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Implicit body representations and the conscious body image

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ABSTRACT

Recent studies have revealed that somatosensory processing relies on a class of implicit body representations showing large distortions of size and shape. The relation between these representations and the conscious body image remains unclear. Dissociations have been reported in the clinical literature on eating disorders between different body image measures, with larger and more consistent distortions found with *depictive* measures, in which participants compare their body to a visual depiction of a body, than *metric* measures, in which participants compare their body to some non-body standard. Here, we compared implicit body representations underlying position sense to the body image measured with both depictive and metric methods. The body image was measured using both a depictive method (template matching) in which participants judged whether their hand was wider or more slender than a shown hand picture, and a metric method (line length) in which participants judged whether different parts of their hand were shorter or longer than a presented line. Consistent with previous findings, characteristic distortions were found for the implicit body representation underlying position sense. These distortions were also found in attenuated form for metric – but not depictive – body image measures. While replicating the basic dissociation between implicit body representations and the conscious body image, these results demonstrate that this dissociation is not absolute and specific tasks may utilise both to varying degrees depending on task demands. Metric measures may not be pure measures of body image, but some combination of visual and somatosensory body representations.

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Introduction

Several aspects of perception require that immediate sensory signals be combined with stored representations of body size and shape. As examples, the use of convergence for visual depth perception requires representation of the inter-ocular distance (Banks, 1988), and auditory localisation requires representation of the distance between the ears (Clifton, Gwiazda, Bauer, Clarkson, & Held, 1988). The role of the body as a reference for perception is especially acute in somatosensation, for which the primary receptor surface (the skin) is coextensive with the body. Indeed, manipulations of perceived body size are known to alter the perceived size of objects touching the skin (e.g., Bruno & Bertamini, 2010; Taylor-Clarke, Jacobsen, & Haggard, 2004). We have recently investigated body representations underlying somatosensation, finding highly distorted representations of the hand underlying position sense (Longo & Haggard, 2010) and tactile size perception (Longo & Haggard, 2011). Intriguingly, these distortions appear to maintain distortions characteristic of primary somatosensory maps in the brain (e.g., the ‘Penfield homunculus’). For example, both position sense and tactile size perception rely on a hand representation wider and squatter than actual hand shape, mirroring known anisotropies both in tactile acuity (Weber, 1834/1996) and receptive field geometry (Brown, Fuchs, & Tapper, 1975). In contrast, when participants selected from an array of hand pictures the hand most like their own, responses were highly accurate (Longo & Haggard, 2010), indicating the existence of an undistorted body representation. This dissociation suggests that somatosensation may rely on a class of *implicit body representation*, distinct from the conscious *body image*. The present study investigated the relation between these classes of body representation.

The concept of the body image has been a topic of lively debate in the literatures both on cognitive neuroscience (e.g., Berlucchi & Aglioti, 2010; Longo, Azañón, & Haggard, 2010) and on eating disorders (e.g., Ben-Tovim, Walker, Murray, & Chin, 1990; Cash & Deagle, 1997), though these literatures have made relatively little contact. Several authors have noted that methods to assess body image in the eating disorders literature fall into two basic classes (e.g., Cash & Deagle, 1997; Smeets, Smit, Panhuysen, & Ingelby, 1997). One class involves comparison of one's actual body to a template body picture; these methods include the distorting mirror (Traub & Orbach, 1964), distorted photograph (Glucksman & Hirsch, 1969), and silhouette (Furnham & Alibhai, 1983) methods. Another class involves comparing the size or shape of some body part with some non-body physical standard; these methods include the movable caliper technique (Reitman & Cleveland, 1964), visual size estimation (Slade & Russell, 1973), and the image marking

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procedure (Askevold, 1975). While these classes are sometimes referred to as 'whole body' and 'body part' methods, respectively, the crucial distinction seems rather to be whether the stimulus being compared to the body is a *depiction* of a body ('depictive' methods) or merely a *metric* standard ('metric' methods). Meta-analyses of studies on anorexia have shown that depictive methods reveal larger (Cash & Deagle, 1997) and more stable (Smeets et al., 1997) body image distortions than metric methods, suggesting that these measures may reflect different aspects of body image.

This study compared implicit body representation to the body image assessed both with depictive and metric methods. Recent results have revealed a striking dissociation between the (highly distorted) hand representation underlying somatosensory processing and the (largely veridical) body image when assessed with a depictive task (Longo & Haggard, 2010). The key question here was whether the body image assessed using a metric task is similarly undistorted, or retains distortions characteristic of implicit representations. This has important implications both for understanding how implicit body representations differ from the conscious body image, as well as how different methods of measuring body image differ from each other. Implicit body representations were measured using the 'psychomorphometric' technique we recently developed (Longo & Haggard, 2010) in which participants indicate the perceived location in external space of landmarks on their occluded hand (*Localisation* task). As a depictive measure of body image, participants saw hand pictures and judged whether each was wider or more slender than their own hand (*Template matching* task). As a metric measure of body image, participants saw lines and judged whether each was shorter or longer than part of their hand (*Line length* task) (Fig. 1).

Methods

Participants

Fourteen healthy volunteers between 19 and 35 years of age (6 female) participated with local ethical committee permission. Participants were right-handed as assessed by the Edinburgh inventory (*M*: 79.5, range: 62.5–100).

Procedure

Localisation task

Procedures for this task were similar to those of Longo and Haggard (2010). Participants placed their left hand palm-down on a table, aligned with their body midline, the hand flat and fingers straight. A board (40×40 cm) rested on four pillars (6 cm high) and occluded the hand. A webcam suspended 27 cm above the occluding board captured photographs (1600×1200 pixels) controlled by a custom Matlab (Mathworks, Natick, MA) script.

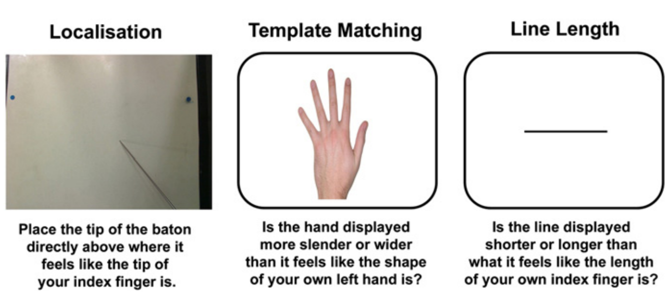

Fig. 1. The three tasks. The Localisation task measured implicit body representations underlying position sense; participants indicated the perceived spatial location of different landmarks on their occluded hand and the relative locations of these landmarks were compared. The Template matching task was used as a depictive measure of the conscious body image; participants were shown hand images and judged whether each one was more slender or wider than their own hand. The Line length task was used as a metric measure of the conscious body image; participants were shown lines and judged whether each was shorter or longer than different parts of their hand.

Participants used a long baton (35 cm length; 2 mm diameter) to indicate the perceived location of different landmarks on their occluded left hand. Ten landmarks were used: the knuckles (i.e., centre of the knuckle at the base of each finger) and tips (i.e., most distal point) of each finger. On each trial, participants were verbally instructed which landmark to localise. They were instructed to be precise and avoid ballistic pointing or strategies such as tracing the outline of the hand. To ensure independent responses, participants moved the baton to a dot at the edge of the board between trials. When the participant indicated their response, a photograph was taken and stored for offline coding.

There were two blocks of 50 trials, each block included five mini-blocks of one trial of each landmark in random order. At the very beginning and end of each block, a photograph was taken without the occluder showing the participant's hand. This allowed measurement of true hand proportions, as well as a check that the hand hadn't moved during the course of the block. To facilitate coding, a black mark was made on each knuckle with a felt pen. A 10 cm ruler appeared in the photographs without the occluder, allowing conversion between pixels and cm.

Template matching task

This task was modelled on the method of Gandevia and Phegan (1999). In previous studies, participants selected from a set of body part images of varied size (Gandevia & Phegan, 1999) or shape (Kammers, Longo, Tsakiris, Dijkerman, & Haggard, 2009; Longo & Haggard, 2010) the one that most closely matched the felt size/shape of their own body. Here, a slightly different procedure was used in which a single image of the back of a left hand was presented on each trial and participants judged whether it was wider or more slender than what it felt like their own left hand was.

Hand shape was quantified using Napier's (1980) *shape index*, a ratio of hand width to length, reflecting the overall aspect ratio of the hand. Following our previous studies (Longo & Haggard, 2010; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2009), hand width was quantified as the distance between the knuckles of the index and little fingers, and hand length as the length (knuckle-to-tip) of the middle finger. The shape index is defined as: $SI = 100 \times (\text{width/length})$. Large values indicate a wide hand, small values a slender hand.

Separate hand images were used for male and female participants. Stimuli were created by stretching a photograph so that the hand had the appropriate aspect ratio. Overall size was controlled by adjusting image size so that all images had equivalent area, differing only in aspect ratio. There were seventeen hand images, ranging from a shape index of 40 to 90, logarithmically spaced. Thus, the central stimulus had a shape index of 60, near the average of previous samples (Longo & Haggard, 2010; Longo et al., 2009). There were two blocks, each including 12 repetitions of each stimulus. Unspeeded responses were made by pressing one of two buttons on a keypad with the right hand. Trials were separated by a 500 ms blank screen. Stimuli were presented by a custom Matlab script according to the method of constant stimuli. Cumulative Gaussian functions were fit to each participant's data with least-squares regression using R 2.8.0 software. The point of subjective equality (PSE; i.e., the hand shape for which a participant was equally likely to judge it wider or more slender than their own hand) were determined as the point the psychometric function crossed 50%.

Line length task

In this task, participants judged whether a visually-presented line was shorter or longer than the felt size of a particular part of their left hand. On each block, participants were given one part of their left hand to judge: one of the five finger lengths, or the distance between the knuckles of the index and little fingers. A staircase procedure was used to estimate perceived length of each body part. On each block, four randomly interleaved staircases were performed, forming a 2 by

2 factorial defined by line orientation (horizontal, vertical) and starting line length (small: 2 pixels/.06 cm; large: 500 pixels/14.80 cm). Lines were approximately 1 mm thick and were white on a black background. The initial step size was 1.89 cm (64 pixels). On each reversal, step size was halved. Staircases ended after five reversals. On each trial, the stimulus was randomly selected from all active staircases. Blocks continued until all staircases had completed. Participants made unspeeded responses, pressing one of two buttons on a keypad with their right hand. Trials were separated by a 500 ms blank screen. There were twelve blocks, two of each body part.

Results

Previous studies using the localisation task (Longo & Haggard, 2010, 2012) have revealed several characteristic distortions of the implicit representation of the hand, including: (1) underestimation of finger length (~20–30%), (2) a radial–ulnar gradient with underestimation increasing progressively from the thumb to little finger, and (3) overestimation of hand width (~60–80%). All were replicated here. There was significant underestimation of finger length (*M*: −30.2%), $t(13) = -9.23$, $p < .0001$ (see Fig. 2, left panel), with significant underestimation of all five fingers (all *ps* < .001). Further, this underestimation increased monotonically from the radial to the ulnar side of the hand (i.e., from thumb to little finger), as revealed by least-squares regression (mean $\beta = 4.9\%$ per finger), $t(13) = 7.28$, $p < .0001$. As previously noted (Longo & Haggard, 2010), this gradient mirrors gradients across the fingers both for tactile acuity (Vega-Bermudez & Johnson, 2001) and cortical magnification (Duncan & Boynton, 2007). Finally, there was significant overestimation of hand width; the distance between the knuckles of the index and little fingers was overestimated by an average of 72.5%, $t(13) = 9.20$, $p < .0001$.

In striking contrast to the large distortions revealed by the localisation task, responses on template matching were quite accurate, with no significant difference between perceived and actual hand shape (mean shape index: 58.8 vs. 60.0), $t(13) = .59$, $p < .20$. There was a clear correlation between actual and perceived hand shape, $r(13) = .520$, $p < .05$, demonstrating that participants were making judgements about the shape of their own hand, rather than hands generally. R-squared values for the psychometric functions ranged from .712 to .995 (*M*: .946), indicating good fit.

This difference between the localisation and template matching tasks replicates the dissociation between implicit body representations and conscious body image reported previously (Longo & Haggard, 2010). The key question here is whether the distortions seen on the localisation task will appear on a metric body image task, the line length task. Indeed, there was significant underestimation of finger length (*M*: −23.8%), $t(13) = -5.49$, $p < .0001$ (see Fig. 2, right panel). As with the localisation task, there was significant underestimation of all five fingers (all *ps* < .01). Underestimation also increased along a radial–ulnar gradient (mean $\beta = 3.2\%$ per finger), $t(13) = 4.46$, $p < .001$, again consistent with the localisation task. Unlike the localisation task, however, there was no significant overestimation of hand width (*M*: 7.6%), $t(13) = 1.03$, $p < .20$.

Given that the participant's hand was oriented with the fingers pointed directly away from the torso, it might be suspected that judged finger length would be more accurate when compared to vertical lines and judged hand width would be more accurate for horizontal lines. Thus, we conducted an analysis of variance (ANOVA) on judged length of body parts (finger length vs. hand width) as a function of line orientation (horizontal vs. vertical). There was a significant main effect of orientation, $F(1, 14) = 44.35$, $p < .0001$, with longer judgements for horizontal than for vertical lines. Critically, however, there was no interaction of body part and orientation, $F(1, 14) = .03$, *n.s.*, indicating that the relation between hand orientation and line orientation did not substantively affect estimation. The main effect of line orientation presumably reflects a horizontal–vertical illusion: since vertical lines appear longer, a shorter stimulus will be perceived equal to body part size.

An ANOVA comparing percent overestimation of finger length for the localisation and line length tasks revealed a significant effect of finger, $F(4, 52) = 25.29$, $p < .0001$, with bias increasing monotonically across the hand from the thumb to the little finger. There was no significant effect of judgement type (i.e., localisation vs. line length task), $F(1, 13) = 1.84$, $p < .10$, nor an interaction of the two factors, $F(4, 52) = 1.00$, $p < .20$. These results suggest that the representation of finger length is similar in the two representations. In contrast, there was a substantial difference in overestimation of hand width, $F(1, 13) = 58.59$, $p < .0001$. Thus, of the three characteristic distortions of implicit body representations observed using the localisation task here and in previous studies (Longo & Haggard, 2010, 2012), two (underestimation of finger length and the radial–ulnar gradient of this underestimation) also appear on the line length task, while one does not (overestimation of hand width).

The shape index, which was used for the template matching task, can be calculated for the localisation and line length tasks as well, allowing comparison of overall hand shape across all tasks as well as the actual hand. These values are plotted in Fig. 3. Shape indices differed significantly across these measures, $F(3, 39) = 53.62$, $p < .0001$. Responses on the hand image task did not differ significantly from actual hand shape, $t(13) = -.59$, $p < .20$. In contrast, both the line length, $t(13) = 5.21$, $p < .0005$, and localisation, $t(13) = 8.18$, $p < .0001$, tasks revealed hand representations that were fatter than actual hand shape. Crucially, shape indices for the line length task were significantly larger than the

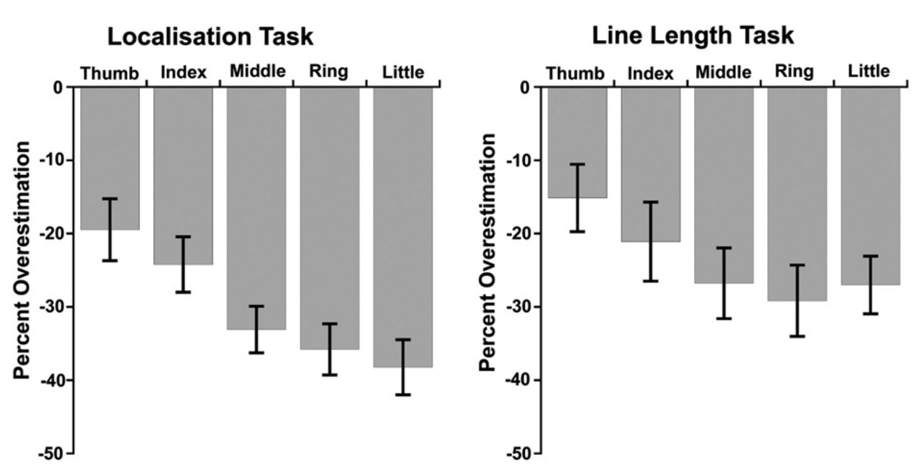

Fig. 2. Percent overestimation [i.e., 100 * (judged length − actual length)/actual length] of finger length for the Localisation and Line length tasks. Clear underestimation of finger length was observed on both tasks, which increased progressively from the thumb to the little finger. Error bars are standard errors.

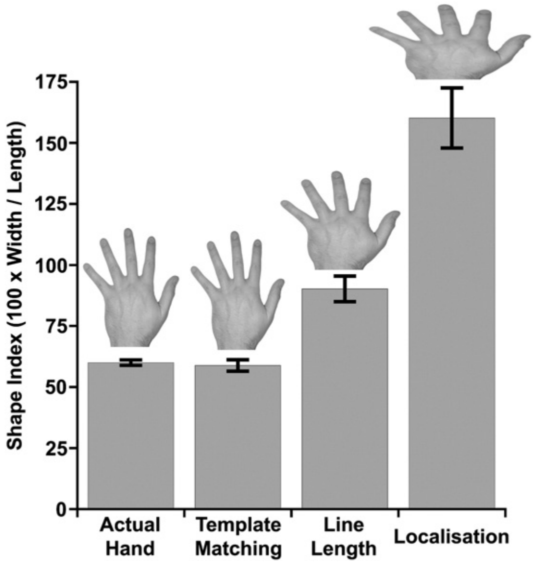

Fig. 3. Mean shape index for participants' actual hands and for each of the three tasks. The shape index measures overall hand shape, with small values indicating a slender hand, and large values indicating a wide hand. Hand images show an example hand stretched to have each shape index.

template matching task, $t(13) = 4.91$, $p < .0005$, but significantly smaller than the localisation task, $t(13) = 5.99$, $p < .0001$, reflecting a representation intermediate between the two.

Discussion

Consistent with recent results (Longo & Haggard, 2010, 2012; Longo, Long, & Haggard, 2012), these results revealed that human position sense relies on a highly distorted hand representation. Crucially, whether these distortions were also reflected in the conscious body image depended on the measurement method. With a depictive task (template matching) in which participants compared the shape of their hand to a hand picture, the body image appeared highly accurate, as in previous studies. In contrast, with a metric task (line length) in which participants compared the size of different parts of their hand to a line, distortions were observed, though smaller than in the localisation task. These results demonstrate that the dissociations between depictive and metric tasks, previously reported in eating disorders (Cash & Deagle, 1997; Smeets et al., 1997), can also be observed in healthy individuals. Further, these results indicate that the distinction between implicit body representations and the conscious body image is not absolute, and that some measures of body image reveal similar distortions. This suggests that metric measures of body image are not pure measures of the visual body image, but some combination with somatosensory body representations.

We previously argued that the distortions characterising body representations underlying somatosensory processing of position sense (Longo & Haggard, 2010) and tactile size perception (Longo & Haggard, 2011) did not make reference to the conscious body image. Indeed, it was on this basis that we termed these *implicit* body representations. The present results, however, indicate that this dissociation is not complete. While no distortions were observed on a depictive body image measure (template matching), distortions were found using a metric measure (line length). While these distortions were less than found with our highly implicit localisation task, they were qualitatively similar. These results suggest that the distinction between implicit body representation and the conscious body image may not be categorical. Rather, both may be employed to varying degrees, depending on the demands of the specific task at hand.

These results also provide insight into the nature of the body image itself. While meta-analyses of the clinical literature have revealed dissociations between *depictive* and *metric* measure of body image in anorexia (Cash & Deagle, 1997; Smeets et al., 1997), the present results are the first, to our knowledge, to show this dissociation in healthy participants. Further, our results provide clues as to the nature of this dissociation. That metric – but not depictive – measures of body image showed the influence of distortions characteristic of somatosensory processing, suggests that the depictive template matching task may be a more pure measure of the conscious body image. We can compare our body more accurately to a visual depiction of a body than to a non-body object. It may be that the localisation and template matching tasks rely predominantly on somatosensory and visual representations, respectively, while the line length task implicates both forms of representation, resulting in a pattern of spatial distortions intermediate between the two. There is of course nothing obviously somatosensory about the line length task. That biases characteristic of somatosensory processing nevertheless influence this task suggests that body representations emerging from somatosensation may have a broader influence on perception and cognition than previously suspected.

There is some evidence, however, that even the implicit body representation revealed by the localisation task is not a pure reflection of primary somatosensory maps. For example, somatosensory maps represent the body as a fragmented set of two-dimensional skin surfaces. Nevertheless, implicit representation of the palmar and dorsal hand surfaces reveal qualitatively similar patterns of distortion, correlated across individuals, suggesting that they are bound into a common underlying representation (Longo & Haggard, 2012). However, the *magnitude* of distortion was significantly reduced on the palm, suggesting that this binding is incomplete. We suggested that the implicit hand representation is intermediate between 2-D representations of individual skin surfaces and 3-D representation of the hand as a volumetric object, what we called a 2.5-D representation (Longo & Haggard, 2012).

The representations underlying performance on the line length task may be similarly intermediate between 2-D and 3-D body representations, but somewhat shifted along this continuum towards the visual, 3-D end. On this view, somatosensory maps and the visual body image reflect two distinct classes of body representation, which can be combined to different extents depending on immediate task demands. This proposal is consistent with previous findings showing bidirectional effects of somatosensory and visual inputs. For example, removing afferent inputs to somatosensory cortex through cutaneous anaesthesia alters the body image assessed through template matching (Gandevia & Phegan, 1999), while modification of visually-perceived body size alters implicit body representations measured with tactile size perception (Bruno & Bertamini, 2010; Taylor-Clarke et al., 2004).

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