RUNNING HEAD: Sex Differences in Touch

No evidence for sex differences in tactile distance anisotropy

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Abstract

Perceptual illusions of the distance between two touches have been used to study mental representations of the body since E. H. Weber's classic studies in the 19^{th} century. For example, on many body parts tactile distance is anisotropic, with distances aligned with body width being perceived as larger than distances aligned with body length on several skin regions. Recent work has demonstrated sex differences in other distortions of mental body representations, such as proprioceptive hand maps. Given such findings, I analysed the results of 24 experiments, conducted by myself and my colleagues, measuring tactile distance anisotropy on the hand dorsum in both women and men. The results showed clear, and highly consistent anisotropy in both women and men, with no evidence for any sex difference.

In his classic studies in the 19th century, Weber (1834) reported that the perceived distance between two points of a compass on the skin felt farther apart when presented on a highly sensitive region of skin than on a less sensitive region. Numerous subsequent studies have replicated Weber's observation, finding a systematic relation between the sensitivity of a skin surface and the perceived distances between touches (Anema, Wolswijk, Ruis, & Dijkerman, 2008; Cholewiak, 1999; Fitt, 1917; Goudge, 1918; Marks et al., 1982; Miller, Longo, & Saygin, 2016; Taylor-Clarke, Jacobsen, & Haggard, 2004). Analogous illusions have also been found comparing tactile distances presented in different orientations on a single skin surface (i.e., tactile distance anisotropy). For examples, Longo and Haggard (2011) found that tactile distances oriented across the width of the hand dorsum were perceived as approximately 40% larger than equivalent distances oriented with hand length. Similar tactile distance anisotropies have been reported on a range of body parts, including the forearm (Green, 1982; Le Cornu Knight, Longo, & Bremner, 2014), thigh (Green, 1982; Tosi & Romano, 2020), shin (Stone, Keizer, & Dijkerman, 2018), feet (Manser-Smith, Tamè, & Longo, 2021), face (Fiori & Longo, 2018; Longo et al., 2020; Longo, Ghosh, & Yahya, 2015), and upper back (Nicula & Longo, 2021). Intriguingly, in each of these cases, the bias is to overestimate distances aligned with the width of the body. The only regions of the body on which this bias has not been found are on the torso, with no apparent bias on the belly (Green, 1982; Longo, Lulciuc, & Sotakova, 2019; Marks et al., 1982) and a reversed bias on the lower back (Nicula & Longo, 2021; Plaisier, Sap, & Kappers, 2020).

Other research has identified connections between perceived tactile distance and several aspects of higher-level body representations. For example, perceived tactile distance has been found to change systematically as a result of factors including illusions altering perceived body size (de Vignemont, Ehrsson, & Haggard, 2005; Tajadura-Jiménez et al., 2012; Taylor-Clarke et al., 2004), tool use (Canzoneri et al., 2013; Miller, Cawley-Bennett, Longo, & Saygin, 2017; Miller, Longo, & Saygin, 2014, 2017), and categorical perception across joint boundaries (de Vignemont, Majid, Jola, & Haggard, 2008; Le Cornu Knight, Bremner, & Cowie, 2020; Le Cornu Knight, Cowie, & Bremner, 2017; Le Cornu Knight et al., 2014). Tactile distance perception also appears to be systematically altered in several clinical disorders, including eating disorders (Engel & Keizer, 2017; Keizer et al., 2011; Keizer, Smeets, Dijkerman, van Elburg, & Postma, 2012; Spitoni et al., 2015), obesity (Mölbert et al., 2016; Scarpina, Castelnuovo, & Molinari, 2014), and low back pain (Adamczyk, Luedtke, Saulicz, & Saulicz, 2018; Adamczyk, Sługocka, Mehlich, Saulicz, & Luedtke, 2018), though interestingly not in focal hand dystonia (Mainka et al., 2021). The perception of tactile distance is thus integrated with many aspects of perception and cognition, making it a valuable tool for research.

It is notable that the overestimation of body width seen in tactile distance perception mirrors similar effects found in a range of other tasks. Overestimation of body width in non-clinical samples has been described in tasks designed for measuring distorted body image in eating disorders, including the moving caliper method (Dolan, Birtchnell, & Lacey, 1987; Halmi, Goldberg, & Cunningham, 1977; Hundleby & Bourgouin, 1993; Pierloot & Houben, 1978), the adjustable light beam apparatus (Dolce, Thompson, Register, & Spana, 1987; Pasman & Thompson, 1988; Thompson & Spana, 1988; Thompson & Thompson, 1986), and the image marking procedure (Bizerra & Gama, 2017; Fonseca, Thurm, Vecchi, & Gama, 2014; Gorham & Hundleby, 1988; Meermann, 1983). Similarly, overestimation of body width has also been found in tasks involving visual comparison estimates of finger length and hand width (Longo & Haggard, 2012; Longo, Mattioni, & Ganea, 2015; Peviani, Magnani, Bottini, & Melloni, 2021), manipulating images of one's own face (D'Amour & Harris, 2017), and positioning landmarks relative to each other (Fuentes, Longo, & Haggard, 2013; Fuentes, Pazzaglia, Longo, Scivoletto, & Haggard, 2013; Fuentes, Runa, Blanco, Orvalho, & Haggard, 2013).

Finally, studies investigating perceptual maps underlying proprioceptive localisation have also shown overestimation of width versus length for the hand (Coelho, Zaninelli, & Gonzalez, 2017; Longo & Haggard, 2010; Peviani & Bottini, 2018; Saulton, Longo, Wong, Bülthoff, & de la Rosa, 2016), and the face (Longo & Holmes, 2020; Mora, Cowie, Banissy, & Cocchini, 2018). In a recent study, Coelho and Gonzalez (2019) compared these perceptual maps for the hand in woman and men. While both sexes showed overestimation of hand width relative to length, quantitative differences in the magnitude of distortions were found. Compared to men, women showed greater overestimation of hand width, but less underestimation of finger length. A meta-analysis of 19 experiments using this paradigm from my own research (Longo, 2019) replicated the pattern of sex differences reported by Coelho and Gonzalez.

Given the qualitative similarity between distortions found in tactile distance perception and perceptual hand maps, and recent reports of sex differences in these maps, I asked whether there are comparable sex differences in anisotropy of tactile distance perception. I therefore conducted a meta-analysis of studies from my own research investigating tactile distance anisotropy on the hand dorsum. The analysis was restricted to the hand dorsum because: (1) this is the body part in which sex differences have recently been reported for proprioceptive hand maps, and (2) it is the skin region tested in the largest number of experiments. As with studies of proprioceptive hand maps, most studies testing tactile distance anisotropy have included substantially more women than men. Nevertheless, across studies, a substantial number of participants of both sexes have been tested.

Methods

Selection of Studies

The purpose of this study is to report data from my own research regarding sex differences in tactile distance anisotropy on the hand. It is not intended to be a comprehensive meta-analysis of the entire literature, although I am not aware of any publicly-available data from other studies that are directly relevant to this question. Studies from my own research were included in the analysis if they met the following criteria: (1) they measured tactile distance perception on the hand dorsum, (2) they compared stimuli oriented in the medio-lateral vs. proximo-distal axis, and (3) they tested both women and men. A total of 24 experiments fit the criteria, and are listed in Table 1. Together, the 24 experiments included 315 women and 173 men. Four experiments were excluded based on criterion 3: three studies which tested only women (Longo et al., 2019; Nicula & Longo, 2021; Tamè, Bumpus, Linkenauger, & Longo, 2017) and Experiment 2 from Longo and Haggard (2011) in which only one man was tested, making estimation of variance impossible. None of these studies screened formally for any clinical disorders.

*** INSERT TABLE 1 ABOUT HERE ***

Coding and Quantification of Results

The approach to coding and quantification of results was similar to that in my recent meta-analysis of tactile distance anisotropy on the palm (Longo, 2020). For each eligible experiment, I coded a number of variables, including the task used, the nature of the stimuli applied, the timing between stimuli (i.e., whether each pair of touches was presented simultaneously or sequentially), which hand was tested, which other skin surfaces were tested, the number of women and men tested, the mean magnitude of anisotropy overall and for each sex, and the standard deviation of each of these means.

Of the 24 eligible experiments, the majority (15) involved two-alternative forced-choice (2AFC) procedures in which participants judged which of two tactile distances felt bigger (Calzolari, Azañón, Danvers, Vallar, & Longo, 2017; Hidaka, Tamè, Zafarana, & Longo, 2020; Le Cornu Knight et al., 2014; Longo, 2017; Longo, Ghosh, et al., 2015; Longo & Haggard, 2011; Longo & Morcom, 2016; Manser-Smith et al., 2021). In each case, psychometric functions were expressed in terms of the proportion of trials on which the stimulus in the medio-lateral axis was judged as bigger as a function of the logarithm of the ratio between the distance in the medio-lateral and proximo-distal axes. The point of subjective equality (PSE) was calculated for each participant as the ratio between the two stimuli for which the participant was equally likely to judge stimuli in each of the two orientations as bigger. Anisotropy was quantified as the logarithm (base 10) of this ratio.

In several studies, participants made absolute estimates of the distance between a single pair of touches. In the studies of Longo and Golubova (2017) and Tamè et al. (Tamè, Tucciarelli, Sadibolova, Sereno, & Longo, 2021), multidimensional scaling (MDS) was used to reconstruct a perceptual map of grid of tactile locations on the hand. Anisotropy in these maps was quantified by finding the extent to which a rectangular grid needed to be stretched or compressed in the medio-lateral axis to maximize its similarity to each perceptual map. The value used here is the logarithm (base 10) of these ratios. In several other studies, participants made verbal estimates of the distance between pairs of touches in the medio-lateral and proximo-distal orientations (Fiori & Longo, 2018; Longo, 2017; Longo & Sadibolova, 2013). Anisotropy was quantified as the logarithm (base 10) of the ratio of judged distance for stimuli aligned with the medio-lateral and the proximo-distal axes. In my recent meta-analysis of tactile distance anisotropy on the palm (Longo, 2020), I referred to the method used by these studies as 'verbal estimation'. Here, I use the phrase 'absolute estimation' instead, since the study of Tamè and colleagues (2021) used a visual matching procedure to obtain distance estimates.

Analysis

For each experiment, a standardised measure of effect size (i.e., Cohen's *d* or d_z, depending on the details of the experiment) was calculated on the basis of the statistical comparison that most directly quantified anisotropy. Because of the small bias introduced by Cohen's *d* in meta-analyses (Borenstein, Hedges, Higgins, & Rothstein, 2009), Hedges's (1981) correction was applied using the "escalc" function in the *metafor* package for R (Viechtbauer, 2010) resulting in all effects being expressed as Hedges's *g*. Effect sizes were coded such that positive values indicate bias for distances aligned with the medio-lateral hand axis to be overestimated relative to the proximo-distal axis, and negative values indicate the converse bias. Meta-analyses were conducted using the random-effects model in the *metafor* package. Separate meta-analyses were conducted on women, men, and the differences between the two sexes, both in standardised units (i.e., Hedges's *g*) and for absolute point-of-subjective equality (PSE).

In addition, Bayesian meta-analyses were run on the difference between men and women, both in standardised units and absolute PSE. These were conducted using the *bayesmeta* package for R (Röver, 2020). This analysis requires that prior estimates be specified for both the effect size being estimated and for the heterogeneity of the effect across studies. For effect size, unit informative priors were used, which are recommended as a relatively neutral prior, allowing the data to speak for itself (Wagenmakers, 2007). These were estimated as a mean of 0 and a SD of 2 for the analysis in standardised units, and a mean of 0 and a SD of 0.2 for the analysis of PSEs. The prior for heterogeneity was a half-normal distribution with SD half the size of the corresponding prior for effect size.

Finally, given that individual participant data was available for all experiments, I used linear mixed-effect models (Baayen, Davidson, & Bates, 2008) to investigate the effects of method (2AFC vs. absolute estimation) and sex on the magnitude of anisotropy. Mixed-effects models were calculated using the lme4 toolbox for R (Bates, Mächler, Bolker, & Walker, 2015). Anisotropy was modelled using method and sex as fixed effects and study as a random effect, including random intercepts for studies. I attempted to include by-study random slopes for the effect of sex, but these were removed as the model failed to converge. The significance of fixed effects was assessed using model comparison (Barr, Levy, Scheepers, & Tily, 2013).

Results

Magnitude of Anisotropy in Standardised Units

Figure 1 shows forest plots of tactile distance anisotropy on the hand dorsum across experiments, separately for women, for men, and for the difference between women and men. There was clear evidence for anisotropy for both women (Hedges's g = 1.306, 95% CI:

[1.155, 1.456]), $z = 16.97$, $p < .0001$, and men (Hedges's $g = 1.074$, 95% CI: [0.881, 1.267]), $z = 10.91$, $p < .0001$. There was no evidence for heterogeneity for either women, $Q(23) = 19.19$, $p = .690$, or men, $Q(23) = 20.82$, $p = .592$.

There was a non-significant trend for anisotropy to be larger in women than in men (Hedges's $g = 0.160$, 95% CI: [-0.033, 0.353]), $z = 1.63$, $p = .104$. There was no evidence for heterogeneity, $Q(23) = 13.26$, $p = .946$. A subgroup analysis provided no evidence that the difference between men and women was moderated by task (i.e., absolute estimation vs. 2AFC), $z = -0.197$, $p = .844$. A follow-up analysis including only studies that used simultaneous presentation of stimuli showed a similar non-significant trend for anisotropy to be larger in women (Hedges's $g = 0.186$, 95% CI: [-0.017 0.388]), $z = 1.80$, $p = .072$.

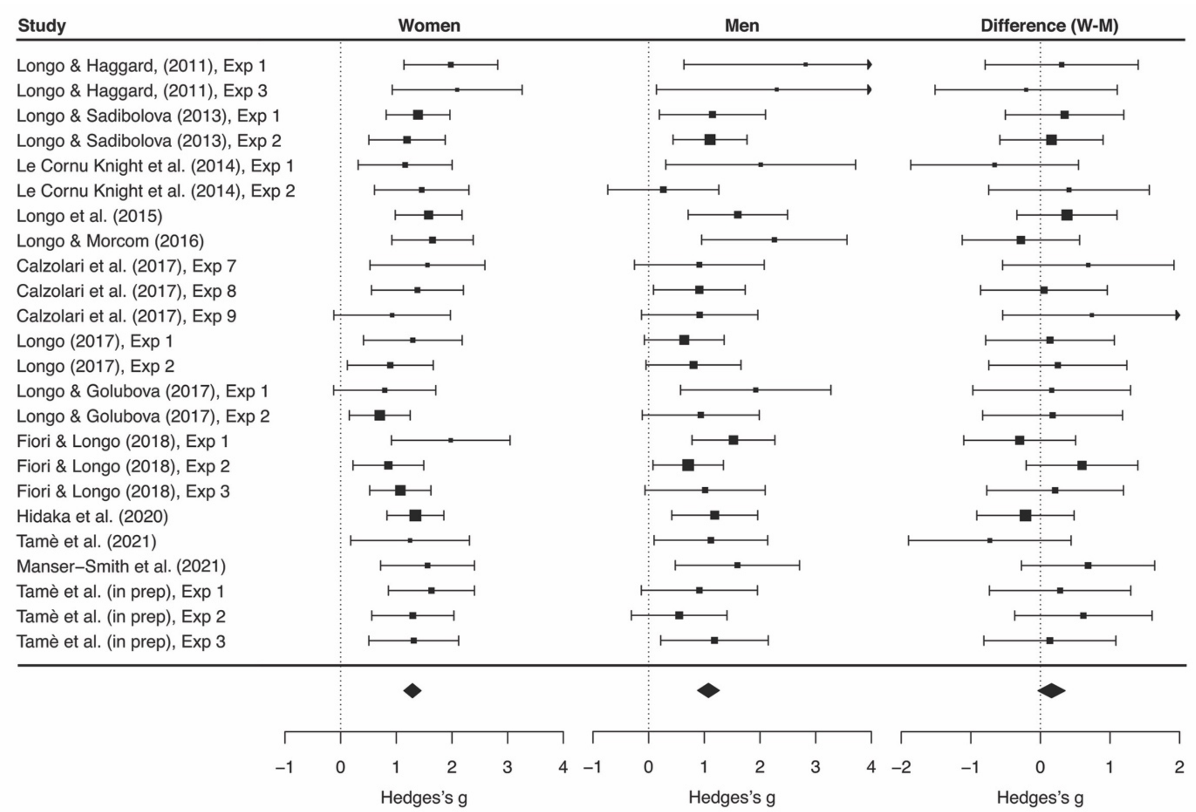

Figure 1: Forest plots showing tactile distance anisotropy on the hand dorsum in standardised units for women (left), men (centre), and the difference between women and men (right). Positive values indicate a bias to overestimated distances oriented across the width of the hand. Clear anisotropy was consistently found in both women and men, with a non-significant trend for this bias to be larger in women.

Magnitude of Anisotropy in Absolute Units

The preceding analysis compared the magnitude of anisotropy across studies using standardized units (i.e., Hedges's *g*). It is also of interest, however, to quantify anisotropy in absolute units – that is, at what ratio are stimuli in the medio-lateral and proximo-distal hand axis perceived as equal? Following my approach in my recent meta-analysis of tactile distance anisotropy on the palm (Longo, 2020), I limited this analysis to studies that used 2AFC methods to estimate the PSE between orientations, given that verbal estimation of distance is subject to a range of potential biases, including preferential use of round numbers, and logarithmic compression of the mental number line (Gallistel & Gelman, 1992; Longo & Lourenco, 2007). The PSE estimated in 2AFC experiments represents the ratio between the stimuli in the two orientations that are perceived as being the same distance apart by the participant.

Figure 2 shows forest plots of the PSEs from studies that quantified anisotropy using 2AFC methods, reporting effect sizes in raw units, rather than standardized units as in the previous analyses. Note that all analyses were conducted on PSEs, represented as the logarithm of the ratio between the two orientations, which were converted back to raw ratios for reporting.

There was strong evidence for anisotropy in both women (*M*: 1.292, 95% CI: [1.256, 1.330]), $z = 17.76$, $p < .0001$, and men (*M*: 1.257, 95% CI: [1.204, 1.312]), $z = 10.48$, $p < .0001$. For women, there was no significant evidence for heterogeneity, $Q(14) = 21.24$, $p = .096$. For men, in contrast, there was evidence for heterogeneity across studies, $Q(14) = 33.70$, $p = .002$; the I^2 statistic indicated that 56.2% of the between-experiment variability was due to heterogeneity.

There was again no significant different in the magnitude of anisotropy between women and men (M: 0.013 log_{10} units, 95% CI: [-0.003, 0.028]), $z = 1.59$, $p = .112$, nor any evidence for heterogeneity across studies, $Q(14) = 11.25$, $p = .666$.

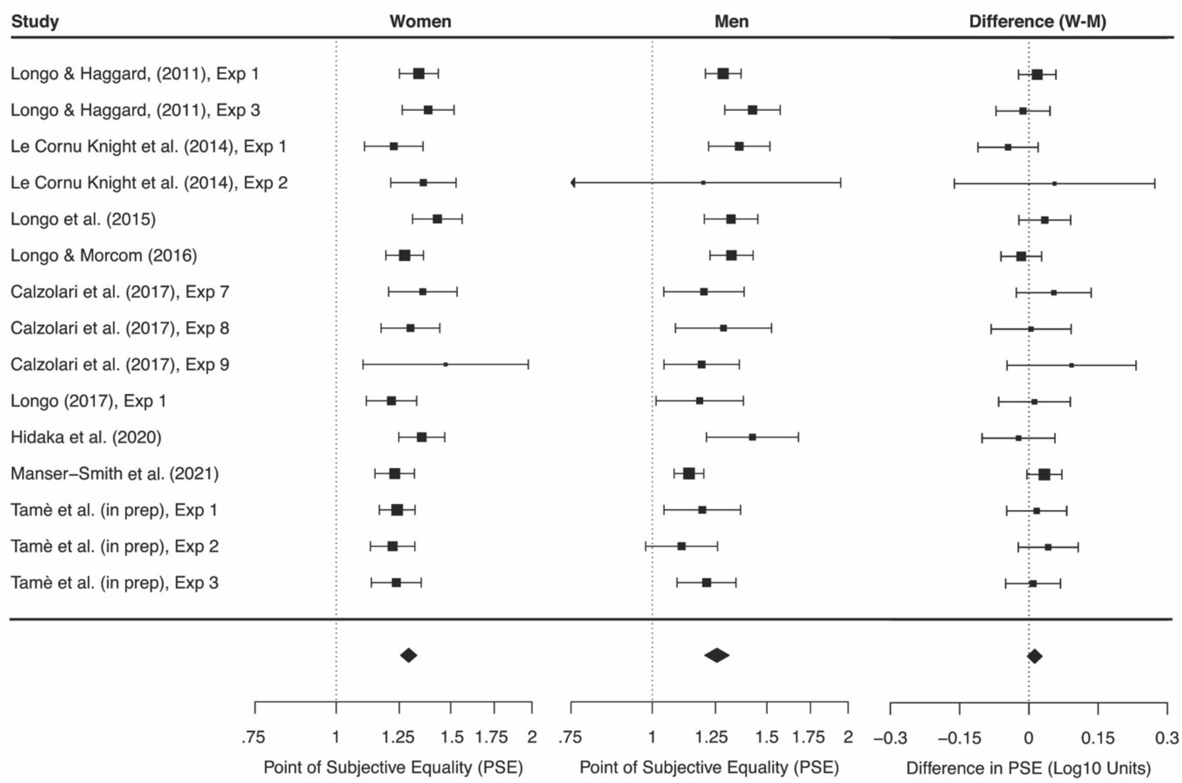

Figure 2: Forest plots showing tactile distance anisotropy on the hand dorsum in raw (PSE) units for women (left), men (centre), and the difference between women and men (right). The PSE indicates the ratio of along to across stimuli which participants judge as equal. Because the PSE is a ratio, a log-scaled axis is used. Clear anisotropy was consistently found in both women and men, with a non-significant trend for this bias to be larger in women.

Bayesian Meta-Analysis

Given the lack of significant difference between men and women in the preceding analyses, I conducted Bayesian meta-analyses on both standardised units and raw PSEs. For standardised units, there was again a non-significant trend for larger anisotropy in women than in men (Hedges's $g = 0.160$, 95% CI: [-0.043, 0.364]). The Bayes factor provided 'substantial' support for the null hypothesis of no sex difference, $BF_{01} = 5.76$, according to standard criteria (Jeffreys, 1981).

The results were similar for raw PSEs, with a non-significant trend (*M*: 0.013 $\log_{10}$ units, 95% CI: [-0.006, 0.031]). The Bayes factor again provided substantial support for the null hypothesis of no sex differences, $BF_{01} = 8.31$.

Individual Participant Data

Because data from individual participants was available for all the studies used in this meta-analysis, I investigated the effects of sex and method using linear mixed-effect models. Sex and method (i.e., 2AFC vs. absolute estimation) were modelled as fixed effects, including random intercepts for studies. By-study random slopes for the effect of sex were not included, as they resulted in failure of module convergence. This analysis revealed no significant effects of either sex ($\beta_{male} = -0.0132$ $\log_{10}$ units), $\chi^2(1) = 2.07$, $p = .150$, or method ($\beta_{2AFC} = -0.156$ $\log_{10}$ units), $\chi^2(1) = 1.12$, $p = .290$.

Discussion

The results of this meta-analysis provide strong evidence for tactile distance anisotropies on the hand dorsum in women and men. Across studies, there was clear evidence for tactile distance anisotropy on the hand in both women and men. In both sexes, tactile distances oriented with hand width were judged as larger than those oriented with hand length, by between 25 and 30%. This bias thus appears to be a general feature of somatosensory organisation. This parallels the findings from a similar meta-analysis of distortions of proprioceptive hand maps (Longo, 2019), in which clear overestimations of hand width and underestimations of finger length were clearly apparent in both sexes. Moreover, it is also consonant with broader findings from studies of body size estimation in which overestimation of body width using metric tasks is found in both women and men

(Dolan et al., 1987; Pasman & Thompson, 1988; Shontz, 1969; Thompson & Thompson, 1986).

Unlike the similar meta-analysis of proprioceptive hand maps (Longo, 2019), however, there was no apparent difference in the magnitude of anisotropy between women and men. This results is particularly notable in light of findings that body size estimation may relate systematically to actual body size (e.g., K. K. Cornelissen, Bester, Cairns, Tovée, & Cornelissen, 2015; P. L. Cornelissen, Johns, & Tovée, 2013; Smeets, Smit, Panhuysen, & Ingleby, 1998). In the context of eating disorders, this has raised concerns that the apparent overestimation of body size in patients may be an artefact of between-group differences in actual body size, rather than reflecting a genuine difference in perceived body size (e.g, Smeets et al., 1998). For example, women with anorexia have smaller actual body sizes than control participants because they are emaciated. Thus, if both groups give the same size estimation in cm, this will result in greater overestimation of body size in patients. Analogously, some authors have suggested that anisotropic biases in touch could reflect the fact that the arm itself is anisotropic in shape, being long and thin (T. S. Wong, Ho, & Ho, 1974). On average, womens' hands are both smaller and more slender than mens' (Tilley, 1993). The absence of any sex difference in the magnitude of anisotropy, therefore, suggests that the anisotropy itself is not systematically related to hand shape. Intriguingly, differences in finger size have recently been related to differences in tactile acuity between women and men (Peters, Hackeman, & Goldreich, 2009; M. Wong, Peters, & Goldreich, 2013) and between children and adults (Peters & Goldreich, 2013). The present results suggest that a similar pattern does not hold for tactile distance perception. This may reflect the reliance of acuity on receptor density. If the same number of mechanoreceptors are present regardless of hand size, then people with smaller hands will have more denselypacked receptors. In contrast, because receptor density is fundamentally a properties of 2-dimensional areas of skin, it cannot differ as a function of orientation, and hence cannot be anisotropic (Longo & Haggard, 2011).

The studies described in this meta-analysis were overwhelmingly consistent in showing the presence of tactile distance anisotropy on the hand dorsum. The variability of mean estimates of the magnitude of this effect across studies were in line with what would be expected given the within-study variation for women, and also for the difference in magnitude between women and men. For the magnitude of the effect in men, however, there was evidence for heterogeneity, suggesting that the magnitude of anisotropy varied systematically across studies. The studies varied in a number of ways, but it is not clear either what variables might have affected the magnitude of anisotropy, nor why such effects would have been specific to men and not also have affected women. One possibility is that factors such as finger splay, which were uncontrolled in most the included studies, may have affected results, as these are known to affect tactile distance perception (Longo, 2017) as well as proprioceptive hand maps (Longo, 2015) and structural body representations (Tamè, Dransfield, Quettier, & Longo, 2017). While we made efforts to keep procedures and instructions broadly similar across these studies, they were run by a number of different experimenters across a substantial period of time. Finally, the composition of the participant pool we recruit from may vary across the year, being more student-heavy during the academic year than during summer, which could also potentially have affected results.

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Data Availability

The data on which the analyses reported in this paper is based are available as supplemental materials.

Study	Exp	Method	N_w	N_m	Stimulus	Timing	Hand Tested	Other Skin Surfaces Tested	Conditions
Longo & Haggard, (2011)	1	2AFC	16	4	Metal Posts	Simultaneous	Left		
Longo & Haggard, (2011)	3	2AFC	9	3	Sticks	Simultaneous	Left		Two hands postures collapsed
Longo & Sadibolova (2013)	1	Absolute estimate	23	7	Sticks	Simultaneous	Left		Three visual conditions collapsed
Longo & Sadibolova (2013)	2	Absolute estimate	14	14	Sticks	Simultaneous	Left		Three visual conditions collapsed
Le Cornu Knight et al. (2014)	1	2AFC	9	4	Sticks	Simultaneous	Left	L Forearm, L Dorsal Wrist	
Le Cornu Knight et al. (2014)	2	2AFC	11	4	Sticks	Simultaneous	Left	L Palm, L Dorsal Forearm, L Volar Forearm, L Dorsal Wrist, L Volar Wrist	
Longo et al. (2015)	1	2AFC	24	11	Sticks	Simultaneous	Both	L/R Palm, Forehead	L/R collapsed
Longo & Morcom (2016)	1	2AFC	17	8	Sticks	Simultaneous	Left		
Calzolari et al. (2017)	7	2AFC	8	4	Sticks	Simultaneous	Both		Only no adaptation condition used; data collapsed across two hands
Calzolari et al. (2017)	8	2AFC	11	8	Sticks	Simultaneous	Left	L Palm	Only no adaptation condition used
Calzolari et al. (2017)	9	2AFC	5	5	Sticks	Simultaneous	Left		Only no adaptation condition used; data collapsed across two postures
Longo (2017)	1	2AFC	9	9	Sticks	Simultaneous	Left		Two postures collapsed

Longo (2017)	2	Absolute estimate	9	7	Sticks	Simultaneous	Left		Two postures collapsed
Longo & Golubova (2017)	1	Absolute estimate	6	6	von Frey Hair	Sequential	Left		
Longo & Golubova (2017)	2	Absolute estimate	16	5	von Frey Hair	Sequential	Left	L Palm	
Fiori & Longo (2018)	1	Absolute estimate	10	15	Sticks	Simultaneous	Left		
Fiori & Longo (2018)	2	Absolute estimate	13	12	Sticks	Simultaneous	Left	L Palm	
Fiori & Longo (2018)	3	Absolute estimate	20	5	Sticks	Simultaneous	Left		Two postures collapsed
Hidaka et al. (2020)	1	2AFC	28	11	Sticks	Simultaneous	Left		
Tamè et al. (2021)	1	Absolute estimate	6	6	Air puffs	Sequential	Right		
Manser-Smith et al. (2021)	2	2AFC	12	7	Sticks	Simultaneous	Left	L Palm, L Foot top, L Foot bottom	
Tamè et al. (in prep)	1	2AFC	15	5	Sticks	Simultaneous	Left		Only sticks condition used
Tamè et al. (in prep)	2	2AFC	13	6	Sticks	Simultaneous	Left		Only sticks condition used
Tamè et al. (in prep)	3	2AFC	11	7	Sticks	Simultaneous	Left		Only sticks condition used