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OBSERVATION

Tactile Localization on Stretched Skin

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The ability to localize touch on the skin is an important aspect of tactile perception. As our limbs move, the skin stretches flexibly, and research has found that signals specifying stretch affect perception of limb posture. Skin stretch also distorts the relative spatial position of different locations on the skin, posing potential problems for tactile localization. Here, we investigated the effects of skin stretch using an established test of tactile localization on the hand. Twenty participants completed a tactile localization task in no-stretch and stretched conditions, respectively, after giving informed consent. The current study found a clear distal and radial bias in both the no-stretch condition and the stretched condition. Indeed, the distal bias was even larger in the stretched condition than at baseline. Critically, however, this change in distal bias was entirely accounted for by changes in the actual location of stimulus as a result of skin stretch, with no corresponding change in the judged location. Thus, the somatosensory system appears to disregard stretch when calculating the location of tactile stimuli. These results mirror recent findings showing that tactile distance perception also fails to take skin stretch into account.

Public Significance Statement
We showed that skin stretch did not affect tactile localization on the back of the hand with a clear distal and radial bias in both the no-stretch condition and the stretched condition. Most likely, there is no central correction for distortions of relative location induced by skin stretch during tactile localization.

Keywords: stretch, tactile localization, dorsum

Localizing tactile stimuli on the skin is a fundamental perceptual ability. One intriguing aspect of tactile localization is skin stretch. As we move, the skin flexibly stretches around our limbs. This alters the spatial relations between locations on the skin, posing obvious issues for tactile localization. It is unknown how tactile localization is affected by skin stretch, though this has important implications for understanding the nature of tactile space. There are reasons both for and against supposing that skin stretch should affect tactile localization.

On one side, the somatosensory system is known to be sensitive to skin stretch as a source of information about joint movements and touch (Edin, 1992, 2004; Grill & Hallett, 1995). Recordings from afferent fibers show sensitivity to stretch in several animals including rodents (Grigg, 1996), cats (Burgess et al., 1968), and monkeys (Kumazawa & Perl, 1977). Moreover, skin stretch influences a large proportion of neurons in primate somatosensory cortex (Cohen et al., 1994). In humans, skin stretch produces proprioceptive illusions of body posture (Collins & Prochazka, 1996; Edin & Johansson, 1995), and affects tactile acuity (Cody et al., 2010) and tactile motion perception (Seizova-Cajic et al., 2014). These results demonstrate that afferent signals specifying skin stretch reach the brain and are used for touch.

On the other side, skin stretch may be disregarded in some spatial aspects of touch. One patient who had surgical elongation of her arms showed misperception of the distance between touches consistent with continuing to use the metric properties of the skin from before the surgery (Cimmino et al., 2013). Other work has found that tactile distance judgments on the lips are modulated by facial expression (Anstis & Tassinary, 1983) and those on the hand are modulated by skin stretch at the wrist (Mainka et al., 2023). In both cases, the effects following stretch are exactly what would be expected if skin stretch was disregarded. Rather, spatial relations on the stretched skin are referred to the typical, unstretched locations, what Anstis and Tassinary call the "'resting' anatomical position" (p. 296), without central correction for distortions of relative location induced by skin stretch. It is unclear whether this lack of central correction is specific to tactile distance perception, or is true for other aspects of tactile spatial perception, such as localization.

We tested the hypothesis that the lack of central correction for skin stretch found for tactile distance perception reflects a more general feature of tactile spatial perception. Participants localized touches on their hand in two conditions, one in which the skin of the hand dorsum was stretched using surgical tape applied at the wrist (*stretch* condition) and another in which the hand was relaxed (*no-stretch* condition). We measured localization using a well-established paradigm in which

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participants indicate the corresponding location on a hand silhouette (Mancini et al., 2011). If afferent signals specifying skin stretch are used to update tactile localization then judged location should shift in a similar way to the actual location following skin stretch. Conversely, if no central correction is applied, then judged location following the stretch should be similar to judged location in the no-stretch condition.

Method

Participants

Twenty participants participated in 2020 after giving informed consent (10 males; $M_{age} \pm SD$, 27.8 ± 11.7 years). All but two were right-handed as assessed by the Edinburgh Inventory (Oldfield, 1971; *M*: 67.8). The age range used in this study was large, which could affect results given known changes in somatosensory function across the lifespan (Kuehn et al., 2018). This large age range was largely driven by a single 70-year-old participant. We have included this participant in analyses, but have confirmed that nothing substantial in our results changes if his data are excluded. Procedures were approved by the Department of Psychological Sciences Research Ethics Committee at Birkbeck.

It is important that we have statistical power both to replicate distal biases in tactile localization (e.g., Mancini et al., 2011) as well as to detect effects of skin stretch. The most relevant study for the latter effect is the recent study of Mainka et al. (2023), who applied a similar manipulation of skin stretch to a different tactile judgment (perceived distance between two points). For both effects, we assessed power using the method and online calculator (https://designingexperiments.shinyapps.io/BUCSS_ss_power_dt/) of Anderson et al. (2017), which corrects reported effect sizes for both publication bias and uncertainty related to sampling and measurement error.

For distal bias, we used Experiment 1 of Mancini et al. (2011; $t = 6.49$, $N = 10$), which indicated that five participants were needed for power of .80. For skin stretch, we used Mainka et al. (2023; $t = 6.13$, $N = 20$), which indicated that seven participants were needed. Thus, our sample size of 20 is well-powered to detect similar effects of both types.

Tactile Localization Task

The task was similar to Mancini et al. (2011). Participants sat at a table with their left-hand palm down with their wrist straight. We marked a 3 × 3 grid of locations on their dorsum with a felt pen using a plastic stencil (Figure 1). We marked the knuckles of their index and little finger as reference points for Bookstein coordinates (see below). At the start of each block, a photograph of the participant's hand was taken directly overhead, with a ruler placed next to the hand to allow conversion between distances in pixels and cm. We occluded the left hand and forearm with a black smock.

In each trial, participants looked at a black screen while the dorsum of their left hand was touched. One of the nine locations was touched using a von Frey hair (100 g force) for approximately 1 s. As we tested on the hairy skin, the overall sensation produced may be a combination of contact with the skin and with hairs. After the stimulus, a life-size silhouette outline of a hand appeared on the screen. The participant moved the mouse cursor to the location on the silhouette corresponding to where they felt the touch. The mouse cursor started at a random location on each trial.

Figure 1
Experimental Conditions

Note. Left panel: A 3 × 3 grid of points was drawn on the left-hand dorsum (no-stretch condition). Right panel: In the stretch condition, surgical tape was used to stretch the skin in the proximodistal axis. Another strip of tape parallel to the wrist helped keep the tape secure.

There were two conditions: no-stretch and stretch. In the stretch condition (Figure 1, right panel), we applied three pieces of surgical tape to stretch the skin in the proximal direction, as in our recent study of tactile distance perception (Mainka et al., 2023). The skin was stretched with moderate pressure and was not painful. Given individual differences in skin elasticity and connections to deep tissue, it was impossible to exactly match the magnitude of stretch across participants. This was calculated for each participant, however, as discussed at the start of the Results.

There were four blocks of 36 trials. Each block consisted of four judgments of each location in random order. There were two blocks of each condition, counterbalanced in ABBA fashion, with the initial condition counterbalanced across participants.

Analysis

Analysis was similar to previous studies using this paradigm (e.g., Mancini et al., 2011; Margolis & Longo, 2015; Medina et al., 2018). A picture of the participant's hand was taken at the beginning of each block. The locations of the knuckles and stimulation locations were coded in *x*/*y* pixel coordinates from these photos. Judgments of stimulus location were recorded in *x*/*y* pixel coordinates on the monitor. We used Bookstein's (1991) two-point registration method. This defines a coordinate system with the knuckles (i.e., the metacarpophalangeal joint) of the little and index fingers defined as points (0, 0) and (1, 0). This has two important benefits. First, it places the locations of the stimuli (coded from a photograph) and the locations of the responses (defined by mouse clicks) into a common reference frame. Second, it defines unit length relative to each participant's hand, removing individual differences in hand size, allowing averaging across participants.

Distal basis refers to deviation of judgments from the actual stimulated location in the proximodistal hand axis. It is calculated by subtracting the actual simulated location from the perceived location in Bookstein *y*-coordinates. Similarly, radial basis refers to analogous deviations in the mediolateral hand axis and is calculated as the difference between judged and actual location in Bookstein *x*-coordinates.

Condition means were calculated using MATLAB and *t* tests and effect size estimates using Microsoft Excel. Bayesian *t* tests were conducted using JASP 0.16.1 software. To compare distal and radial bias to veridical performance, we used one-sample *t* tests to compare mean bias in each condition to 0. To compare bias in the stretch and no-stretch conditions, we used paired *t* tests. As measures of effect size, we used Cohen's *d* for one-sample *t* tests (i.e., the mean divided by the *SD* of that mean) and Cohen's d_z for paired *t* tests (i.e., the mean difference score divided by the *SD* of that mean).

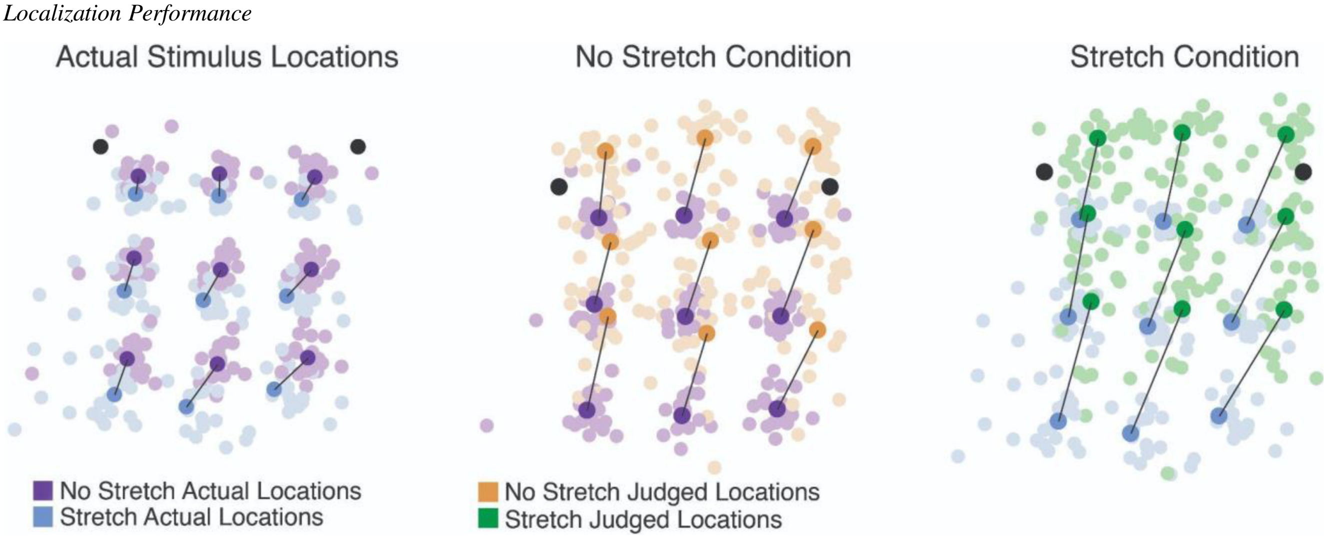
Transparency and Openness

We report justification of our sample size, data exclusions, inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and measures in the study. The study was not preregistered. The raw data and analysis code are available on the Open Science Framework: https://osf.io/b2xvn/.

Results

Results are shown in Figure 2. We first quantified the effects of stretch on actual stimulus location (Figure 2, left panel). We quantified proximal shift induced by skin stretch by comparing the Bookstein *y*-coordinates between conditions. Across the nine stimulus locations, skin stretch led to a proximal shift of 0.113 Bookstein units (*SD*: 0.037), $t(19) = 13.63$, $p < .001$, $d_z = 3.05$. This corresponds to an average proximal shift of 0.76 cm (*SD*: 0.22). Analysis of the Bookstein *x*-coordinates also showed a modest ulnar shift (i.e., toward the little finger) following skin stretch (*M*: −0.024 Bookstein units, *SD*: 0.045), $t(19) = -2.41$, $p = .026$, $d_z = 0.54$.

Figure 2
Localization Performance



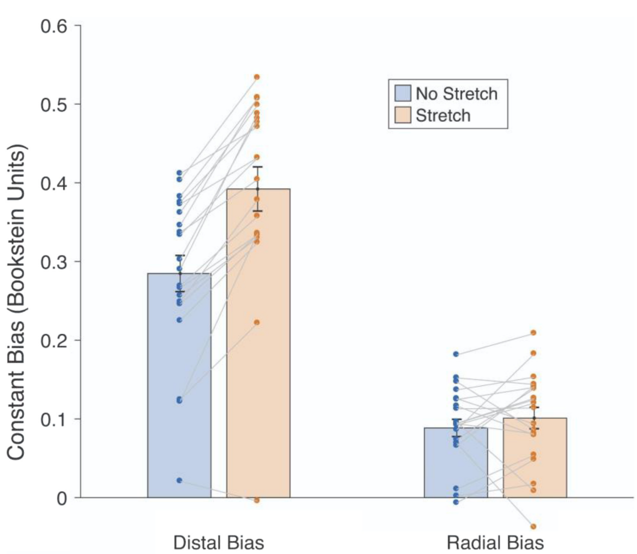
Note. Left panel: The effects of skin stretch on actual stimulus location. The locations of the knuckles of the little and index finger are shown in black. Center panel: Localization judgments in the no-stretch condition. Consistent with previous findings, large distal biases were found. Right panel: Localization judgments in the stretch condition. Distal biases were again apparent, of even larger magnitude. This increase in bias, however, reflects the proximal shift of actual stimulus location, and not a change in judgments. See the online article for the color version of this figure.

Distal Bias

Figure 3 shows distal and radial bias in each condition. We found a significant distal bias in the no-stretch condition, $M \pm SE$, 0.303 Bookstein units $\pm$ 0.103; $t(19) = 13.33$, $p < .001$, Cohen's $d = 2.98$, consistent with previous research (Mancini et al., 2011). There was a similar distal bias in the stretched condition, $M \pm SE$, 0.405 Bookstein units $\pm$ 0.120; $t(19) = 15.07$, $p < .001$, Cohen's $d = 3.37$.

Critically, there was a significant difference between distal bias in those two conditions, with greater bias in the stretched condition, $t(19) = 7.73$, $p < .001$, Cohen's $d_z = 1.73$. To interpret this difference, it is important to remember that the stretch caused a proximal shift in the *actual* location of stimuli. Thus, increased distal bias following stretch could reflect change in actual skin location, with no change in judgments. Indeed, the increase in *distal* bias in the stretch condition (0.102 Bookstein units) was very similar to the *proximal* shift in actual stimulus location (0.113 Bookstein units), and these values were strongly correlated across participants, $r(18) = .878$, $p < .001$. The increase in distal bias could thus be explained entirely by the change in actual stimulus location, with no corresponding change to the location where participants respond. This would indicate a complete failure to take skin stretch into account for tactile localization. To assess this possibility, we compared the Bookstein *y*-coordinates of judged locations in the two conditions. Notably, these values did not differ, $M \pm SE$, 0.010 Bookstein units $\pm$ 0.032; $t(19) = 1.44$, $p = .166$, $d_z = 0.32$. A Bayesian paired *t* test using JASP 0.16.1 software provided anecdotal evidence in support of the null hypothesis, $BF_{01} = 1.76$. The absolute magnitude of the observed shift in judgments was just 9.2% of the observed shift in actual skin locations, suggesting that even if there is partial compensation for skin stretch, it is only a modest fraction of actual stretch. Therefore, responses were similar in the stretch and no-stretch conditions, meaning that increased distal bias in the stretch condition represents a *failure* to account for skin stretch. Following the stretch, participants responded as if their skin was not stretched.

Figure 3
Distal and Radial Biases in the No-Stretch and Stretch Conditions



Note. Error bars are one standard error of the mean. See the online article for the color version of this figure.

Radial Bias

We found significant radial bias in the no-stretch condition, $M \pm SD$, 0.089 Bookstein units $\pm$ 0.044; $t(19) = 9.08$, $p < .001$, Cohen's $d = 2.03$, again consistent with previous research (Mancini et al., 2011). There was also significant radial bias in the stretched condition, $M \pm SD$, 0.106 Bookstein units $\pm$ 0.058; $t(19) = 8.13$, $p < .001$, Cohen's $d = 1.82$. There was no difference between conditions in the magnitude of radial bias, $t(19) = 1.51$, $p = .148$, Cohen's $d_z = 0.34$. A Bayesian paired *t* test provided anecdotal evidence supporting the null hypothesis, $BF_{01} = 1.63$.

Discussion

Consistent with previous studies (e.g., Mancini et al., 2011; Margolis & Longo, 2015; Medina et al., 2018), we found distal and radial biases for tactile localization on the hand dorsum in both conditions. Distal bias was significantly larger when the skin is stretched in the proximal direction. However, the *y*-coordinate of the perceived touched location in the stretched condition is similar in both conditions. This suggests that localization judgments disregard the stretch. This shows that skin stretch alters tactile localization judgments without central correction mechanisms.

Our finding that stretch is disregarded during localization is consistent with previous studies measuring perceived tactile distance. Changes in tactile distance perception were seen following skin stretch-induced surgically (Cimmino et al., 2013), by facial expressions (Anstis & Tassinary, 1983), or by using surgical tape (Mainka et al., 2023). In each case, changes in skin stretch altered tactile distance judgments consistent with distance being computed based on the *usual* configuration of the skin. Long-term follow-up of an individual following surgical arm elongation indicates that stretch may eventually be taken into account, but this may require prolonged learning (Cimmino et al., 2013).

Such results are consistent with evidence that tactile processing is enhanced when the hand is placed into specific "standard" postures (Manser-Smith et al., 2021; Romano et al., 2017, 2019). Romano et al. (2017) found that responses to touches were faster on the thumb when it was positioned lower than the other fingers, but on the fingers when they were positioned above the thumb. They interpreted such results as indicating that tactile signals are referenced to a default or standard posture of the body, an effective Bayesian prior for posture. The present results showing that tactile localization judgments are linked to the unstretched configuration of the skin at rest are consistent with this idea, and suggest that the skin stretch may be a constituent element of the standard posture.

As discussed above, there is clear evidence that skin stretch is used by the somatosensory system, such as for judgments of body posture (Edin & Johansson, 1995) and tactile motion (Seizova-Cajic et al., 2014). It remains uncertain; however, what differentiates these situations from others such as tactile distance perception and tactile localization in which stretch is disregarded. One potential factor is that stretch caused by active movements may differ from that induced externally. For example, Sadibolova et al. (2018) found that tactile localization on the forearm differed depending on forearm rotation, which causes the skin to stretch. Stretch caused by active movement may be importantly different from skin stretch-induced using tape. This may implicate proprioceptive and/or motor signals in the sensory interpretation of skin stretch (Sadibolova et al., 2018). This is consistent with recent results showing that skin stretch plays an important role in predictive control of grip force during grasping (Farajian et al., 2020).

There are several constraints to the generalizability of our results. We tested a relatively homogenous group of participants in central London. We used only one type of tactile stimulus and applied stimuli on a single skin surface. Distal localization biases have been found to differ dramatically, even between the palmar and dorsal surfaces of the hand (Mancini et al., 2011). The hand dorsum may be a region in which the skin is less tightly connected to the underlying deep tissues, making the skin more easily stretched. The lack of correction for skin stretch in our task may reflect the fact that such stretch is less of an issue on skin regions such as the palm and fingertip which are more commonly used for localization in daily life.

In conclusion, our results add to the evidence showing that changes in skin stretch distort spatial perception of touch, whether the stretch is induced surgically (Cimmino et al., 2013), by changes in posture (Anstis & Tassinary, 1983), or by using tape (Mainka et al., 2023; this study). These results are surprising in light of evidence that afferent signals of skin stretch affect perception of body posture (e.g., Collins & Prochazka, 1996; Edin & Johansson, 1995). Future research should determine which specific aspects of somatosensory processing are updated by signals specifying skin stretch, which may provide rich insight into processing stages involved in somatosensory coordinate transformations.

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