Representations of the Relative Proportions of Body Part Width

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Abstract

Despite our wealth of experience with our bodies, our perceptions of our body size are far from veridical. For example, when estimating the relative proportions of their body part lengths, using the hand as a metric, individuals tend to exhibit systematic distortions which vary across body parts. Whilst extensive research with healthy populations has focused on perceptions of body part length, less is known about perceptions of the width of individual body parts and the various components comprising these representations. Across four experiments, representations of the relative proportions of body part width were investigated for both the self and other, and when using both the hand, or a hand-sized stick as the metric. Overall, we found distortions in the perceived width of body parts; however, different patterns of distortions were observed across all experiments. Moreover, the variability across experiments appears not to be moderated by the type of metric used or individuals' posture at the time of estimation. Consequently, findings suggest that, unlike perceptions of body part length, assessed using an identical methodology, our representations of the width of the body parts measured in this task are not fixed and vary across individuals and context. We propose that, as stored width representations of these parts are not necessarily required for navigating our environments, these may not be maintained by our perceptual systems, and thus variable task performance reflects the engagement of idiosyncratic guessing strategies.

Key words: *body perception, body representation, affordances, somatosensation, visual perception*

Introduction

Successful environmental navigation requires the performance of fine motor actions and the ability to safely traverse apertures (Newcombe, 2019). Given this, one may expect that different schematic representations of the body are accurate. However, a growing body of evidence suggests that this is not the case (see Longo, 2017 for a review). Since the seminal work of Weber (Weber, 1834/1996), it has been known that the distance between tactile stimuli applied to more sensitive body parts is perceived as greater than that of less sensitive body parts. Moreover, across a number of body parts, including the back (Nicula & Longo, 2021), head (Longo et al., 2020), and thigh (Green, 1982), tactile anisotropies are observed wherein the distance between two tactile points across the mediolateral axis (i.e., across the body part) is perceived as greater relative to the rostrocaudal axis (i.e., along the body part). Similarly, when investigating the implicit body representation underlying position sense, Longo and Haggard (2010) observed patterns of systematic distortions whereby participants overestimated the width of the hand and underestimated its length.

Strikingly, this pattern of distortions across body parts of different sensitivity appears to mirror the organisation of body part representations in somatosensory cortex. Specifically, more sensitive body parts are allocated greater cortical surface area within somatotopic maps (Penfield & Boldrey, 1937; Nakamura et al., 1998) and have a greater density of tactile receptors (Corniani & Saal, 2020) relative to those of lower sensitivity. Furthermore, the receptive fields of tactile receptors present in hairy skin (Johansson, 1978) and somatosensory cortex (Brooks et al., 1961) are ovular in shape. Accordingly, the pixel model (Longo & Haggard, 2011) proposes that tactile distance perception varies in accordance with the number of receptors stimulated. Hence, tactile distance is presumed to be perceived as greater on more sensitive body parts due to higher receptor density. Specifically, an applied stimulus of a given size spans a greater number of receptive fields on regions of higher sensitivity relative to the same stimulus size on regions of lower sensitivity. Moreover, width is hypothesised to be overestimated relative to length due to the ovular shape of tactile receptor fields. Seemingly, the same metric distance encompasses more receptive fields across the width of body parts than along their length.

Nevertheless, the magnitude of distortion observed on tactile distance estimation tasks is less than 10 percent of that which would be expected should perceptions of tactile size derive entirely from the organisation of receptive fields (Taylor-Clarke et al., 2004). For instance, participants may only estimate the tactile distance in two areas to be 30 percent different despite the difference in neural density between these two areas being around 340 percent (see Taylor-Clarke et al., 2004). Therefore, differences in tactile distance perception cannot be fully explained by differences in neural density alone.

A possible reason for this discrepancy between differences in neural density and differences in tactile distance perception across body parts is provided by (Linkenauger et al., 2015). In their paradigm, representations of body part length are assessed by asking participants to judge how many measuring units of either their hand, or a hand-sized stick make up the length of different body parts. Interestingly, across several replications (Linkenauger et al., 2015; Readman et al., 2022; Sadibolova et al., 2019) patterns of systematic distortions have been observed on this task whereby individuals consistently overestimate the torso (a less sensitive body part; Solomonow et al., 1977) the most, and the foot (a highly sensitive body part; Corniani & Saal, 2020), the least (Linkenauger et al., 2015; Readman et al., 2022; Sadibolova et al., 2019) when using the hand as the metric. In contrast, when using a hand-sized stick, these distortions are drastically reduced (Linkenauger et al., 2015; Sadibolova et al., 2019). In reconciling these findings, Linkenauger et al. (2015) proposed the reverse distortion hypothesis. This proposes that, when using the hand as a metric, distortions in body length arise from a proportional perceptual magnification of the estimated body part relative to the difference between the size of that body part’s representation in somatosensory cortex and that of the hand. Hence, less sensitive body parts are overestimated more as there is a greater size disparity between their representation in somatosensory cortex and the hand. This compensatory perceptual mechanism facilitates reliable somatoperception by counteracting Weber’s illusion, thus maintaining tactile constancy. In turn, by using the hand as a metric, this paradigm provides useful insights into the influence of somatosensory representations on conscious body perception.

Typically, body part representations can be measured using two main forms of task; depictive or metric. In metric tasks, participants are required to judge the size of their own body part with reference to another metric, such as the distance between two light points (e.g., Thompson and Spana, 1988). Whereas depictive tasks require participants to judge which, of a series of distorted templates or photographs, best depicts the perceived size of their body part (e.g., Freeman et al., 1985). Critically, performance on these two tasks is dissociable. On depictive tasks, estimations of body part length, and width tend to be accurate. In contrast, on metric tasks distortions are observed whereby individuals tend to underestimate the length and overestimate the width of their body parts (see Longo, 2015 for a review).

Given the dissociation between these tasks, it has been proposed that depictive and metric tasks draw upon different body representations varying along the implicit to explicit continuum (Longo & Haggard, 2012). Specifically, depictive tasks are proposed to correspond to explicit representations of the body (i.e., the body image). In contrast, the similar patterns of distortions (namely, an overestimation of width and underestimation of length) across metric, implicit localisation (Longo & Haggard, 2010), and tactile distance estimation tasks (Longo & Haggard, 2011) could indicate that metric tasks may reflect more implicit somatotopic representations, rescaled in accordance with visual information (Longo

& Haggard, 2012; Longo, 2015). Therefore, in contrast to the reverse distortion hypothesis (Linkenauger et al., 2015), some propose that performance on metric tasks is directly proportional to the distortions present in somatosensory cortex (Longo & Haggard, 2012).

However, despite an extensive body of evidence using metric tasks to investigate representations of *length* across body parts in non-clinical populations (see Longo, 2017 for a review), investigations of representations of body part *width* have predominantly focused upon people with eating disorders and how they differ from non-clinical groups. These studies have shown that people with eating disorders tend to overestimate the width of their bodies, relative to healthy controls (see Mölbert et al., 2017 for a review). Similarly, people with eating disorders also exhibit a tendency to overestimate their aperture passing affordance (their perceived ability to traverse an aperture; Guardia et al., 2012; Keizer et al., 2013), perhaps suggesting a correspondence between explicit and implicit representations of body width in this population.

In contrast, whilst estimates of aperture passing capabilities are fairly consistent in non-clinical individuals (Warren & Whang, 1987), when making explicit body width judgements inconsistent findings have been observed in this group. For example, using a task involving adjusting the distance between two light points, Slade and Russell (1973) found that healthy controls were mostly accurate when estimating the width of the waist and hips. In contrast, Button et al., (1977) observed an overestimation of the waist and hips, using the same task. Consequently, it is possible that non-clinical individuals exhibit a disconnect between implicit and explicit body width judgements that is not present in eating disorders.

However, previous research with non-clinical populations has tended to focus upon estimations of a small number of body parts (most commonly the waist, and hips), therefore impeding conclusions as to how the magnitude of distortions varies across different body parts. Moreover, individuals tend to make estimates for frontal body parts, therefore understanding of how posterior body parts are represented is limited. Peviani et al. (2019), using a line length judgement task, found that estimations of the dorsal part of the neck (a less visually accessible region) were accurate, whereas the lips, nose, hands, and feet were underestimated. Additionally, distortion magnitude was similar across the lips, hands, and feet despite differences in the actual size of these body parts. Critically, width distortions were not predicted by the actual size, nor the tactile acuity of the body parts, indicating that estimations may not be related to somatosensory representations. Instead, these findings suggest that representations of width may be related to cumulative visual experience with estimates of posterior body parts being more accurate due to our limited visual experience with these parts. Hence, studying representations of width across body parts spanning both the front and back of the body could help to elucidate how body width is represented in non-clinical individuals and the possible components comprising these representations.

Consequently, this study aimed to explore representations of body width in non-clinical individuals across body parts spanning both anterior and posterior bodily planes. Participants performed an adapted version of the Linkenauger et al. (2015) paradigm in which they judged the width of their body parts using the hand, or a hand-sized stick as the metric. As has been done for length representations, we compared judgements between corporeal and non-corporeal metrics to elucidate the influence of somatosensory components on representations of body width. Moreover, we measured representations of body part width across both the front and the back of the body to determine whether consistent distortions of body part width, are present across the whole body and whether these distortions, if present, manifest as over-, or underestimations. By improving understanding of how body width is represented in non-clinical populations, it is hoped these findings may help to provide further insight into distortions of the body observed in clinical groups, such as those with eating disorders.

Accordingly, four experiments were conducted. In Experiment 1, participants' representations of the relative proportions of body part length and width, using the hand as a metric, were explored. In Experiment 2, width representations were again investigated using both the hand, and a hand-sized stick as a metric. Experiment 3 assessed width representations of another person using both the hand, and a hand-sized stick as metrics. Finally, Experiment 4, considered the effects of posture on width representations of the self.

General Method

Transparency and Openness

To ensure the reproducibility and transparency of the current findings, all data files and associated analysis code have been made available at the Open Science Framework and can be accessed at https://osf.io/839pz/. Analyses were conducted using the *BayesFactor* (Version 0.9.12-4.4; Morey et al., 2018) and *Rstatix* (Version 0.7.2; Kassambra, 2022) packages available in RStudio (Version 4.2.1). In addition, we clearly report any participant exclusions and tests of assumptions in the analysis code.

This study was conducted in accordance with the Declaration of Helsinki (2013). Ethical approval for this study was granted by the Faculty of Science and Technology Research Ethics Committee at Lancaster University. Participants in all experiments gave informed consent before taking part in the study.

Experiment 1

The aim of Experiment 1 was to use an adapted version of the Linkenauger et al. (2015) task to investigate representations of body part width of the self in non-clinical individuals, when using the hand as a metric. In addition, we aimed to replicate the distortions of body part length previously observed using this paradigm.

We hypothesised that a) in line with the Reverse Distortion Hypothesis and previous findings (Linkenauger et al., 2015; Sadibolova et al., 2019; Readman et al., 2022), the length of all body parts will be overestimated (i.e., will show an accuracy ratio > 1.0) with the greatest overestimation of body parts which have lower tactile sensitivity (e.g., the torso) and the least overestimation of more sensitive body parts (e.g., the foot) b) given the findings of Peviani et al. (2019), we expected body part width estimates will vary across body parts, with greater overestimation of body parts with which we have more visual experience (i.e., those at the front of the body) relative to those with which we have less (i.e., those at the back of the body). Specifically, we expect individuals to have the most cumulative visual experience with the thigh, given that this body part can be most easily viewed by looking down at oneself, and is readily visible in a mirror. Consequently, if visual experience does affect estimates, we may expect this body part to be overestimated the most. Whereas, the hips, torso, and shoulders are increasingly more difficult to view when looking down at one's body but are still easily viewed in a mirror. In contrast, the head is only visible when looking in the mirror and the back is not easily visually accessible, even when using a mirror. Therefore, we expect overestimation to decrease across estimates for these body parts, with estimates close to unbiased for the back (i.e., accuracy ratios near to 1.0).

Method

Sample Size

The required sample size for Experiment 1 was determined *a priori* using G*Power (Faul et al., 2009). Power was determined for a repeated-measures ANOVA with one repeated-measures variable (Body Part) comprising of six levels (corresponding to each estimated body part). As two models were constructed in this experiment, a Bonferroni correction was applied to the desired significance level (α) of 0.05. Thus, a significance level of .025 was used. To maximise the likelihood of detecting a true difference should one exist, the required power (1- β) was set at 0.95. Effect sizes were obtained from Sadibolova et al. (2019) who, using a similar paradigm to that employed here, found a main effect of body part with an effect size of $f = 0.86$ for length estimations, and $f = 0.86$ for volume estimations when comparing estimates using the hand and a hand-sized stick as a metric. To be as conservative as possible, a very small correlation between repeated measures ($r = 0.02$) was assumed. This was calculated by using the smallest correlation between body parts in the length condition of the Sadibolova et al. study. Based upon these parameters, a required minimum sample size of $N = 7$ was obtained. However, Sadibolova et al. did not measure estimates of body part width which may potentially show a smaller effect size than that typically observed for length estimates. Hence, a larger sample size than this estimate was sought to ensure there was sufficient power to detect potentially smaller effects sizes for width estimates.

Participants

Fifteen healthy adults (14 females) aged 19-52 years (*M* = 24.8 years, *SD* = 8.3) consented to participate. Participants were required to be aged 18-55 years with normal or corrected-to-normal vision and no current or historic visual impairment, cognitive impairment, or diagnosis of an eating disorder. As individuals with eating disorders may exhibit distortions in perceptions of their body size (see Mölbert et al., 2017 for a review), participants were required to score below threshold (global score >4) on the Eating Disorder Examination Questionnaire (EDE-Q; Fairburn & Beglin, 1994). Whilst older adults have been shown to have comparable performance to younger adults when making length estimates, using the same paradigm as in this study (Readman et al., 2022), to the authors’ knowledge, how representations of body part width are affected by ageing has yet to be studied. Nevertheless, older adults (≥ 65 years) do overestimate their aperture passing affordance relative to younger adults (Hackney & Cinelli, 2013), thus implying a potential change in representations of body width, at least at the implicit level. Therefore, to ensure findings were not confounded by age-related factors, we limited our sample to adults aged 18-55 years.

As previous investigations using the same paradigm with length estimates have found no effect of anxiety on task performance (Readman et al., 2022), participants who self-reported having an anxiety diagnosis were not excluded. However, participants with other psychiatric conditions were not included.

Materials

Questionnaire Measures. To ensure the absence of any eating disorders amongst the included sample, participants were measured on the EDE-Q (Fairburn & Beglin, 1994), a self-report measure of eating disordered tendencies consisting of four subscales: Restraint, Eating Concern, Shape Concern, and Weight Concern. Both subscale scores and a global score of eating disorder severity (the global average of each subscale score) are calculated.

Design and Procedure

Experiment 1 constituted a partial replication of the methodology used in previous studies (Linkenauger et al., 2015; Readman et al., 2022). Specifically, the length condition in this study comprises a full replication of the methodology used by Readman et al. (2022); whereas, the width condition consists of a partial replication to accommodate width estimates. Participants completed this repeated-measures study in two parts. First, the questionnaires were completed online via Qualtrics (Qualtrics, Provo, UT).

Following the questionnaires, participants made their body part estimates. This experiment was conducted post-Covid, at a time when in-person research was still not recommended. Considering that previous studies have replicated the distortions observed in the Linkenauger et al. (2015) paradigm for length using an online format (Readman et al., 2022), participants completed this study online to widen the available participant pool. Over a Microsoft Teams call, Participants were asked to estimate how many hands comprise the length or width of different body parts as accurately as possible, using fractions/decimals where necessary. Prior to making the estimate, the body part was defined by the researcher (See Table 1 for the full definitions provided per body part). The definitions and body parts used for length were chosen to be an exact replication of those used in previous investigations with the same paradigm (Linkenauger et al., 2015; Readman et al., 2022). Similarly, to faciliate comparisons between our findings and those of previous investigations, the body parts to be estimated for width were chosen based upon body parts typically estimated in previous investigations of body part width. These include estimates of the width of the shoulders (e.g., Strober et al., 1979; Whitehouse et al., 1986), waist (e.g., Slade & Russell, 1973; Shontz, 1963), hips (e.g., Slade & Russell, 1973; Button et al., 1977), thigh (e.g., Thompson & Spana, 1988; Waldman et al., 2013), and head (e.g., Shontz, 1965, 1967). Additionally, we had participants estimate back width to investigate whether less visually accessible body parts differ in the degree of distortion observed. Participants were asked not to place their hand on the body or to base estimates on previous responses. All estimates were performed whilst seated.

Table 1. *Body part definitions used for length and width estimates.*

Body Part	Definition
	Length Estimations

Hand	The distance from the palm-wrist intersection to the tip of the longest finger on the dominant hand
Full Body	From the top of the head to the bottom of the heel whilst standing
Torso	From the top of the shoulder to the top of the hip bone
Leg	From the top of the hip bone to the bottom of the heel whilst standing
Arm	From the protrusion of the shoulder to the tip of the longest finger when the arm is outstretched
Head	From the tip of the head to the lowest point of the jawline
Foot	From the back of the heel to the tip of the longest toe
	Width Estimations
Hand	From the knuckle of the thumb to the opposing side of the dominant hand, when the fingers are together
Shoulders	From the protrusion of the right shoulder, to the protrusion of the left shoulder
Back	From the right edge of the back to the left edge of the back, just underneath the shoulder blades
Torso	From the right edge of the torso to the left edge, just above the hip bones
Hips	From the right side, to the left side of the body at the widest point of the hips
Thigh	From the outer edge to the inner edge of the thigh at its widest point
Head	From one temple to the other, just above the brow ridge

Length and width estimates were separated into two separate experimental blocks with participants completing both blocks in a randomised order. The order of body parts in each condition was randomised across participants. Participants made one estimate per body part in each condition. After providing both length and width estimates, a helper measured the participant’s body parts using a soft tape measure. To ensure measurements were taken accurately, an instruction booklet was sent to the participant once all estimates were completed. To verify the measures, the helper measured the participant's body parts in view of the camera, whilst the experimenter observed. To ensure consistency across participants in the body part measurements, prior to providing a measure for each body part, helpers indicated to the researcher the endpoints of their measure and the researcher would instruct them to adjust this if necessary. Helpers were asked to provide measures to the nearest millimetre.

Analysis

The dependent variable used for analyses was accuracy ratios (the ratio of estimated to actual body part size). To calculate this, hand estimates for each body part were multiplied by participants' actual hand length/width to convert them to centimetres. This converted estimate was then divided by the actual length/width of the respective body part. Hence, an accuracy ratio of 1 indicates an unbiased estimate, a ratio >1.0 is indicative of overestimation, and a ratio <1.0 indicates underestimation. Accuracy ratios have been widely used with this paradigm (Linkenauger et al., 2015; Linkenauger et al., 2017; Sadibolova et al., 2019). Additionally, this outcome measure is statistically equivalent to measures used in other paradigms, such as percent overestimation (Longo & Haggard, 2010; Longo & Haggard, 2012), and the body perception index (Docteur et al., 2010; Lautenbacher et al., 1992).

All statistical analyses were carried out using RStudio (Version 4.2.1). Prior to analysis, data was checked for outliers using the median absolute deviation (MAD) approach (Leys et al., 2013). For both length and width analyses, participants with accuracy ratios three median absolute deviations above or below the median for any body part were removed.

To ascertain the degree of bias in the representations of the width of one's body parts, Holm-Bonferroni adjusted frequentist one-sample *t*-tests were conducted to compare whether accuracy ratios for each body part differed significantly from one (i.e., an unbiased estimate) for the full sample. In such analyses greater deviations from one are indicative of greater distortions in the representation of that body part.

To determine whether accuracy differed significantly across body parts, and whether body parts varied in the degree to which they were over, or underestimated, separate repeated-measures ANOVAs, were conducted for length and width estimates. In each model, Body Part formed the repeated-measures variable, and accuracy ratios the dependent variable. Normality assumptions were checked using Q-Q plots and the Shapiro test of normality. Where Mauchly's test indicated a violation of the sphericity assumption, the Huynh-Feldt correction was applied. Where a significant effect of Body Part was observed, Holm-Bonferroni adjusted pairwise t-test comparisons were conducted. Specifically, as we were interested in how the magnitude of distortion differed across body parts in each experiment, based upon the body part's tactile sensitivity (for length estimates), or visual experience with the body part (for width estimates), we compared the body part with the lowest tactile sensitivity or visual experience to each body part in order of increasing sensitivity/visual experience. This was then repeated for the body part with the second-lowest sensitivity/visual experience and so forth until all body parts were compared. This approach allowed us to compare the magnitude of distortion as tactile sensitivity or visual experience increased.

As traditional frequentist statistics cannot quantify the strength of evidence in favour of the null hypothesis (Dienes et al., 2018), Bayes Factors were used to corroborate conclusions of all analyses. Default priors were used as these are based upon the frequency of observing different effect sizes across psychology, and thus are not reliant upon a single previous study which may have methodological flaws (Rouder et al., 2012). Percentage error is reported alongside Bayes Factors where an error of <20% is deemed to be acceptable (van

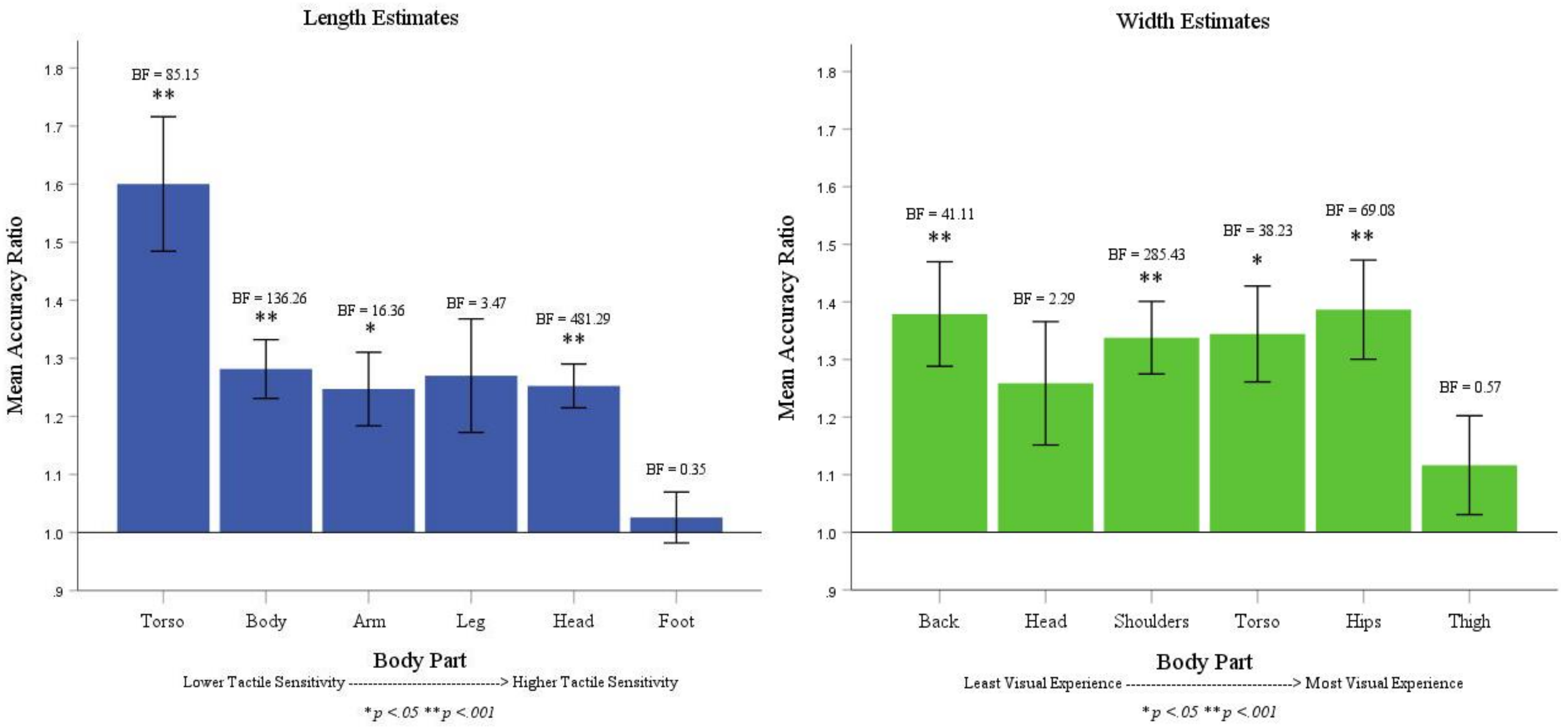
Doorn et al., 2021). The strength of evidence was judged according to the criteria provided by Kass & Raftery (1995) where Anecdotal evidence is regarded as inconclusive.

Results

Length Analyses

Prior to analysis, outliers ($n = 4$) identified using median absolute deviation were removed. A repeated-measures ANOVA showed that accuracy ratios significantly differed between Body Parts, $F(5, 50) = 6.83$, $p < .001$, $\eta_p^2 = 0.41$ (See Figure 1). Bayes Factor provided Extreme evidence for this conclusion ($BF = 1031.18$ ±0.19%).

Figure 1. *Mean accuracy ratios with* $^{+}/_{-}$ *1 standard errors (presented as error bars) for each body part estimate for the length (left) and width (right) conditions. The results of one-sample t-tests assessing over/underestimation of each body part are provided as Bayes Factors with significant findings indicated by an asterisk.*



To determine the pattern of differences in overestimation across body parts, Holm-Bonferroni corrected frequentist, and Bayes Factor, *t*-test pairwise comparisons were conducted based upon the order of tactile sensitivity shown in Figure 1 for length estimates. These comparisons provided Very Strong – Strong evidence that the torso, body, and head lengths were significantly overestimated relative to the foot (see Table 2). In addition, Moderate evidence supported an overestimation of the torso relative to the body, head and leg. Moderate evidence for the null hypothesis was found when comparing the body and leg, body and arm, arm and leg, leg and head, and arm and head whereas only Anecdotal support for the null hypothesis was found when comparing the body and head. Therefore, the torso was overestimated the most, and the foot the least.

Table 2. *Results of Holm-Bonferroni corrected pairwise t-tests with Bayes Factors comparing accuracy ratios between body parts for length.*

Pairwise comparison	Statistic	*BF*	*BF* Error (±%)
Torso – Body	$t(10) = 2.71$, $p = .022$	3.24	0.00
Torso – Arm	$t(10) = 2.41$, $p = .036$	2.17	0.00
Torso – Leg	$t(10) = 2.89$, $p = .016$	4.16	0.00

Torso – Head	*t(*10) = 2.69, *p* = .023	3.13	0.00
Torso – Foot	*t*(10) = 4.61, *p* <.001*	41.57	0.00
Body - Arm	*t*(10) = 0.71, *p* = .709	0.32	0.01
Body– Leg	*t*(10) = 0.15, *p* = .880	0.30	0.01
Body - Head	*t*(10) = 0.49, *p* = .491	0.37	0.01
Body - Foot	*t*(10) = 4.31, *p* = .002*	28.24	0.00
Arm – Leg	*t*(10) = -0.20, *p* = .848	0.30	0.01
Arm – Head	*t*(10) = -0.06, *p* = .953	0.30	0.01
Arm – Foot	*t*(10) = 2.39, *p* = .038	2.12	0.00
Leg – Head	*t*(10) = 0.19, *p* = .850	0.30	0.01
Leg – Foot	*t*(10) = 2.65, *p* = .024	2.98	0.00
Head – Foot	*t*(10) = 4.33, *p* = .001*	28.94	0.00

*Significant after Holm-Bonferroni adjusted alpha value

To determine whether any body parts were significantly over- or underestimated, Holm-Bonferroni adjusted frequentist, and Bayes Factor one-sample *t*-tests were conducted. Moderate – Very Strong evidence was found to suggest that the arm, full body, head, leg, and torso were overestimated (See Table 1 in the Supplemental Materials). In contrast, only Anecdotal support for the null hypothesis was observed for the foot. These findings are depicted in Figure 1. Therefore, as has been found in previous investigations using this methodology (Linkenauger et al., 2015; Readman et al., 2022; Sadibolova et al., 2019), systematic distortions were observed across body parts with large overestimations of the torso and full body.

Width Analyses

A repeated-measures ANOVA found that accuracy ratios significantly differed across body parts, $F(5, 70) = 2.54$, $p = .036$, $\eta_p^2 = 0.15$ (See Figure 1), however this had only Anecdotal support ($BF = 1.50$ ±0.16%).

After Holm-Bonferroni correction, no frequentist pairwise *t*-test comparisons were significant. However, Bayes Factors provided Moderate evidence to support overestimation of the back, shoulders, and hips relative to the thigh. Whereas Moderate evidence for the null hypothesis was found when comparing the back to the shoulders, the torso to the hips, the shoulders to the torso and hips, the head to the torso, and the torso to the hips, meaning there were no significant differences between estimates for these body parts. For all other comparisons, only Anecdotal support for the null (i.e., no difference between body parts), or alternative hypotheses (i.e., a significant difference between body parts) was observed (see Table 3). Therefore, according to Bayes Factors the back, shoulders, and hips were overestimated the most and the thigh the least, however as the frequentist tests approached, but did not reach significance for these comparisons, caution should be applied to this interpretation.

Table 3. *Results of Holm-Bonferroni corrected pairwise t-tests comparing accuracy ratios between body parts for width.*

Pairwise comparison	Statistic	*BF*	*BF* Error (±%)
Back – Head	$t(14) = 1.17$, $p = .260$	0.47	0.01

Back – Shoulders	*t*(14) = 0.53, *p* = .603	0.30	0.01
Back – Hips	*t*(14) = -0.09, *p* = .932	0.26	0.01
Back – Thigh	*t*(14) =3.15, *p* = .007	7.35	0.00
Head – Shoulders	*t*(14) = -1.01, *p* = .332	0.40	0.02
Head – Torso	*t*(14) = -0.68, *p* = .508	0.32	0.01
Head – Hips	*t*(14) = -0.97, *p* = .347	0.39	0.02
Head – Thigh	*t*(14) = 1.66, *p* = .120	0.80	0.02
Shoulders – Torso	*t*(14) = -0.08, *p* = .934	0.26	0.01
Shoulders – Hips	*t*(14) = -0.57, *p* = .578	0.30	0.01
Shoulders – Thigh	*t*(14) = 3.25, *p* = .006	8.67	0.00
Torso – Hips	*t*(14) = -0.57, *p* = .576	0.30	0.01
Torso – Thigh	*t*(14) = 2.58, *p* = .022	2.96	0.02
Hips – Thigh	*t*(14) = 2.78, *p* = .015	4.03	0.00

*Significant after Holm-Bonferroni adjustment

To determine whether estimates for width were significantly overestimated or underestimated, Holm-Bonferroni adjusted frequentist, and Bayes Factor, one-sample *t*-tests were conducted (see Table 2 in the Supplemental Materials). Strong – Extreme evidence supporting overestimation of the back, hips, shoulders, and torso was observed. Whereas only Anecdotal support for overestimation of the head was found. In contrast, there was Anecdotal evidence that estimates for the thigh were unbiased. Therefore, the shoulders, hips, back, and torso were overestimated. However, there was insufficient evidence to suggest estimates for the thigh or head were distorted. These findings are depicted in Figure 1.

Discussion

In accordance with the first hypothesis, and prior findings (Linkenauger et al., 2015; Readman et al., 2022; Sadibolova et al., 2019), differing patterns of length distortions were observed across body. Specifically, in line with the 'reverse distortion' hypothesis (Linkenauger et al., 2015), the torso was overestimated the most, and the foot the least, relative to other body parts.

Concerning width estimates, though frequentist analyses were indicative of differing patterns of distortions across body parts, Bayes Factors provided inconclusive evidence towards the null. At a body part level, Bayes Factors indicated that the torso, hips, shoulders and back were overestimated the most and the thigh the least. Whilst this pattern of distortion magnitude was not supported by frequentist comparisons (after correction for multiple comparisons), both one-sample frequentist t-tests and Bayes Factors indicated that the torso, hips, shoulders, and back were all significantly overestimated. As there was no difference between body parts ranking both higher (i.e., the hips) and lower (i.e., the back) on visual accessibility, differences in distortions do not appear to be related to visual experience with the body part.

It is also possible that, as has been observed for length (Linkenauger et al., 2015), tactile sensitivity could also influence width estimates. With respect to this, the reverse distortion hypothesis (Linkenauger et al., 2015) might expect body parts which are lower in tactile sensitivity along the horizontal axis to be overestimated more than those of higher sensitivity. However, whilst there is some evidence to suggest that some body parts exhibit tactile anisotropies (i.e., width is overestimated relative to length on tactile distance estimation tasks) (see Longo, 2015 for a review), the presence of anisotropies has not been investigated across all body parts estimated in this task. Moreover, studies mapping tactile acuity across the body tend to apply stimuli across the proximo-distal axis (e.g., Mancini et al., 2014), and therefore the tactile sensitivity of body across the medio-lateral axis, and whether this differs from the proximo-distal axis, is not known. Consequently, we were unable to make explicit hypotheses regarding the effects of tactile sensitivity on width estimations. Nevertheless, body parts which exhibit an overestimation of width relative to length on tactile distance estimation tasks, including the thigh (Green et al., 1982) and head (Longo et al., 2020), were not overestimated on this task. Therefore, width representations on this task may not derive from somatosensory representations, as has been suggested for findings from other tasks (Longo & Haggard, 2011). Moreover, given that overestimation was observed for both body parts which exhibit tactile anisotropies (e.g., the back; Nicula & Longo, 2021), but also those that do not (e.g., the torso; Longo et al., 2019), no clear inverse relationship between tactile anisotropies and overestimation is apparent. Thus, the reverse distortion hypothesis (Linkenauger et al., 2015) would also not provide a comprehensive account of these findings. In turn, the fact that overestimation was observed for body parts varying in both their degree of visual experience, and whether they exhibit tactile anisotropies, would also suggest that the combination of visual and somatosensory components also does not predict width estimations.

Alternatively, the overestimation of length, and of the width of the shoulders, torso, hips and back observed here could reflect an adaptive mechanism whereby individuals form a conservative, protective perceptual buffer which facilitates safe navigation of apertures. Conversely, prior evidence indicates that humans have a propensity to incorporate non-corporeal objects into the body schema (such as tools (e.g., Cardinali et al., 2009), or wheelchairs (e.g., Arnhoff & Mehl, 1963)). Given that participants were seated in Experiment 1, an alternative explanation is that the overestimation observed may reflect embodiment of the chair. Indeed, the fact that distortions were observed for body parts which the back of the chair extends out beyond, namely the torso, shoulders, hips, and back, could imply that the overestimation of these parts may reflect an expansion of the body representation to incorporate the back of the chair. Alternatively, the tactile stimulation of these parts arising from being seated on the chair may increase the salience of these body parts, potentially also enhancing the size of their representation. Nevertheless, previous research (Schontz, 1965) has failed to observe differences in width estimates between standing and seated postures. Yet, the sample size used for this study was relatively small and hence further research is required.

In addition, inaccuracies could also emerge from a lack of familiarity with the hand metric. Specifically, in Experiment 1, the hand width was defined by incorporating the knuckle of the thumb, a joint typically positioned below the level of the hand dorsum along the mediolateral axis. Therefore, participants may have struggled to visualise the metric used. Moreover, previous research has shown that hand width is already overestimated (Longo & Haggard, 2010; Longo & Haggard, 2011). Therefore, the distortions observed for other body parts may be a consequence of using an already distorted metric. Indeed, previous research investigating length representations using this paradigm has shown that length estimates using a hand-sized stick tend to be accurate, despite overestimation with the hand (Sadibolova et al., 2019; Linkenauger et al., 2015). Thus, it is possible that somatotopic distortions of hand width may be affecting representations of other body parts.

Experiment 2

To investigate whether the observed overestimations in length, and the width of the shoulders, torso, hips and back are artefacts of the measurement metric, or methodological set up (i.e. participants making estimates seated), a second experiment was conducted. In this experiment, participants estimated body part width using a new definition of the hand whilst in a standing posture. Furthermore, to investigate the influence of the type of metric, Experiment 2 compared estimates when using the hand, or a hand-sized stick.

We hypothesised, given the tendency for width to be overestimated on metric tasks (Longo, 2017), that width would be overestimated across body parts. Moreover, as the differing patterns of overestimation observed in Experiment 1 may have arose from an embodiment of the chair, we hypothesised that, in this standing experiment, width overestimation would be consistent across body parts for both hand and stick measures. In addition, given that previous research has shown that estimates with a hand-sized stick tend to be more accurate (Linkenauger et al., 2015), we hypothesised that estimates with this metric would be less biased.

Method

Sample Size

As with Experiment 1, the sample size for this experiment was based upon the findings of Sadibolova et al. (2019). However, as this experiment aimed to investigate whether body part estimates differed when using hand or hand-sized stick metrics, the effect size used was that for the interaction between metric and body part when estimating length in the Sadibolova et al. (2019) study (Cohen's f = 0.29). We estimated the sample size required to obtain a power of 0.95 using G*Power (Faul et al., 2009). The alpha value was set at .05 and, to be as conservative as possible, a small correlation among repeated measures of 0.2 was set. This power analysis showed that a minimum total sample size of N = 32 (n = 16 in each condition) was required.

Participants

Seventeen participants (16 females) aged 18-24 years (*M* = 19.35 years, *SD* = 1.73) were randomly assigned to the Hand group and a further sixteen participants (10 females) aged 18-22 years (*M* = 19.50 years, *SD* = 1.10) were randomly assigned to the Stick group.

Design and Procedure

Following the design employed in previous paradigms with length estimates (Sadibolova et al., 2019), a between-subjects design with separate participants in the Hand and Stick conditions was employed. In this experiment, only body part width was estimated with participants estimating the same body parts as in the width condition of Experiment 1.. The same procedure was performed as in Experiment 1, except estimates were performed in-person with the researcher taking the actual measurements of participants' body parts once all estimates had been made. Prior to beginning the experiment, participants' hand widths were measured, and they were told that these measurements were to be used for a later experiment taking place after the current experiment. Hand width was defined as *the first knuckle of the index finger to the first knuckle of the little finger*, roughly at the metacarpo-phalangeal joints. For stick estimates, the metric was defined by a piece of tape which marked a distance from one end of the stick equivalent to the measure of the participant's hand width taken at the beginning of the experiment. Participants were not aware that the stick length was equivalent to their hand width.

Analysis

As with Experiment 1, Holm-Bonferroni adjusted and Bayes Factor one-sample *t*-tests were used to determine whether accuracy ratios differed significantly from one (complete accuracy) for body part estimates in each group.

In addition, to understand whether there were differences in accuracy across body parts, conditions, or an interaction between these two variables a Mixed ANOVA was conducted. Condition (Hand or Stick) was entered as the between-subjects variable and Body Part as the repeated-measures variable. A mixed ANOVA was used as this analysis allowed conclusions as to whether distortions differed across conditions (and hence, whether different representations are drawn upon for the different metrics), as well as across body parts.

Results

After removal of four outliers, results of a mixed ANOVA indicated that accuracy differed across body parts $F(5,135) = 4.13$, $p = .002$, $\eta_p^2 = 0.13$. Holm-Bonferroni adjusted pairwise comparisons indicated that the hips were significantly overestimated relative to the shoulders, with Bayes Factors providing Strong support for this conclusion. After Holm-Bonferroni adjustment, no other pairwise comparisons were significant, however Bayes Factors found Moderate support that the hips were overestimated relative to the thigh, and that the shoulders were underestimated relative to the hips, back, and head. In addition, there was Moderate evidence to suggest accuracy did not differ between estimates for the torso, head, and back. For all other comparisons, only anecdotal support for the existence of a difference, or no difference between body parts was provided (See Table 4). Therefore, across body parts there was a pattern of overestimation of the hips and an underestimation of the shoulders relative to other body parts.

Table 4. *Holm-Bonferroni adjusted pairwise comparisons for accuracy ratios across body parts.*

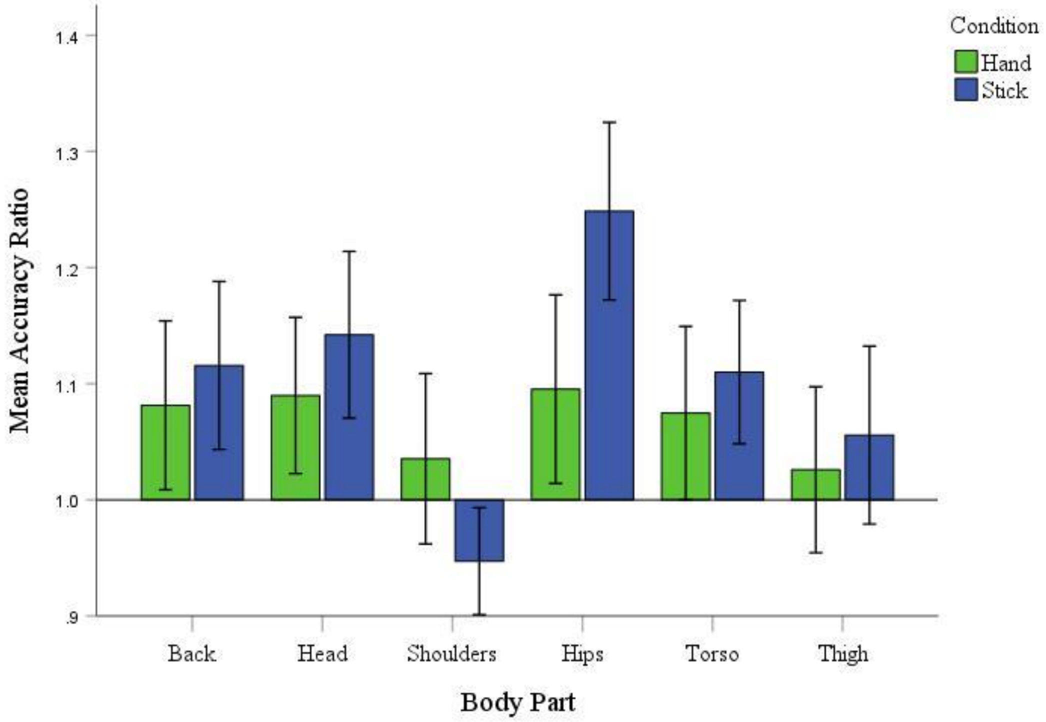
Pairwise comparison	Statistic	*BF*	*BF* Error (±%)
Back – Head	$t(28) = -0.36$, $p = .723$	0.21	0.03

Back – Shoulders	$t(28) = 2.75$, $p = .010$	4.15	0.00
Back – Torso	$t(28) = 0.20$, $p = .847$	0.20	0.03
Back – Hips	$t(28) = -1.70$, $p = .099$	0.71	0.03
Back – Thigh	$t(28) = 1.46$, $p = .155$	0.51	0.03
Head – Shoulders	$t(28) = 2.63$, $p = .014$	3.48	0.00
Head – Torso	$t(28) = 0.55$, $p = .589$	0.23	0.03
Head – Hips	$t(28) = -1.05$, $p = .303$	0.33	0.03
Head – Thigh	$t(28) = 1.43$, $p = .163$	0.49	0.03
Shoulders – Torso	$t(28) = -2.55$, $p = .016$	2.99	0.00
Shoulders – Hips	$t(28) = -3.55$, $p = .001$*	24.92	0.00
Shoulders – Thigh	$t(28) = -1.23$, $p = .231$	0.39	0.03
Torso – Hips	$t(28) = -1.70$, $p = .101$	0.71	0.03
Torso – Thigh	$t(28) = 1.22$, $p = .231$	0.39	0.03
Hips – Thigh	$t(28) = 2.85$, $p = .008$	5.46	0.00

*Significant after Holm-Bonferroni adjustment.

In contrast, there was no significant main effect of Condition, $F(1, 27) = 0.19$, $p = .669$, $\eta_p^2 = 0.01$ and no significant interaction $F(5,135) = 1.56$, $p = .175$, $\eta_p^2 = .06$ (See Figure 2).

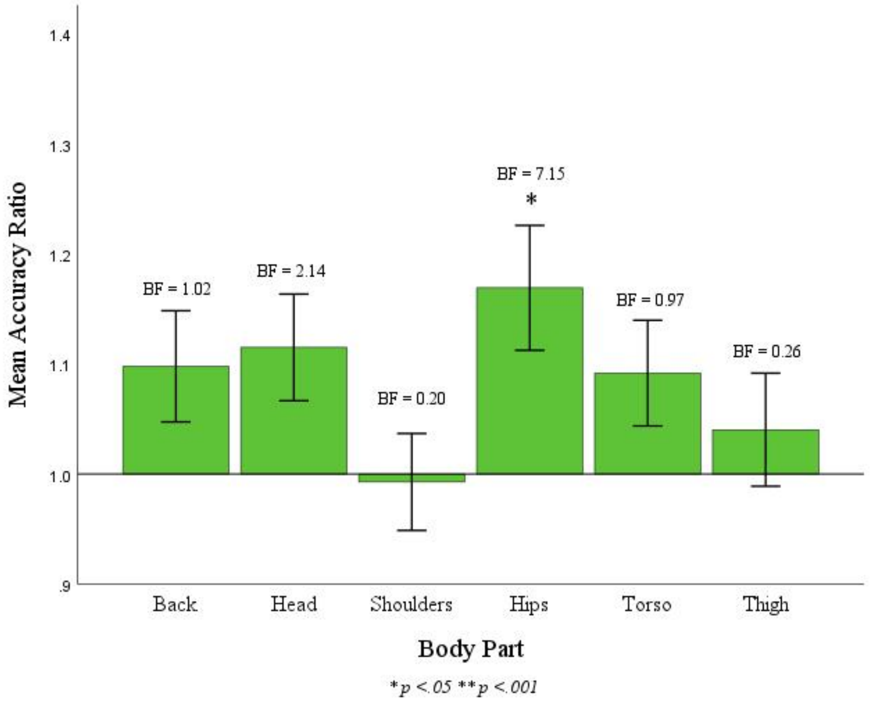
Figure 2. *Mean accuracy ratios* $^{+}/_{-}$ *1 standard error for each body part in the Hand condition and the Stick condition).*



To provide additional support for the frequentist conclusions, a Bayes Factor mixed ANOVA was conducted. We found Strong evidence to support a main effect of Body Part relative to the null hypothesis that there was no effect of this variable (*BF* = 11.24 ±0.73%). In contrast, there was Anecdotal evidence favouring the null hypothesis that there was no main effect of Condition (*BF* = 0.44 ±1.11%). In addition, there was Anecdotal evidence to suggest that including both the main effects of Condition and Body Part did not improve model fit relative to including the main effect of Body Part alone (*BF* = 0.41 ±3.25%). Moreover, there was Strong evidence to suggest that including the interaction did not significantly improve the fit of the model, relative to a model containing only the main effect of Body Part (*BF* = 0.15 ±5.16%). Therefore, a model with only Body Part was the best fit to the data, supporting the frequentist conclusion of a significant effect of this variable, but not Condition or the interaction. Hence, in contrast to previous investigations with length (Linkenauger et al., 2015), estimates for the hand and stick metrics did not differ.

To determine whether mean accuracy ratios for any body part differed significantly from 1.0, we conducted Holm-Bonferroni adjusted and Bayes Factor one-sample *t*-tests. As no significant difference between measurement conditions was observed, these were conducted using the full sample, collapsed across conditions. There was Moderate Evidence to suggest the hips were overestimated and the torso and thigh were unbiased (see Table 3 in Supplemental Materials 1). All other body parts were supported by only Anecdotal evidence. These findings are depicted in Figure 3.

Figure 3. *Mean accuracy ratios with* $^{+}/_{-}$ *1 standard errors (presented as error bars) for each body part estimate collapsed across Hand and Stick Conditions. The results of one-sample t-tests assessing over/underestimation of each body part are provided as Bayes Factors with significant findings indicated by an asterisk.*



Discussion

Previous findings with length have shown that distortions are drastically reduced when using a hand-sized stick, versus the hand as a metric (Linkenauger et al., 2015). This finding is thought to reflect the influence of somatosensory distortions on perceptual representations when comparing body parts. Therefore, in Experiment 2, we also expected to find reduced distortions in the stick condition. However, contrary to expectations, no significant difference between estimates for the stick and the hand were observed. Consequently, this finding could suggest that when estimating width, representations may not derive from somatosensory components.

Moreover, we expected to observe consistent overestimation across body parts. However, whilst estimations were mostly consistent, with the exception of the hips, body part estimates were not significantly different from an unbiased estimate. Possibly, the discrepancy between the findings of Experiment 1 and 2 could arise from the differences in postural stance employed. Specifically, in Experiment 2 participants performed estimates whilst standing whereas Experiment 1 had participants perform estimates seated. Therefore, width overestimations in Experiment 1could be attributed to an embodiment of the chair, rather than an overrepresentation of body part width *per se.*

Experiment 3

Experiments 1 and 2 assessed the estimation of the length and width of one’s own body, thus it is unclear whether these body representations are inherent to only self-perception or generalise to body perception more generally. Previous research has shown that length estimates for another person follow similar patterns of distortions as those observed for the self (Linkenauger et al., 2017). Consequently, in Experiment 3, participants made the same width estimates as in Experiment 2, but for another person. We hypothesised that width estimates using the hand and a hand-length stick will follow the same patterns as those observed in Experiment 2.

Method

Participants

A total of 32 (all female) participants, took part in this experiment. Sixteen participants aged 18-51 years (*M* = 23.00 years, *SD* = 8.22) were randomised to the Hand group and 16 participants aged 18-28 years (*M* = 21.30 years, *SD* = 2.89) were randomised to the Stick group. The sample size for this experiment was based upon the same power analysis used in Experiment 2.

Design and Procedure

The same methodology as for Experiment 2 was used, except that participants were asked to make estimates for another person. All participants made estimates for the same person, a female aged 23 years, of average body type (approximately 5 foot 2 inches, and 52 kilograms). The person to estimate stood facing the participants and held up their hand or a stick (in a horizontal orientation) of the same length as the model's hand width. Participants followed a similar procedure to Experiments 1 and 2, however instead of using their own hand/stick and body parts, they estimated how many of the other person's hands/hand-sized stick made up the width of the other person's body parts. The same body parts used in Experiments 1 and 2 were estimated. Participants were allowed to instruct the person to adjust her position/orientation so that they could have a better view of the body part they were estimating**.**

Analysis

Analysis was conducted using the same procedure as Experiment 2.

Results

After removal of outliers, a mixed ANOVA found that accuracy differed significantly across body parts $F(5,110) = 36.00$, $p < .001$, $\eta_p^2 = 0.62$. Holm-Bonferroni adjusted *t*-test pairwise comparisons indicated that the shoulders and head were significantly underestimated relative to the torso, back, thigh and hips with Extreme evidence supporting this conclusion. No other frequentist analyses reached significance. In addition, there was Moderate evidence to suggest that estimates for the hips, back, thigh, and torso did not differ in their accuracy. Only Anecdotal evidence was found to suggest that accuracy for shoulder and head estimates did not differ. Therefore, the torso, back, thigh, and hips were overestimated the most and the shoulder and head the least (Table 5).

Table 5. *Holm-Bonferroni adjusted pairwise comparisons for accuracy ratios across body parts.*

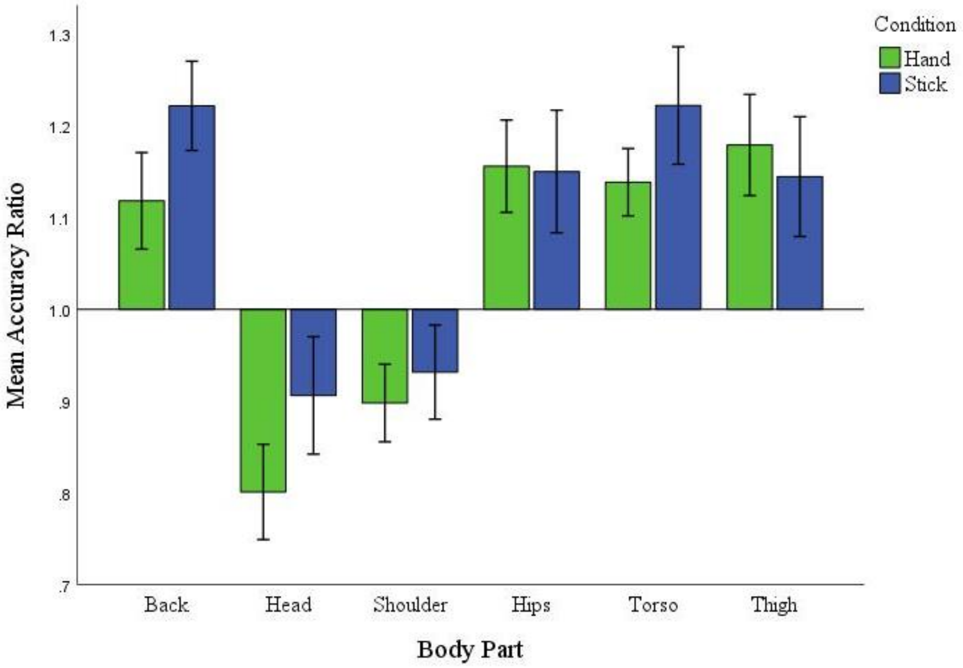
Pairwise comparison	Statistic	*BF*	*BF* Error (±%)

Back – Head	$t(23) = 7.97$, $p = <.001$*	3.10 x 10^5	0.00
Back – Shoulders	$t(23) = 8.35$, $p = <.001$*	6.56 x10^5	0.00
Back – Torso	$t(23) = -0.36$, $p = .724$	0.23	0.02
Back – Hips	$t(23) = 0.92$, $p = .366$	0.31	0.03
Back – Thigh	$t(23) = 0.43$, $p = .673$	0.23	0.02
Head – Shoulders	$t(23) = -1.52$, $p = .141$	0.59	0.03
Head – Torso	$t(23) = -7.29$, $p = <.001$*	78193.85	0.00
Head – Hips	$t(23) = -7.03$, $p = <.001$*	45696.68	0.00
Head – Thigh	$t(23) = -6.21$, $p = <.001$*	7823.94	0.00
Shoulders – Torso	$t(23) = -8.96$, $p = <.001$*	2.11 x10^6	0.00
Shoulders – Hips	$t(23) = -7.62$, $p = <.001$*	1.54 x10^5	0.00
Shoulders – Thigh	$t(23) = -7.90$, $p = <.001$*	2.71 x10^5	0.00
Torso – Hips	$t(23) = 1.09$, $p = .287$	0.36	0.03
Torso – Thigh	$t(23) = 0.63$, $p = .547$	0.26	0.02
Hips – Thigh	$t(23) = -0.26$, $p = .799$	0.22	0.02

*Significant after Holm-Bonferroni adjustment

No significant effect of Condition, $F(1,22) = 0.52$, $p = .477$, $\eta_p^2 = 0.02$, or the interaction $F(5,110) = 1.45$, $p = .211$, $\eta_p^2 = 0.06$ was observed (see Figure 4).

Figure 4. *Mean accuracy ratios $^+/_-$ 1 standard error for each body part in the Hand condition and the Stick condition).*

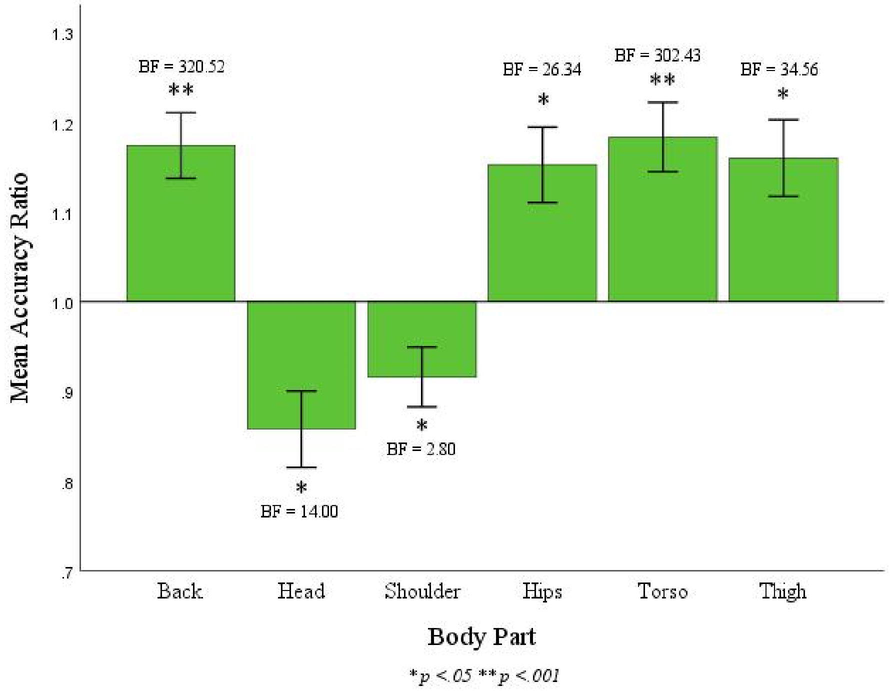


To provide additional support to the frequentist conclusions, a Bayes Factor mixed ANOVA was conducted. There was Extreme evidence to support a main effect of Body Part, relative to no effect (*BF* = 3.95 x 10^{18} ±0.58%). Therefore, variance in Body Part estimates predicted variance in accuracy scores. In contrast, there was only Anecdotal evidence supporting no effect of Condition (*BF* = 0.41 ±0.72%). Furthermore, there was Anecdotal evidence to suggest that including both the main effects of Condition and Body Part did not improve the model fit relative to including the main effect of Body Part alone (*BF* = 0.54 ±1.7%). Moreover, there was Moderate evidence to suggest that including both the main effects and the interaction did not improve the model fit relative to a model containing only the main effect of Body Part (*BF* = 0.18 ±1.48%). Therefore, a model with only Body Part was the best fit to the data, supporting the frequentist conclusion of a significant effect of this variable, but not Condition or the interaction. Therefore, as in Experiment 2, hand and stick estimates did not differ significantly. However, different patterns of distortions were observed between these two experiments. Specifically, overestimation of the thigh and underestimation of the head were found in Experiment 3, in contrast, overestimation of the hips was seen in Experiment 2.

To determine whether these differences between self and other estimates were significant, an additional, exploratory analysis was conducted. Specifically, hand estimates for another person from Experiment 3 were compared to hand estimates in Experiment 1 and Experiment 2 using separate mixed ANOVAs. In addition, stick estimates from Experiment 3 were compared to stick estimates for the self from Experiment 2. For all models, a significant interaction between Estimation Condition (self or other) and Body Part was observed (see Supplemental Materials 2). Specifically, in all three models the head was underestimated for another person relative to estimates for the self (though this only approached significance after Holm-Bonferroni correction for stick estimates). Therefore, it appears that individuals may underestimate the head of another, relative to when individuals are asked to estimate their own head width. Thus, whilst previous research with both adults (Linkenauger et al., 2017) and children (Speranza & Ramenzoni, 2022) has indicated that distortions follow similar patterns when estimating the length of the self and another person, width estimates appear to differ when estimating the self versus another person.

As in Experiments 1 and 2, Holm-Bonferroni adjusted frequentist, and Bayes Factor, one-sample *t*-tests were conducted to determine whether estimates for each body part differed significantly from 1.0. As there was no difference between Stick and Hand conditions, these were performed collapsed across metric conditions for each body part (see Table 4 in Supplemental Materials 1). There was Strong – Extreme evidence that the hips, back, torso, and thigh were overestimated. In addition, Strong evidence was found to suggest the head was underestimated, whereas evidence that the shoulders were underestimated was only Anecdotal. These results are depicted in Figure 5.

Figure 5. *Mean accuracy ratios with* $^{+}/_{-}$ *1 standard errors (presented as error bars) for each body part estimate collapsed across Hand and Stick Conditions. The results of one-sample t-tests assessing over/underestimation of each body part are provided as Bayes Factor with significant findings indicated by an asterisk.*



Discussion

The aim of Experiment 3 was to ascertain whether the patterns of width estimations seen in Experiment 2 are unique to representations of the self, or whether they represent a more general perceptual mechanism. In contrast to the mostly unbiased patterns of estimations observed for the self in Experiment 2, when estimating another, participants overestimated the torso, back, thigh, and hips. Whilst these findings therefore show some similarities to Experiment 1, the shoulders were overestimated and the head trended towards this in Experiment 1, whereas the head and shoulders were underestimated for another person. Furthermore, when comparing findings to those of Experiments 1 and 2, it was found that the head was underestimated for another person, more than when estimating the self.

Moreover, patterns of distortions did not differ significantly when using the hand, or a hand-length stick as the metric, indicating a common representation may have been used for both metrics.

In turn, these results contrast with previous investigations of length estimates wherein participants' estimates of another person showed a similar pattern of distortions as to those observed for the self (Linkenauger et al., 2017). Additionally, the pattern of distortions observed for length estimates of the self have also been consistent across numerous studies (Linkenauger et al., 2015; Sadibolova et al., 2019; Readman et al., 2022). Thus, this finding suggests that whilst a similar representation may be engaged when making length estimates for the self and others, for width estimates, the process is less clear.

Experiment 4

Experiment 4 constituted a further investigation into the discrepancies observed between the findings of Experiment 1 and Experiment 2. Specifically, when performing estimates whilst seated (Experiment 1), overestimation of the back, torso, hips, and shoulders was observed. In contrast, when making estimates from a standing position (Experiment 2) individuals' estimates were unbiased. Hence, it is possible that the differences in findings between these two experiments could be attributable to postural differences.

To investigate this further, participants were randomly assigned to one of three conditions: standing, seated upon a chair, or seated upon a stool. The stool was used as a control condition. If overestimation whilst seated does reflect embodiment of the back of the chair, then overestimation should not be expected when seated upon a backless stool. Therefore, we hypothesised that there would be a main effect of Condition with greater overestimation in the Chair condition relative to the Standing and Stool conditions. In addition, a significant interaction was expected whereby overestimation of the back, torso, hips, and shoulders was expected to be greater in the Chair condition relative to the Standing and Stool conditions.

Method

Sample Size

A new power analysis was conducted for this experiment. This is because, for Experiments 1-3, the power analysis was based upon the findings of Sadibolova et al. (2019), who found medium-large effect sizes for differences across body parts and the body part by metric interaction, whereas Experiment 4 aimed to compare body part estimates across different postural conditions. Hence, we also needed to obtain power for an interaction between postural conditions and body parts. Given the relative novelty of the experimental design, we had no suitable data upon which to base estimates of effect size. Therefore, power was simulated using the ANOVA_power shiny app (Lakens & Caldwell, 2021; https://shiny.ieis.tue.nl/anova_power/). Power was estimated for a 3x6 mixed ANOVA with subsequent Holm-Bonferroni adjusted pairwise comparisons. Condition (3 levels: Standing, Chair, or Stool) was entered as the between-subjects variable, and Body Part (6 levels: Shoulders, Back, Torso, Hips, Thigh, and Head) formed the within-subjects variable.

The common standard deviation entered into the simulation was 0.31. This was calculated by averaging across the standard deviations in Experiments 1 and 2. For the Chair condition, the mean body part estimates were taken from Experiment 1, whereas the means for the Standing and Stool conditions were taken from Experiment 2. Experiment 2 was used to estimate means for the Stool condition because, if overestimation occurs due to an embodiment of the back of the chair, then we would expect estimates for a backless stool to be unbiased. Given the large main effect of body size observed in both Experiment 1 and 2, sufficient power to observe a large effect size ($\eta_p^2 \geq 0.15$) was desired for this variable. As there was no suitable data from which to base an estimate of effect size for the effects of Condition and the interaction, power to detect a small effect size ($\eta_p^2 < 0.06$) was sought for these effects. In turn, by seeking to obtain power to observe small effect sizes for these comparisons, we acknowledged that the required sample size for this study was likely to be much higher than that of Experiments 1-3 where medium-large effect sizes were expected. The number of simulations was set at 2000 with an alpha level of 0.05. A minimum desired power of 0.80 was required for all effects in the model.

Based upon these parameters, a total sample size of $N = 99$ ($n = 33$ in each condition) was required to obtain sufficient power.

Participants

Participants were required to be aged 18-55 years with no previous, or current psychiatric, visual, or cognitive impairment, or diagnosis of an eating disorder. Participants were not excluded on the basis of a diagnosis of anxiety, or depression given that previous research has shown that the presence of these variables does not bias results in healthy younger controls (Readman et al., 2022).

A total of 123 (61 females) participants ranging from 18 to 68 years (M = 28.80 years, SD = 10.79) were recruited via opportunity sampling for this study. A higher sample size was initially recruited to ensure sufficient power was present after excluding participants who did not make the inclusion criteria. A total of 15 participants were excluded for failing to meet the inclusion criteria, leaving a final sample of N = 108 (50 females) participants ranging from 18 to 55 years (M = 27.98 years, SD = 9.56).

Reasons for exclusion included a current or historic psychiatric impairment ($n = 2$) or eating disorder ($n = 4$), falling outside the study age restrictions ($n = 3$), visual impairment (*n*

= 2), being pregnant (*n* = 1), failing to provide demographic information needed to determine eligibility (*n* = 2), and a self-reported misunderstanding of task instructions (*n* = 1).

Design and Procedure

After providing consent and completing a short self-report demographic and clinical questionnaire, participants were randomised to one of the three conditions (Standing, Chair, or Stool). After being allocated to a condition, participants followed the same procedure as the previous experiments. Only hand estimates were performed with the hand definition used corresponding to that of Experiments 2 and 3.

Participants in the Standing condition performed all estimates whilst stood upright, without leaning on any surfaces. In the Chair condition, participants were seated upon a standard desk chair with a high back and no arm rests. In the Stool condition, participants were seated upon a fixed height bar stool with no back. Participants completed only one of the three conditions with the condition completed counterbalanced across participants. The order of body parts estimated was randomised for each participant.

After participants made their estimates, the researcher measured the actual width of their body parts using a tape measure. The study took around 10 minutes to complete.

Analysis

Outliers in this experiment were removed using the same approach as in Experiments 1-3.

To test the study hypotheses that patterns of distortions differ across different postures, the data was analysed using both frequentist, and Bayes Factor, 3x6 mixed ANOVAs. Body Part was entered as the within-subjects variable, and Condition as the between-subjects variable. All assumptions were checked prior to conducting the analysis. As in previous experiments, where the sphericity assumption was violated, results are reported after the Hunyh-Feldt correction.

Where a significant main effect of Body Part or Condition was observed, Holm-Bonferroni adjusted frequentist, and Bayes Factor, pairwise t-test comparisons were conducted to determine the differences underlying these effects.

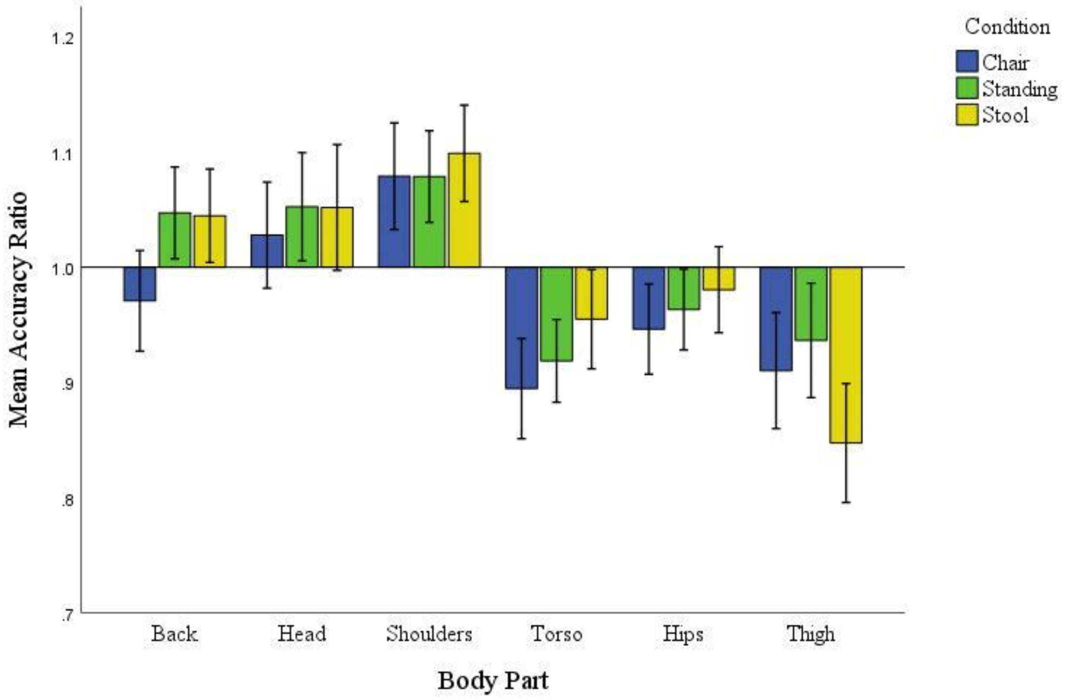
As in the previous experiments, to determine whether body part width estimates differed significantly from 1.0 (i.e., an unbiased estimate), Holm-Bonferroni adjusted frequentist, and Bayes Factor, one-sample *t*-tests were conducted for each body part.

Results

After removing outliers ($n = 11$), Mauchly's test for sphericity indicated the assumption of sphericity was violated. Therefore, the Hunyh-Feldt correction was applied to the necessary analyses.

A significant main effect of Body Part was observed $F(3.55, 333.45) = 0.71$, $p < .001$, $\eta_p^2 = 0.14$, indicating that accuracy ratios differed across body parts. However, there was no effect of Condition $F(2,94) = 0.27$, $p = .764$, $\eta_p^2 = 0.01$, and no significant interaction (see Figure 6), $F(7.09, 333.45) = 0.71$, $p = .589$, $\eta_p^2 = 0.02$.

Figure 6. *Mean accuracy ratios ⁺/₋ 1 standard error for each body part in each condiion (Chair, Standing, and Stool).*



Findings from the Bayesian Mixed ANOVA indicated extreme evidence in favour of a main effect of Body Part, relative to the null model (*BF* = 5.31 x10^{10} 0.57%). In contrast, there was Strong evidence that a model containing only the main effect of Condition did not significantly improve on the null model (*BF* = 0.11 ±0.96%). In addition, there was Moderate evidence to suggest that adding both the main effects of Condition and Body Part did not improve model fit relative to a model containing only the main effect of Body Part, (*BF* = 0.11 ±0.94%), indicating no additive effect of Condition in the model. Moreover, there was Extreme evidence for the null hypothesis that a model containing both main effects and the interaction did not improve model fit relative to a model containing the main effect of Body Part only (*BF* = 9.72 x10^{-4} ±0.95%). Consequently, the Bayesian ANOVA corroborated frequentist conclusions that only a main effect of Body Part was present in the data.

To ascertain how accuracy ratios differed across body parts, pairwise Holm-Bonferroni adjusted frequentist, and Bayesian, *t*-test comparisons were conducted (see Table 6). Bayes Factors provided Strong evidence to suggest that the shoulders were overestimated relative to the back and Moderate-Extreme evidence that the back, shoulders, and head were overestimated relative to the torso, hips, and thigh. Whereas there was only Anecdotal evidence to suggest the hips were overestimated relative to the thigh. In contrast, there was Moderate evidence to suggest accuracy ratios did not differ when comparing the back and head, shoulders and head, and torso and thigh. Therefore, the shoulders and head were overestimated the most and the torso and thigh the least.

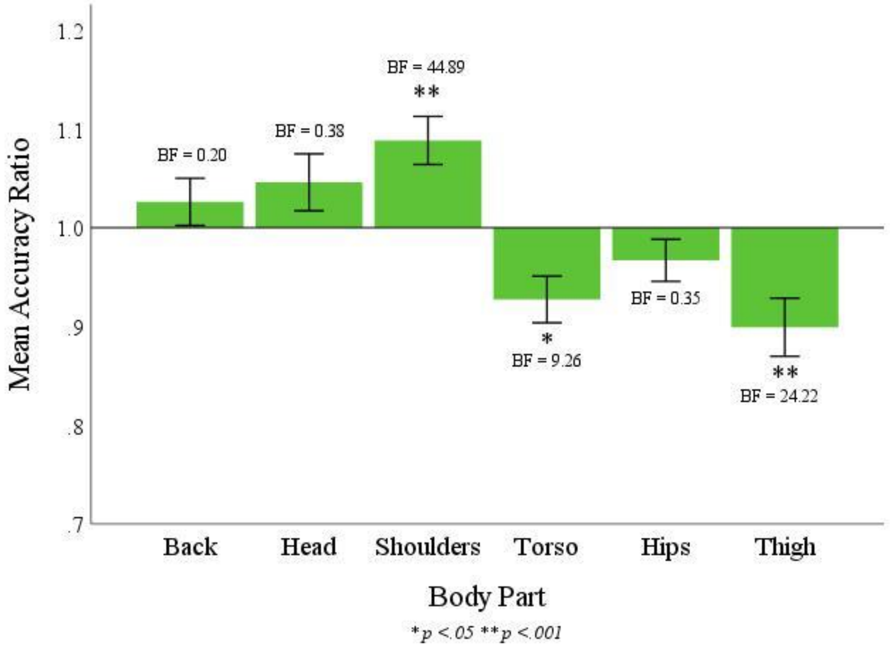
Table 6. *Results of Holm-Bonferroni adjusted and Bayesian pairwise t-tests comparing accuracy ratios across body parts.*

Pairwise comparison	Statistic	*BF*	*BF* Error (±%)
Back – Head	*t*(96) = -0.65, *p* = .520	0.14	0.12
Back – Shoulders	*t*(96) = -3.11, *p* = .002*	9.94	0.00
Back – Torso	*t*(96) = 5.54, *p* = <.001*	48957.69	0.00
Back – Hips	*t*(96) = 3.01, *p* = .003*	7.63	0.00
Back – Thigh	*t*(96) = 3.90, *p* <.001*	110.49	0.00
Head – Shoulders	*t*(96) = -1.33, *p* = .187	0.26	0.07
Head – Torso	*t*(96) = 4.14, *p* = <.001*	241.10	0.00
Head – Hips	*t*(96) = 2.65, *p* = .010	3.01	0.01
Head – Thigh	*t*(96) = 4.91, *p* = <.001*	4042.09	0.00
Shoulders – Torso	*t*(96) = 7.79, *p* = <.001*	1.08×10^9	0.00
Shoulders – Hips	*t*(96) = 6.15, *p* = <.001*	6.38×10^5	0.00
Shoulders – Thigh	*t*(96) = 6.02, *p* = <.001*	3.73×10^5	0.00
Torso – Hips	*t*(96) = -2.33, *p* = .022	1.47	0.02
Torso – Thigh	*t*(96) = 0.91, *p* = .366	0.17	0.10
Hips – Thigh	*t*(96) = 2.14, *p* = .035	0.99	0.02

*Significant after Holm-Bonferroni adjustment

To determine whether accuracy ratios differed significantly from 1.0 (i.e., an unbiased estimate), Holm-Bonferroni corrected frequentist, and Bayesian, one-sample *t*-tests were conducted. Given that no significant main effect of Condition, or an interaction between Condition and Body Part was observed, these were performed using the full sample for each body part (see Table 5 in the Supplemental Materials). There was Strong evidence to suggest the Shoulders were overestimated, and the Torso and Thigh were underestimated. In contrast, there was Strong evidence to suggest that estimates did not differ from the null for the Back, hence estimates for this body part were unbiased. Whereas there was only Anecdotal evidence to suggest that estimates for the Hips and Head were accurate. The results of these *t*-tests are depicted in Figure 7.

Figure 7. *Mean accuracy ratios with $^{+}/_{-}$ 1 standard errors (presented as error bars) for each body part estimate collapsed across posture conditions. The results of one-sample t-tests assessing over/underestimation of each body part are provided as Bayes Factor with significant findings indicated by an asterisk.*



Discussion

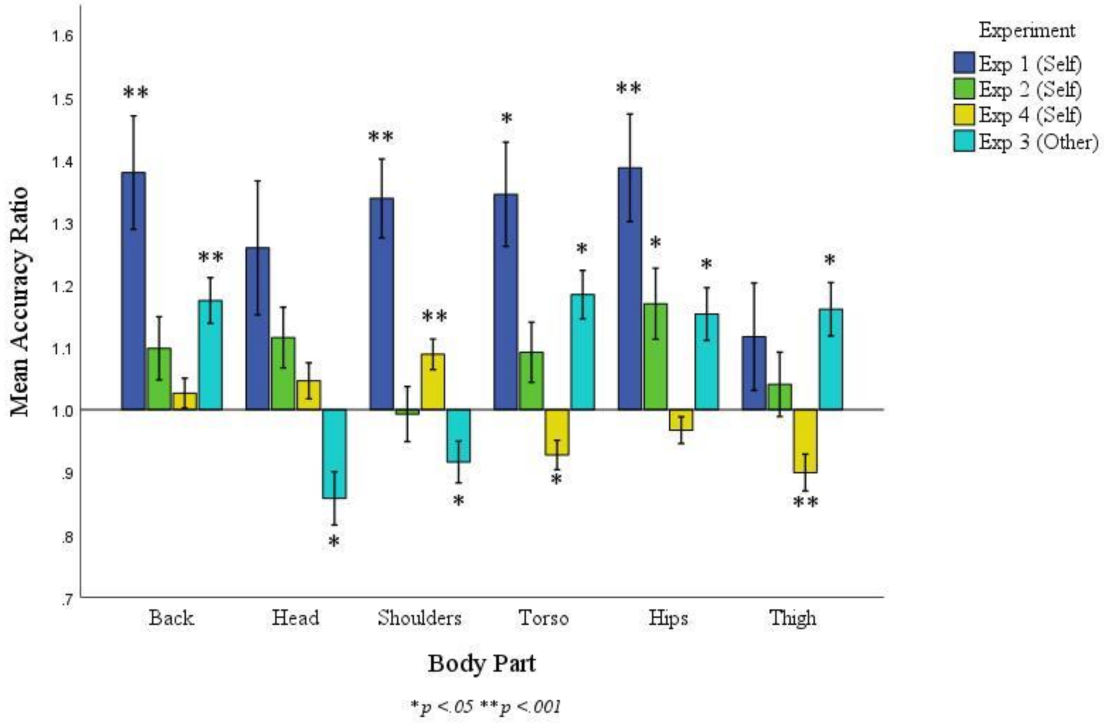
The aim of Experiment 4 was to determine whether width representations vary with posture. In contrast to the study hypotheses, no effect of condition, or the interaction was observed. In turn, these findings corroborate with that of Shontz (1965) who observed no differences in width estimates between standing and seated postures. Therefore, width estimates do not appear to be moderated by posture.

As with Experiments 1 and 2, width estimates were found to vary across body parts. However, the patterns of distortions were not the same as were observed in either of these experiments. Specifically, in this experiment, the shoulders were overestimated and the thigh and torso were underestimated. In addition, estimates for the back were unbiased and those for the head and hips trended towards this. In contrast, in Experiment 1, overestimation was observed for the torso, back, hips, and shoulders and in Experiment 2 no over, or underestimation of body parts was found. Therefore, in contrast to the consistent pattern of distortions observed when estimating body part length (Linkenauger et al., 2015; Readman et al., 2022; Sadibolova et al., 2019), these findings suggest width representations vary across individuals and contexts.

Summary of Results

To aid visualisation of the main findings across experiments, Figure 8 depicts mean accuracy ratios for each body part in each experiment. As no differences were observed between hand and stick metrics (Experiments 2 and 3), or across postures (Experiment 4), for simplicity, estimates have been collapsed across these conditions.

Figure 8. *Mean accuracy ratios* $^{+}/_{-}$ *1 standard error for each body part in each Experiment, collapsed across any experimental conditions. Asterixis denote body parts which were significantly over/underestimated in each experiment.*



Note. To aid visualisation, Experiments 1, 2, and 4 are presented adjacent to each other such that patterns for self-estimates across experiments are clear. Estimates of another person (Experiment 3) form the right-most bar for each body part.

Exploratory Analyses

As Experiments 1 and 2 included only a small number of male participants, we conducted a series of exploratory analyses to determine whether the pattern of findings changed when using a solely female sample. It was found that the pattern of findings according to Bayes Factors remained the same with the female-only sample (see Supplemental Materials 3).

In addition, using median absolute deviation for outlier identification resulted in a number of participants being excluded across experiments. Therefore, we conducted a series of exploratory analyses to determine whether the pattern of findings changed when considering the full sample (Supplemental Materials 4). The width estimates in Experiment 1 were not included in these analyses given that no outliers were excluded in this experiment. It was found that, across experiments, though the significance of some individual pairwise comparisons were different, the direction of effects from ANOVA analyses and the overall patterns of distortion magnitude did not change when analysing the full sample.

General Discussion

This study explored how non-clinical individuals represent the width of their body parts, or those of another, relative to the hand (or a hand-sized stick). Contrary to our expectations, we did not observe a consistent pattern of body part width distortions across experiments. Specifically, for self estimates, where the torso, hips, back and shoulders were overestimated in Experiment 1, estimates for these body parts were mostly unbiased in Experiment 2 whereas Experiment 4 found underestimation of the torso and thigh and overestimation of the shoulders. Similarly, the patterns of distortion magnitude also varied across experiments. Whilst some trends were noticeable, for example, accuracy ratios for the back and head were consistently greater than one across all three self-estimation experiments, whether these accuracy ratios reflected significant overestimation or unbiased estimates for these body parts still varied across experiments. Moreover, self-estimates did not appear to be moderated by the metric used (Experiment 2) or participants' posture when making estimates (Experiment 4). When estimating another, estimates also did not differ across metrics, but participants tended to underestimate the head and shoulders and overestimate other body parts (Experiment 3).

Heterogeneity in width estimations has also been observed across other metric tasks within non-clinical groups. For example, when participants estimate body part width by adjusting points on a horizontal bar, some have observed accurate estimates for the hips and waist (Slade & Russell, 1973; Button et al., 1977), whereas others have found the waist to be overestimated (Proctor and Morley, 1986; Casper et al., 1979). Similarly, when making estimates by adjusting the distances between two cuffs, in some studies participants overestimate the head, hips, and waist (Shontz, 1963,1965& 1967), whilst in others the waist is underestimated (Hester, 1970). Taken together, these findings could suggest that representations of body part width are not stable and vary across individuals and tasks.

Successful navigation of apertures within our environments is dependent upon one's ability to accurately perceive the relationship between aperture width and one's body width. Therefore, at first glance, an unstable representation of body width may appear maladaptive. Yet, within affordance accounts (Gibson, 1979), judgements of object length and width can be obtained from the visual angle between the object and the perceiver's eye height (Sedgwick, 1973; see Sedgwick, 2021). More specifically, judgements of aperture width can be derived from perceiving the ratio of the horizontal visual angle of an object at eye height, to the declination angle (the angle specifying the relationship between eye height and the base of the object) (see Warren, 2021 for a discussion). As eye height is four times greater than shoulder width on average, individuals can use optical information to judge passability, without an implicit representation of shoulder width.

Indeed, despite seemingly heterogenous perceptions of body width within non-clinical populations, healthy individuals display a consistent critical value (the ratio of shoulder width to aperture width) of around 1.16 when judging aperture passability (Warren & Whang, 1987). Furthermore, Franchak et al. (2010) found height was the strongest predictor of individuals' judgements when traversing apertures, with body width contributing very little variance. Critically, decreasing the declination angle by secretly raising floor height leads participants to believe they can traverse smaller apertures (Warren & Whang, 1987). Consequently, if one can judge action capabilities without a stable width representation, then maintaining such a representation may be perceptually inefficient. Accordingly, variable width estimations across individuals may reflect the absence of a common width representation and the subsequent engagement of idiosyncratic guessing strategies for estimating body part width.

Given the consistency of aperture estimates across individuals, it is possible that, for tasks involving fitting one's body into something (e.g., an opening), individuals do possess some form of stable, shared width representation. Whereas for tasks where individuals judge how many units comprise a body part (as used here), a stable representation may not be maintained. However, this seems unlikely given that individuals can be led to incorrectly assume they can traverse smaller apertures, simply by adjusting visual angles (Warren & Whang, 1987). Thus, it is more likely that individuals do not possess a representation of body part width.

Putting perceptual (in)efficiencies aside, the absence of a width representation may also be adaptive. Where body part length remains relatively stable across adulthood, body width can change considerably both rapidly (e.g., by donning a backpack, or adding layers of clothing) or gradually (e.g., through weight gain, or pregnancy), yet we can readily adapt to this. For example, individuals can maintain a consistent aperture critical ratio both with, and without wielding a tray wider than their own bodies (Hackney et al., 2014). Moreover, whilst pregnant women exhibit a tendency to overestimate their body size (particularly in the earlier stages), relative to nonpregnant individuals (Slade, 1977), their errors in aperture judgements remain stable and comparable to nonpregnant individuals across pregnancy (Franchak & Adolf, 2014). Consequently, an absent stored width representation may facilitate the rapid recalibration of one's affordances to changes in body width using action experience and visual information alone, thus facilitating optimal action behaviour.

The above-discussed evidence suggests that individuals can make judgements of the angle at which they need to position their bodies to traverse an opening based upon visual angles and experience alone (see Warren, 2021 for a discussion). Therefore, one may question whether the separation of width and length body representations is somewhat redundant. From an ecological perspective, we only perceive what is necessary for us to interact optimally within our environments (Gibson, 1979). Hence, the perceptual system may not possess a means of differentiating between width and length as, typically, our actions require a combinatorial calculation of body part length and width to determine one's ability to perform actions at different bodily angles or positions. Yet, if it were the case that our perceptual system does not disambiguate between length and width, we may expect to see similar levels of heterogeneity in body part length estimates. However, estimates of body part length appear consistent across individuals. For example, using an adaptation of the Body Image Task (Fuentes et al., 2013), where participants indicate their perceived location of their body landmarks on a wall in front of them, consistent underestimation of upper limb length and overestimation of lower limb lengths has been observed (Caggiano & Cocchini, 2020; Caggiano et al., 2021). In contrast, as observed in the current study, estimates estimates of shoulder and hip width were inconsistent across experiments when using this paradigm (Caggiano & Cocchini, 2020). Object height can be judged by calculating the ratio of the perceiver's eye height by the horizon ratio (Warren, 2021). Moreover, with just two minutes of general wheelchair locomotion experience, non-wheelchair using adults can accurately judge the minimum lintel under which they can pass (Stoffregen et al., 2009). Therefore, like width, accurate height judgements can be made using action experience and visual information alone. Consequently, the observed consistency of length estimates, despite the apparent redundancy of a length representation to action performance could somewhat refute our proposition that width estimates are variable due to the lack of requirement, and therefore absence, of a stable width representation for action performance.

However, unlike body width, the length of our bodies typically remains relatively stable across adulthood, therefore it may be that maintaining a consistent length representation is more efficient than constant calculation of visual angles. Yet, this would not explain why these length representations are usually distorted. Aside from passing under, or through, obstacles, we also need to perform fine motor movements such as reaching, grasping, and directing kicking movements which might require accurate representations of the body in space. Hence, we may possess more stable representations of body parts required for fine motor movements. For example, Caggiano and Cocchini (2020) argued that arm length may be underestimated to faciliate reaching (i.e., bringing objects towards the body), whereas lower body parts typically perform extension movements (e.g., kicking) and hence are overestimated.

In contrast, in the current study, and previous investigations of body width (including the task used by Caggiano and Cocchini, 2020), participants estimated the width of body parts which are only salient when making judgements of overall body width (e.g., the shoulders, or hips), such as when traversing apertures. Hence, it may be unnecessary to form stable representations of these body parts as they are not directly implicated in fine motor movements. If this hypothesis were true, one may expect width representations of the foot, a body part involved in fine motor movements (e.g., directed kicking of a football), to be more consistent.

Interestingly, when using the methodology of Linkenauger et al. (2015) a different, but also consistent, pattern of distortions to those found by Caggiano and colleagues (Caggiano & Cocchini, 2020; Caggiano et al., 2021) has been observed (Linkenauger et al., 2015; Sadibolova et al., 2019; Readman et al., 2022; Experiment 1 of this study) wherein the length of less sensitive body parts is overestimated more than more sensitive body parts. As argued by Caggiano and Cocchini (2020), this discrepancy may arise from differences in the salience of the spatial context. In the Body Image Task, body landmark locations are estimated relative to one another which may require a representation of the body in space and may therefore activate sensorimotor representations implicated in action performance. Contrastingly, when comparing body parts to another metric (i.e., Linkenauger et al., 2015), the spatial context may be less salient and hence representations possibly primarily derive from somatosensory inputs. In turn, task-dependent engagement of different body representations would facilitate optimal perceptual performance (Pitron et al., 2018). For example, the inverse distortion of somatotopic representations observed in the Linkenauger et al. (2015) task may facilitate the maintenance of tactile constancy. Whereas, the distortions observed in the Body Image Task may increase the accuracy of fine motor actions.

Consequently, we propose that in action contexts which do not require fine motor movements, our perceptual systems can accurately perceive one's action capabilities using visual angles and experience alone, making an accurate representation of one's body part width or length unnecessary. Accordingly, stable width representations of the body parts estimated in this task may not be required, nor maintained, leading to the heterogeneity observed. Of course, other interpretations of our results are possible. For one, it is possible that the overestimations observed in Experiment 1 were attributable to participants' seated posture. However, Experiment 4 found that estimates were not moderated across different seated and standing postures, a finding which is consistent with that of Shontz (1965). Indeed, Scandola et al. (2019) found that wheelchair users' perceptions of peri personal space only changed when using their own wheelchair, and not an unfamiliar chair with which they have no previous action experience. Modulations of body width perception may therefore only occur in situations where the action-context is salient, and affordances are activated. Hence, embodiment of the chair would not provide a strong explanation for the variability observed.

The online format of Experiment 1 may also have been influential. However, although the experimenter was not present in-person, as participants made estimates using their own hand, for their own body, the estimation procedure and stimuli did not differ between this experiment and that of Experiments 2-4 for the participant. Moreover, though measurements were taken by a helper in Experiment 1, these were monitored by the experimenter for accuracy. Critically, we replicated previous findings observed using in-person investigations for body part length in Experiment 1. Therefore, we do not feel the online format was a moderator of the results observed. Indeed, we still observed variability in the pattern of estimations observed between Experiments 2 and 4, both of which were conducted in-person.

Alternatively, as the body parts estimated in this study were observed from either a first-person perspective, or were visually inaccessible (i.e., the head and back), it is possible that variability emerges from individuals' reliance upon memories of their body size which vary in accuracy. Yet, accuracy of width estimates does not improve with online mirror feedback (Ben-Tovim & Walker, 1990; Thaler et al., 2018), thus refuting this notion. Variability may also have arisen from a lack of familiarity with using the hand as a metric. However, Experiment 2 showed that self estimations were comparable when using both the hand and a hand-sized stick as a metric and considerable variability is also observed across other metric tasks. It could also be the case that the larger sample size used in Experiment 4 may have affected patterns of significance by increasing or decreasing the likelihood that a body part was found to be over, or underestimated. However, we note here that all studies were suitably powered for the effect sizes that were observed. Moreover, it was not just that the patterns of significance changed over experiments, but also whether the body part was over, or underestimated. Thus, we do not feel that differences in sample size could explain this variability. Finally, it could be that individuals have a general deficit in size perception. However, several studies have shown that distortions (Shontz, 1967; Bergström et al., 2000;

Thaler et al., 2018) and variability in estimates (Shontz, 1967) are greater when estimating the width of body parts versus non-corporeal objects. Therefore, distortions in width representations seem to be body-specific rather than reflective of a more general perceptual deficit.

Noteworthily, the pattern of self-estimates discussed here for non-clinical populations contrasts from those observed in eating disorders wherein consistent overestimation (see Mölbert et al., 2017) of body part width, and overestimation of the aperture passing affordance (Beckmann et al., 2021; Keizer et al., 2013 Guardia et al., 2012) has been observed. People with eating disorders exhibit deficits in multisensory integration (Brizzi et al., 2023). Accordingly, people with eating disorders may be unable to perceive and integrate the different sensory signals arising from their environment in order to accurately calculate action affordances. In turn, it has been proposed that deficits in the integration of online sensory information renders individuals reliant upon rigid and distorted schematic representations of the body (Riva, 2012), thus resulting in overestimations of both perceptual and implicit body part width. Future research investigating the relationship between implicit and explicit judgements of body width in eating disorders, as well as how people with eating disorders adapt their affordance judgements to changes in body width could aid understanding in this area.

Concerning estimates of another, participants underestimated the head and shoulders and overestimated all other body parts. These results thus corroborate with previous research findings showing that participants underestimated the head of another (Bianchi et al., 2008), as well as overestimated the width of a mannequin’s thigh more than their own thigh (Stone et al., 2018). During social interactions, we typically fixate upon the head and face (Rogers et al., 2018) of our social partners. Similarly, when estimating others’ size, non-clinical groups tend to fixate upon the head and breast regions (Von Wietersheim et al., 2012).

Consequently, we may overestimate the head and shoulders of others the least because we have more experience with perceiving these body parts. However, without corroboration from eye-tracking data and further replications of this finding, this interpretation remains speculative. Furthermore, as the sample and model used in Experiment 3 were all female, it is possible that patterns of estimations may not generalise to male models and participants. For example, Phillipou et al. (2016) found that participants overestimated the body size of males more than females.

Moreover, we found that participants underestimated the head of another more than when making estimates of the self. In contrast, length estimates, using the same paradigm as in this study, tend to be consistent across self and other estimates (Linkenauger et al., 2017). However, this analysis was exploratory and therefore planned further investigation with a within-subjects design would help to support this notion. It is possible that differences in self and other estimates may arise from differences in estimation perspectives (first- vs. third-person). Yet, the lack of difference observed for length estimates of the self versus another (Linkenauger et al., 2017) and findings that self-width estimation accuracy does not improve with mirror feedback (Ben-Tovim & Walker, 1990; Thaler et al., 2018), would dispute this.

Whilst every effort was made to recruit a diverse range of participants, use of opportunity sampling has meant that the current set of experiments included some predominantly female samples. Though some previous studies have found that females overestimate their body widths more than males (Thompson & Thompson, 1986; Bergström et al., 2000), others have found no sex differences (Dolan et al., 1987; McCabe et al., 2006; Gardner & Bokenkamp, 1996). Critically, when using the same paradigm for estimates of body part length, the sex of participants has not impacted on accuracy ratios (Linkenauger et al., 2017). Moreover, we did not find the pattern of distortions changed when excluding males from analyses in Experiments 1 and 2. Therefore, whilst we have little reason to assume sex has precluded the generalisability of the findings observed, further investigation would help to support this assumption.

In addition, some evidence suggests factors such as body dissatisfaction can lead to width overestimation (Ben-Tovim et al., 1990), though this is not consistent (Sunday et al., 1990; see Gardner, 2011 for a discussion). As we did not measure these variables in this study, further research is required to establish whether variability in body width relates to bodily attitudes and other psychosocial variables.

Conclusion

In sum, across four experiments, representations of the relative proportions of body part width were shown to be highly variable both across individuals, and body parts when using both the hand, and a hand-sized stick as the metric. As the body parts estimated in this task are not typically implicated in fine motor movements, it is possible that a stable representation of these parts is not necessary for optimal performance within our environment. Hence, the observed heterogeneity in width representations of the body parts estimated on this task may reflect the fact that individuals do not require, and therefore do not maintain, a stable percept of the width of these body parts and therefore engage in idiosyncratic guessing strategies to estimate their size.

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Declaration of Interest

The authors report no known conflicts of interest.

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