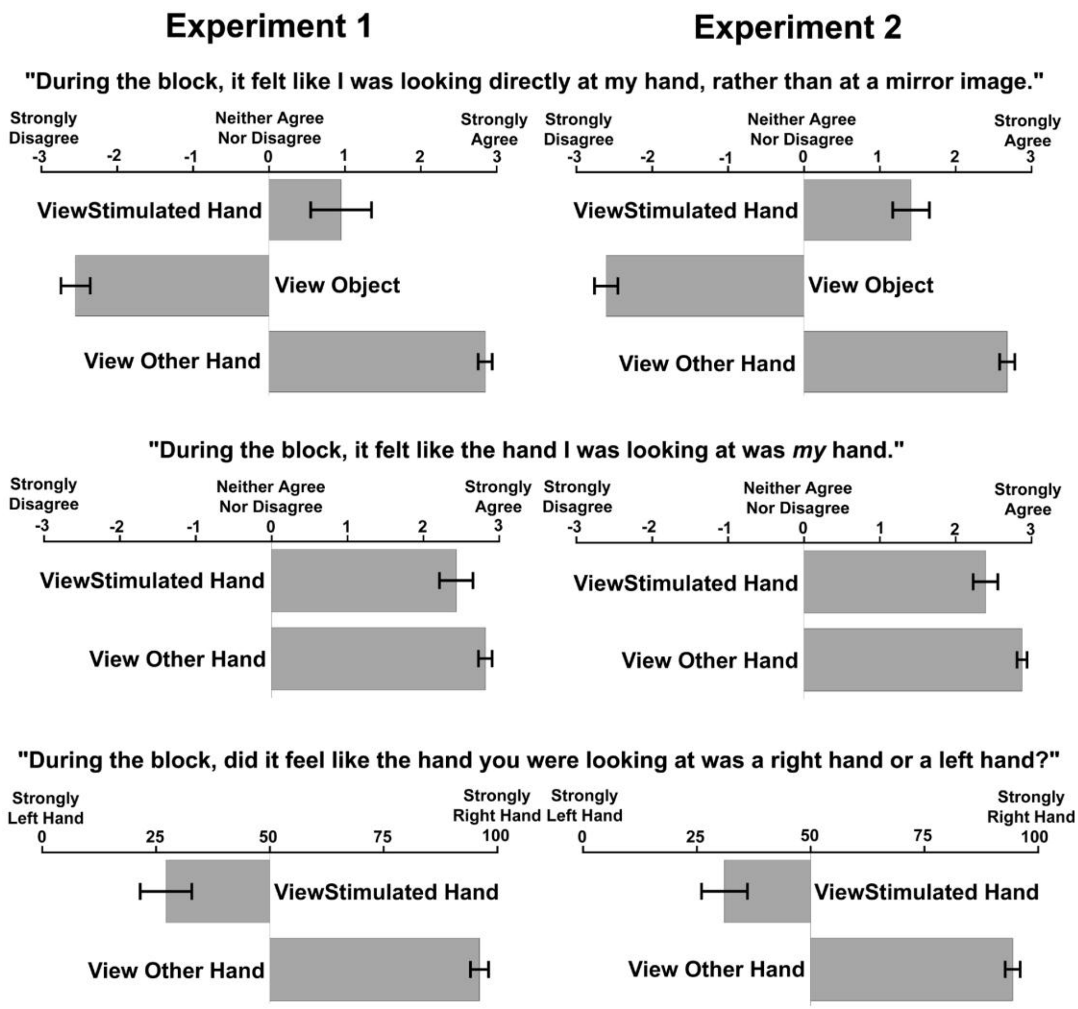

Figure 2: Mean responses to the mirror box illusion questionnaire. Error bars are standard errors

Tactile Size Judgments

Mean size judgments in the two experiments are shown in Figure 3. An ANOVA was conducted on mean size judgments from Experiment 1 including Visual Context (View Stimulated Hand, View Object, View Other Hand), Orientation (Across, Along), and Size (20, 30, 40 mm) as within-subjects factors. Unsurprisingly, judgments increased with stimulus size, $F(2, 58) = 70.08$, $p < .0001$. Consistent with previous findings (Longo & Haggard, 2011), judgments were significantly larger for stimuli running across than along the hand, $F(1, 29) = 51.93$, $p < .0001$ (Figure 3, bottom panel), as well as an interaction of Orientation and Size, $F(2, 58) = 23.82$, $p < .0001$.

Most critically, there was a significant main effect of Visual Context, $F(2, 58) = 4.88$, $p < .05$, with judgments being smaller in the View Stimulated Hand condition (25.49 mm), than in either the View Object (27.68 mm) or View Other Hand (26.82 mm) conditions (Figure 3, top panel). This main effect, however, was modulated by a significant interaction of Visual Context and Size, $F(4, 116) = 11.97$, $p < .0001$. As is clear in Figure 3, this interaction is driven by the absence of any difference between visual contexts for the 20 mm stimuli. It is possible that this is a form of floor effect, driven by the fact that this stimulus may be close to the two-point discrimination threshold. Indeed, across participants 16.08% of 20 mm stimuli were judged as a single point (i.e., participants judged the distance as 0 mm), compared to 3.66% and 0.83% for the 30 and 40 mm stimuli, respectively.

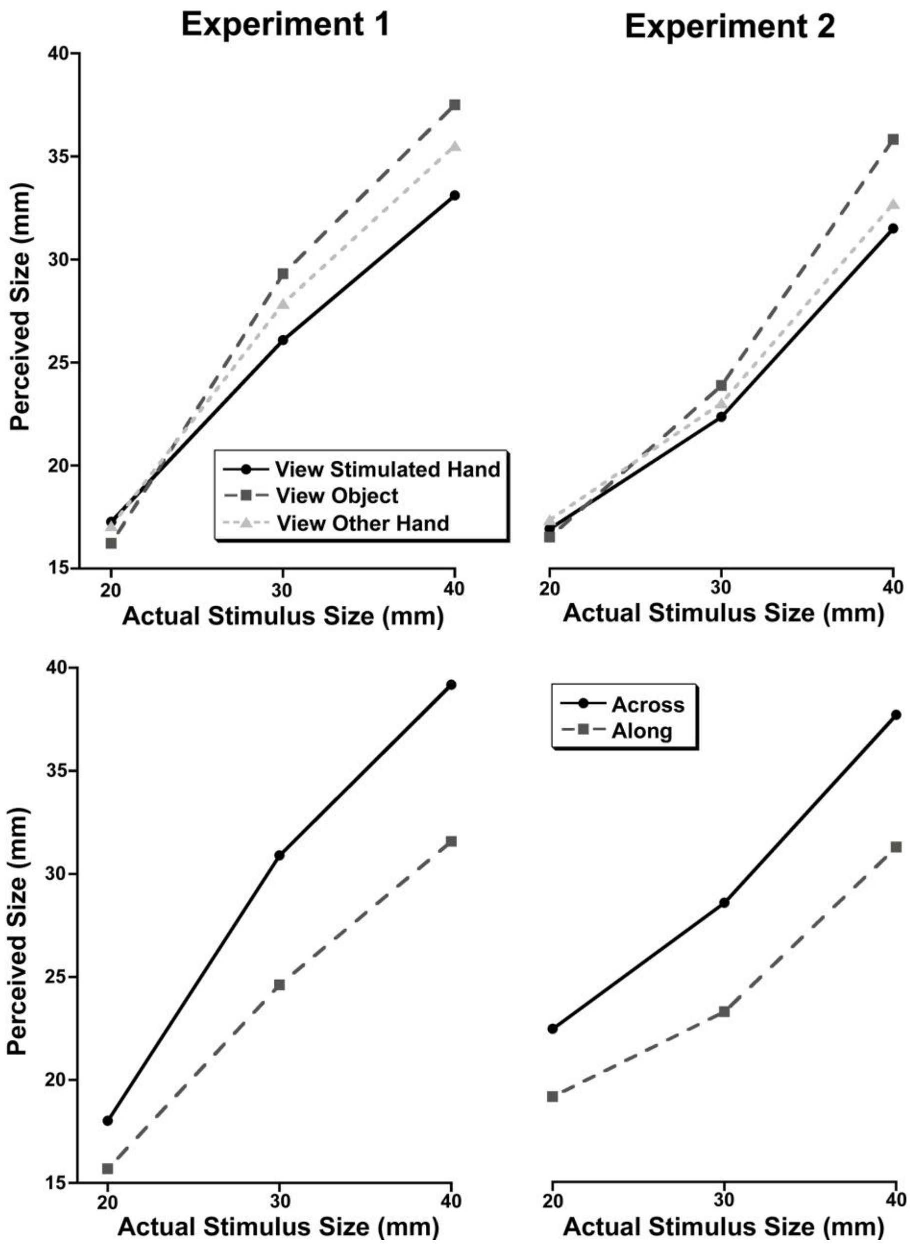

Figure 3: Mean size judgments. *Top panel*: perceived size in the two experiments as a function of actual stimulus size and visual context. *Bottom panel*: perceived size in the two experiments as a function of actual stimulus size and orientation on the hand.

Thus, to further investigate this effect, we conducted an additional ANOVA excluding the 20 mm stimuli. As before, there were significant effects of Size, $F(2, 58) = 102.63$, $p < .0001$, and Orientation, $F(1, 29) = 59.97$, $p < .0001$. Most importantly, there was a strong effect of Visual Context, $F(2, 58) = 13.26$, $p < .0001$ (see Figure 4). Bonferroni corrected t-tests showed that vision of the stimulated left hand caused the perceived size of touch to be smaller than in either the View Object, $t(29) = 4.38$, $p < .0001$, or View Other Hand, $t(29) = 3.00$, $p < .01$, conditions. Perceived size was also significantly smaller in the View Other Hand condition than in the View Object condition, $t(29) = 2.70$, $p < .02$, indicating that seeing contralateral hand produces an intermediate effect.

Results from Experiment 2 were similar, with significant main effects of Size, $F(2, 54) = 141.95$, $p < .001$; Orientation, $F(1, 27) = 63.99$, $p < .001$; and Visual Context, $F(2, 54) = 6.10$, p =003. As before, there were also significant interactions of Orientation and Size, $F(2, 54) = 9.34$, $p < .0005$; and Visual Context and Size, $F(4, 108) = 7.23$, $p < .0001$. A follow-up ANOVA without the 20 mm stimuli revealed similar results, with significant main effects of Size, $F(1, 27) = 150.440$, $p < .0001$; Orientation, $F(1, 27) = 70.15$, $p < .0001$; and Visual Context, $F(2, 54) = 13.82$, $p < .0001$; plus a significant interaction of Visual Context and Size, $F(2, 54) = 6.00$, $p < .005$. Because results were predicted to replicate those of Exp 1, one-tailed t-tests were used to compare conditions, revealing that seeing the left hand reduced perceived size compared to the object, $t(27) = 4.41$, $p < .0001$, and the other hand, $t(27) = 1.87$, $p < .05$. Also as in Exp 1, seeing the non-stimulated right hand reduced perceived size compared to the object, $t(27) = 3.80$, $p < .001$.

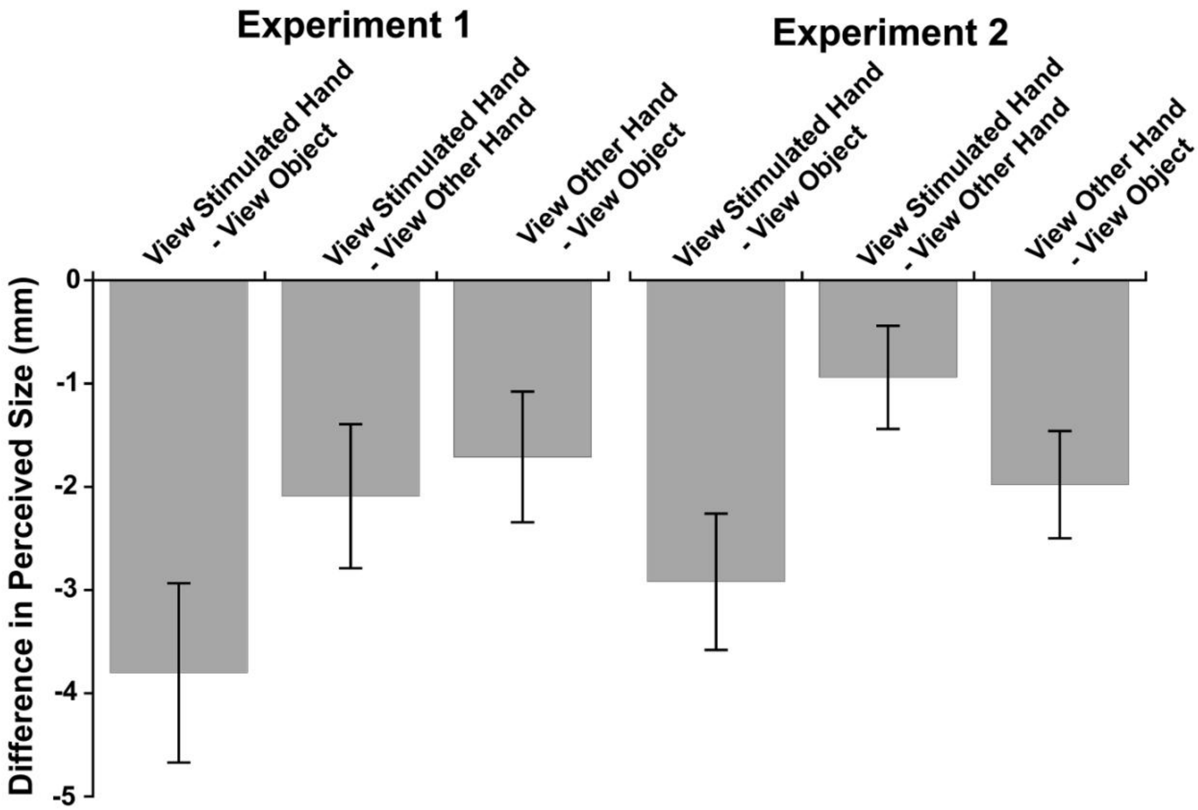

Figure 4: Pairwise comparisons of the three visual conditions on tactile size perception for the 30 and 40 mm stimuli. Error bars are standard errors.

Body Size Judgments

Percent overestimation of hand width (distance between knuckles of index and little fingers) and length (distance between wrist and knuckle of middle finger) was calculated for each participant in each condition by calculating the difference between the judged and actual length as a percentage of actual length (Figure 5). Thus, positive values indicate overestimation of size and negative values indicate underestimation. First, to investigate overall biases in perceived hand size, we collapsed across all conditions to compare responses to veridical judgment (0% overestimation). There was significant overestimation of hand width (29.79%), $t(26) = 9.83$, $p < .0001$. On average, there was slight underestimation of hand length (-3.05%), though this was not significant, $t(26) = -1.36$, *n.s.* The magnitude of overestimation was significantly different between the two orientations, $t(26) = 15.44$, $p < .0001$, indicating that participants perceive their hand as wider and fatter than it actually is, consistent with our recent findings (Longo & Haggard, 2010, 2012) and mirroring the anisotropy in tactile size perception (this study; Longo & Haggard, 2011).

To investigate whether vision of the body altered perceived hand shape, we conducted an ANOVA on the change in percent overestimation from pre-test to post-test as a function of Visual Context and Orientation. Critically, there was no significant main effect of Visual Context, $F(2, 52) = 1.58$, *n.s.*, nor any other significant effects. Thus, there was no evidence that seeing the hand altered perceived hand size.

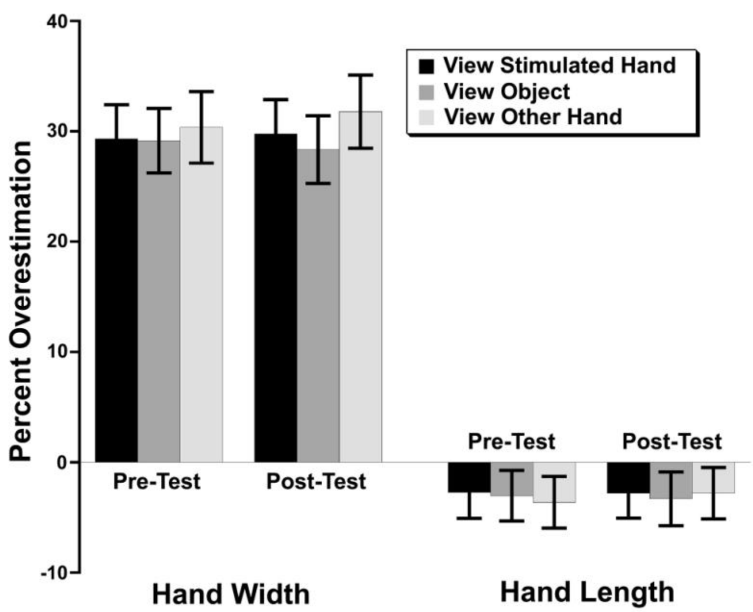

Figure 5: Percent overestimation of hand width (i.e., the distance between the knuckles of the index and little fingers) and length (i.e., the distance between the centre of the wrist and the knuckle of the middle finger). Across conditions, there was a large bias to overestimate hand width, but not hand length, consistent with previous results (Longo & Haggard, 2010, 2012). There were no significant changes to perceived hand width or length from pre-test to post-test. Error bars are standard errors.

Discussion

Vision of the body, though completely non-informative about stimulation, modulated tactile size perception. The illusion of seeing the stimulated hand reduced the perceived distance between pairs of tactile stimuli, compared to seeing a non-hand object. Seeing the contralateral hand produced an intermediate effect. Unlike previous results, showing that vision of the body alters perceptual sensitivity (Kennett et al., 2001; Harris et al., 2007), the present findings show that vision actively distorts touch, altering the perceived size of stimuli touching the body.

At baseline, the perceived size of touch is larger on skin regions with high sensitivity than on those with lower sensitivity, the classic Weber's illusion (Weber 1834/1996; Taylor-Clarke et al., 2004; Anema et al., 2008). This suggests that both acuity and tactile size perception depend on common features of the organization of somatosensory cortex. Critically, however, the effects of seeing the body produce contrary effects on these two abilities: seeing the body *increases* the acuity of touch (Kennett et al., 2001; Cardini et al., 2011) but *shrinks* the perceive size of tactile stimuli (this study). This pattern demonstrates that tactile size perception cannot be simply reduced to spatial acuity, since they are differentially affected by seeing the body.

Recent studies have suggested that vision increases tactile acuity by increasing intracortical inhibition in the somatosensory cortex (Cardini et al., 2011) which shrinks the size of tactile receptive fields (Haggard et al., 2007). It is clear how this could increase spatial acuity, but less obvious why it should decrease the perceived distance between touches on the skin. We can only speculate about the neural mechanisms underlying this effect. An intriguing clue comes from studies of anesthesia showing that reducing the inflow from the peripheral nerves of the hand to the somatosensory cortex increases both perceived finger size (Gandevia & Phegan, 1999) and the perceived size of objects held in the hand (Berryman et al., 2006). Such effects have been linked specifically to reduced input from C-fibres (Paqueron et al., 2003), which are known to provide a tonic source of inhibition to somatosensory cortex (Calford & Tweedale, 1991). By increasing such inhibition (Cardini et al., 2011), vision of the body may produce exactly the opposite effect, yielding the present results.

Previous results have shown that illusions altering perceived body size produce corresponding effects on the perceived size of touch (Taylor-Clarke et al., 2004; de Vignemont et al., 2005; Bruno & Bertamini, 2010). In the present study, however, modulation of perceived tactile size was found without any corresponding change in perceived hand size. The absence of an effect on body size may be particularly surprising in light of the perceived swelling of hand size seen following anesthesia (Gandevia & Phegan, 1999). It is important to keep in mind that the situation we investigated (seeing the body) is uniquely unsuited to assessing alterations of perceived body size caused by modulation of somatosensory organization, since veridical information about hand size is available continuously through vision. It is possible that seeing the body produces changes somatosensory cortex that would – on their own – reduce perceived hand size, but that such effects are overridden by the strong visual cues to stability of hand size. Unfortunately, it is not possible to provide vision of the body without that vision providing information about body size.

In conclusion, the present results show that seeing the body distorts tactile size perception. These results add to a growing body of research demonstrating widespread effects of vision of the body on somatosensation, including tactile reaction time (Tipper et al., 1998), tactile spatial acuity (Kennett et al., 2001; Harris et al., 2007), receptive field size (Haggard et al., 2007), intracortical inhibition (Cardini et al., 2011), somatosensory evoked-potentials (Taylor-Clarke et al., 2002; Longo et al., 2011), and pain (Longo et al., 2009; Mancini et al., 2011).

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Footnotes

1. For one participant, no photograph of the hand was taken due to experimenter error. This participant was excluded from analyses of hand size.

Acknowledgments

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