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**RESEARCH ARTICLE**

# Multisensory distortions of the hand have differential effects on tactile perception

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**Abstract** Research has suggested that altering the perceived shape and size of the body image significantly affects perception of somatic events. The current study investigated how multisensory illusions applied to the body altered tactile perception using the somatic signal detection task. Thirty-one healthy volunteers were asked to report the presence or absence of near-threshold tactile stimuli delivered to the index finger under three multisensory illusion conditions: stretched finger, shrunken finger and detached finger, as well as a veridical baseline condition. Both stretching and shrinking the stimulated finger enhanced correct touch detections; however, the mechanisms underlying this increase were found to be different. In contrast, the detached appearance reduced false touch reports—possibly due to reduced tactile noise, as a result of attention being directed to the tip of the finger only. These findings suggest that distorted representations of the body could have different modulatory effects on attention to touch and provide a link between perceived body representation and somatosensory decision-making.

**Keywords** Tactile perception · Multisensory illusions · MIRAGE · Somatic signal detection task · Signal detection

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## Introduction

The human brain integrates information from the senses to form a stable percept of the body and surrounding objects. On most occasions, this information is effectively coordinated to produce a coherent image of our sensory environment, although there are instances in which this information is misinterpreted, resulting in a mismatch between reality and our somatic experiences. For example, many amputees continue to experience vivid sensations (including pain) from their amputated limb (Ramachandran and Hirstein 1998), while poor tactile acuity is reported in patients suffering from chronic pain states such as complex regional pain syndrome (CRPS) and knee osteoarthritis (Moseley et al. 2008a, b; Moseley and Wiech 2009; Stanton et al. 2013).

Experimentally induced somatic illusions have shown that even healthy individuals can misinterpret bodily events through relatively simple cross-modal manipulations. For instance, in the 'parchment skin' illusion (Jousmäki and Hari 1998), skin texture is felt to change when participants rub their hands together in synchrony with a grating sound, while in the ubiquitous rubber hand illusion (Botvinick and Cohen 1998), watching a fake rubber hand being stroked in synchrony with one's unseen real hand creates a feeling of ownership towards the rubber, and remaps the felt position of the real hand towards the location of the rubber hand. Additionally, illusory touch in the absence of any tactile stimulation is frequently reported on the somatic signal detection task (SSDT; Lloyd et al. 2008). This task involves detection of near-threshold vibrations (present in 50 % of trials) in the presence and absence of a simultaneously presented light. In neurologically healthy participants, the light enhances correct detection of the vibration when it is present and increases the number of
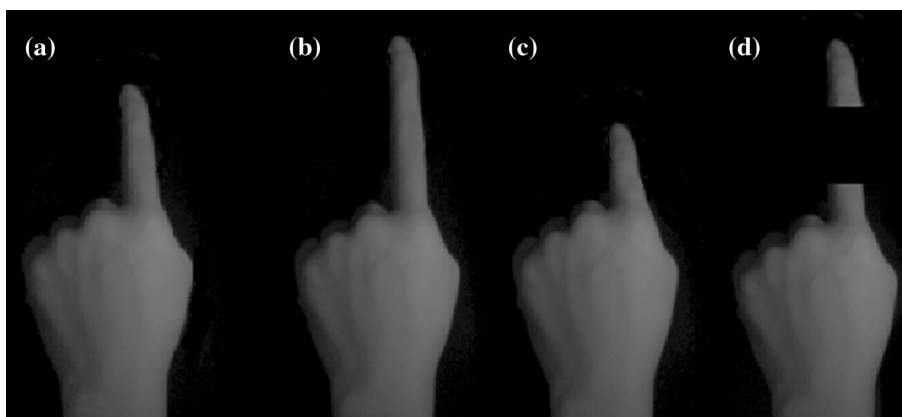
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**Fig. 1** Multisensory illusions and veridical baseline condition: **a** veridical baseline, **b** stretched finger, **c** shrunken finger and **d** detached finger

false touch reports in vibration-absent trials (Lloyd et al. 2008). Performance on this task has been found to be altered by simple perceptual factors, for example, significantly more light-present illusory touch reports are made when vision of the hand is available compared to when it is not, perhaps due to the light directing tactile attention towards the hand (Mirams et al. 2010). Visual modulation of touch is also dependent on particular measures of tactile judgment; viewing the stimulated hand has been found to increase tactile acuity in two-point discrimination tasks in healthy individuals (Kennett et al. 2001; Press et al. 2004) and in patients suffering from somatosensory deficits (Serino et al. 2007), whereas non-informative vision of the stimulated body part has been found to impair detection and discrimination of simple near-threshold tactile stimuli, but to enhance discrimination between above-threshold tactile stimuli (Harris et al. 2007).

Manipulating the perceived shape and size of the body has also been found to further alter tactile judgements. For instance, while visually attending to the hand reduces two-point discrimination thresholds, magnifying the stimulated hand has been found to further improve this effect (Kennett et al. 2001). In line with this finding, de Vignemont et al. (2005) showed that illusory elongation of perceived finger length significantly increased the perceived distance between two simultaneous tactile contacts. Manipulations of perceived body (part) size has also been found to alter haptic judgements, such that an object is judged to be larger following enlargement of perceived hand size and vice versa for 'reduced' hand sizes (Bruno and Bertamini 2010). Interestingly, alterations made to perceived body size have different modulatory effects on chronic and acute pain. Visual enlargement has been found to enhance analgesia (Mancini et al. 2011) and reduce physiological responses (Romano and Maravita 2014) to acute pain but increase pain and swelling (evoked by movement) in chronic pain (Moseley et al. 2008a, b). Manipulating the perceived size of painful body parts through visuo-proprioceptive illusions has been also found to have strong analgesic effects

in patients with osteoarthritis (Preston and Newport 2011). Collectively these findings suggest that both touch and pain can be modified by manipulated representations of perceived body size.

While most previous studies have investigated how changing the visual size of a stimulated body part affects tactile detection on tasks with a spatial component, as yet few studies have explored whether the reported effects are due to changes in response bias or increased tactile sensitivity (although see Romano and Maravita 2014, in which differing physiological responses to visually enlarged/reduced body parts were found using skin conductance). The current study therefore aimed to investigate how multisensory illusions applied to the hand would affect simple near-threshold tactile perception using the SSDT (Lloyd et al. 2008). This task allows us to determine whether a particular manipulation affects tactile perception via changes in tactile sensitivity or by altering response bias. Participants completed the SSDT under the influence of three multisensory illusions: stretching, shrinking and 'detaching' the stimulated finger, as well as a veridical baseline condition in which no illusion was applied (see Fig. 1 below). Given that previous studies have reported increased tactile acuity following visual enlargement and illusory elongation of a body part (Kennett et al. 2001; de Vignemont et al. 2005), we predicted that correct tactile detections would increase significantly (as a result of increased sensitivity) when the finger appeared to be stretched, compared to the veridical baseline condition. Shrinking the finger was expected to result in one of the two outcomes: either no difference in tactile perception between the baseline and shrunken finger conditions (de Vignemont et al. 2005) or a significant reduction compared to baseline (Kennett et al. 2001). The detached condition was included to examine how observing body discontinuity would affect tactile perception. In line with previous findings, we expected the finger to be disembodied during this condition (Newport and Preston 2010; Perez-Marcos et al. 2011; Tieri et al. 2015) and lead to reduced tactile sensitivity. These predictions were tested

a priori using direct comparisons between SSDT responses during the veridical baseline condition and the three multisensory illusions.

## Method

### Participants

Thirty-one right-handed (Oldfield 1971) participants (10 male) aged 18–26 years (mean age = 19.55; SD 1.31) were recruited. Written informed consent was obtained prior to participation, and none of the participants reported any sensory deficits. All procedures were approved by the University of Nottingham Malaysia Campus Research Ethics Committee.

### Apparatus and material

#### Questionnaire measures

*Trait anxiety inventory* The Trait Anxiety Scale (STAI-T) from the State–Trait Anxiety Inventory (Spielberger et al. 1983) was used to control for trait negative affect (Watson and Pennebaker 1989) as this has been found to affect somatic perception, such that higher negative affect scores are associated with perceiving benign somatic sensations as being particularly disturbing/intense. It contains statements such as 'I feel calm', 'I feel frightened' and asks participants to rate these statements according to how they generally feel, on a scale of 1 (not at all) to 4 (very much so).

*Somatosensory amplification scale* The somatosensory amplification scale (SSAS; Barsky et al. 1990) was used to control for tendencies of amplifying ambiguous sensory information in line with findings that have shown amplification to be related to heightened somatic perceptions as well as depression and anxiety (Barsky et al. 1988). Ratings were made to statements such as 'sudden loud noises really bother me', 'I hate to be too hot or too cold' on a Likert scale ranging from 1 (not at all true) to 5 (extremely true).

*Acclimatisation questionnaire* The acclimatisation questionnaire (Newport et al. 2010) consisted of six items (e.g. 'It seemed like the image of the hand was my own', 'It seemed like the image of the hand belonged to me') that measured sense of ownership towards the video image of the hand in its actual location prior to the illusions.

*Illusion strength and ownership questionnaires* These questionnaires aimed to assess the extent to which each illusion was incorporated into participants' body image (adapted from Preston and Newport 2012). They measured how strongly participants felt each multisensory illusion (e.g. 'I felt like my finger was really being stretched/shrunk') and participants' sense of ownership towards the distorted appearance of their finger[1] (e.g. 'I feel like I am watching myself').

In both the acclimatisation and illusion strength and ownership questionnaires, participants made verbal judgements on a nine-point rating scale in which nine indicated strong agreement and one indicated the least agreement.

#### MIRAGE system

The MIRAGE system (the University of Nottingham) is a mediated reality device, consisting of an arrangement of mirrors and cameras that provide participants with real-time video footage of their own hand in its actual location (see Newport et al. 2010 for further details) with a delay <17 ms—a delay found to be behaviourally negligible (Newport et al. 2009; Newport et al. 2010).

The captured images were either displayed unaltered or manipulated by in-house software (Newport et al. 2009, 2010). In the current study, participants were presented with three visuo-proprioceptive illusions on their index finger (see Fig. 1): 'stretched finger', 'shrunken finger' and 'detached finger'. During the stretched finger condition, the experimenter grasped and pulled participants' index finger with slight pressure, while the image of their finger (seen through the device) was simultaneously seen to grow longer (Preston and Newport 2011). In the shrunken finger condition, participants' index finger was gently 'pushed', while they simultaneously watched their finger shrink (Preston and Newport 2011). During the detached finger condition, the index finger was pulled until the tip became elongated and then 'detached' from the rest of the finger (Newport and Preston 2010), and as a visual convincer, a pen was passed through the detached part of the finger and the stump.

#### Somatic signal detection task (SSDT; Lloyd et al. 2008)

The stimulus array in the SSDT consisted of a polystyrene wedge, into which a miniature electromagnetic solenoid stimulator (Dancer Design tactor; diameter 1.8 mm) and a red light-emitting diode (LED) 4 mm in diameter were mounted. The tactor was affixed to the participant's left index finger with double-sided adhesive pad. Vibrations were then delivered to the left index finger in line with evidence that the left (non-dominant) hand is more

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[1] During the veridical baseline condition, participants were only presented with questionnaire items that measured sense of ownership towards their hand, as no illusion was presented.

sensitive to vibrotactile stimuli than the right (dominant) hand (Rhodes and Schwartz 1981). Vibrations were produced by sending amplified square wave sound files (100 Hz, 20 ms) to the electromagnetic solenoid stimulator using E-Prime software (Psychology Software Tools Inc., Pittsburgh, PA, USA). A green LED attached on the right side of the stimulus array with double-sided adhesive pad flashed for 250 ms and signalled the start of each trial, prompting participants to look at their left index finger. White noise was played via headphones throughout the experiment to prevent participants from hearing any experimentally informative sounds from the electromagnetic solenoid stimulator.

*Thresholding procedure* A threshold was found for each participant using a staircase procedure (Cornsweet 1962). Participants were presented with blocks of thirteen trials comprising of ten tactile present and three tactile absent trials. The LED attached next to the stimulus array lit up for the 250 ms, signalling the start of every trial. This was followed by a stimulus period of 1020 ms. In vibration-present trials, the 20 ms vibration was delivered to the participant's index finger with a delay of 500 ms before and after the stimulus. In vibration-absent trials, the start cue was followed by an empty period of 1020 ms. At the end of each trial, the experimenter asked the participant to report whether they did ('yes') or did not ('no') feel the vibration. The experimenter inputted participants' responses on a keyboard.

If the tactile pulse was perceived on less than 40 % of the stimulus-present trials, intensity of the tactile pulse was increased. If the pulse was perceived on more than 60 % of the stimulus-present trials, intensity was reduced, and this procedure was repeated until the stimulus intensity approached the participant's 50 % threshold. This was considered to be the level necessary for the participant to correctly perceive the tactile pulse on 40–60 % of the trials, and participants had to score within this range on three consecutive blocks.

*Experiment proper* The SSDT consisted of four blocks of 80 trials—each corresponding to one of the four experimental conditions (veridical baseline stretched finger, shrunken finger and detached finger). In each block, four different trial types (vibration only, vibration plus light, light only and catch-no stimulus) were presented 20 times in a random order. The tactile pulse was presented at the intensity previously determined during the thresholding procedure. Touch only and catch trials were identical to those presented during thresholding trials. In trials with a light, the LED (in the stimulus array) flashed for 20 ms either alone (light only trials) or together with the tactile pulse (light and touch trials). Participants were given no information about the purpose of light and were only asked to indicate whether or not they

felt a tactile pulse at the end of each trial using 'yes' and 'no' responses.

## Design and procedure

This study used a $4 \times 2 \times 2$ repeated measures design in which condition (veridical baseline, stretched finger, shrunken finger, detached finger), light (present, absent) and tactile pulse (present, absent) were within-participant variables and the participant's responses 'yes' and 'no' were the dependent variables.

Participants initially received both written and verbal instructions about the task, after which they were seated in front of the MIRAGE-mediated reality device. They were then given a brief period of acclimatisation (approximately 30 s) during which time they viewed their un-manipulated hand moving freely in its actual location. Following this, the acclimatisation questionnaire was administered. Next, the participants' left index finger was placed on the SSDT stimulus array, and his/her individual tactile threshold was found using the staircase procedure described above.

During the experiment proper, participants first responded to statements assessing their sense of ownership towards the video image of their hand (as seen through the MIRAGE) during the veridical baseline condition, after which they completed the first block of the SSDT. The veridical condition was used as a baseline reference by which performance in other illusions was compared against and was conducted first for all participants to ensure that it was not contaminated by any carry-over effects from the three multisensory illusions. Following this, participants were subjected to one of the three multisensory illusions in a counterbalanced order. Participants responded to illusion strength and hand ownership questionnaires corresponding to each illusion condition prior to completing the SSDT. At the end of each block, the participant's finger was brought back to its original length/appearance[2] and a break of 3 min was given before the next condition began. Participants were instructed to keep their hand still during the course of the experiment and received no feedback.

## Results

Inferential statistics were initially conducted to examine differences in illusion strength and hand ownership questionnaire ratings across the four conditions. The influence of each independent variable (condition and light) on SSDT parameters (hit rates, false-alarm rates, $d'$ and $c$) was then

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[2] This was only conducted in conditions with a multisensory illusion. Participants were still given a break during the veridical condition.

investigated. All main effects of condition were followed up by planned comparisons between the veridical baseline condition and each illusion condition.

## Questionnaire responses

### Acclimatisation questionnaire

Responses to this questionnaire showed a strong sense of ownership towards the video image of the hands. Participants strongly agreed with statements such as 'It seemed like the image of the hand was my own' (Median 9) and 'It seemed like the image of the hand belonged to me' (Median 9).

### Illusion strength and hand ownership questionnaires

Illusion strength and hand ownership responses for each condition were separately examined. Ratings to ownership statements indicated that participants strongly agreed that the video image of the hand belonged to them in all conditions, whereas illusion strength ratings indicated that participants strongly felt their index finger being stretched and shrunken, but felt the detached finger condition to a lesser extent (see Fig. 2). All questionnaire ratings were significantly negatively skewed and remained so following transformation; therefore, nonparametric analyses were used. A Freidman's ANOVA conducted on responses to statements 'I felt like my finger was really being stretched', 'I felt like my finger was really being shrunk' and 'I felt like the tip of my finger had become detached from the rest of my finger' revealed significant differences in illusion strength between the stretched, shrunken and detached finger conditions [$\chi^2$ (2, $N = 31$) = 11.78, $p = .003$]. Wilcoxon signed-rank tests (with a Bonferroni-corrected significance level of .016) indicated higher illusion strength ratings when the finger felt to be stretched (Median 7) compared to when it felt to be detached (Median 4; $Z = -3.42$, $p = .001$). Illusion strength was also higher when the finger was shrunken (Median 6) compared to when it was detached (Median 4; $Z = -2.81$, $p = .005$). No difference in illusion strength was seen between the stretched (Median 7) and shrunken (Median 6) conditions ($Z = -.87$, $p = .38$). A Freidman's ANOVA conducted on ownership ratings to the statement 'I feel like I am watching myself' revealed no significant difference between the three multisensory illusions or the baseline condition [$\chi^2$ (2, $N = 31$) = 4.73, $p = .19$].

## SSDT parameters

Responses were classified as hits (touch-present trials with a correct 'yes' response), misses (touch-present trials with an incorrect 'no' response), false alarms (touch-absent trials with an incorrect 'yes' response) and correct rejections
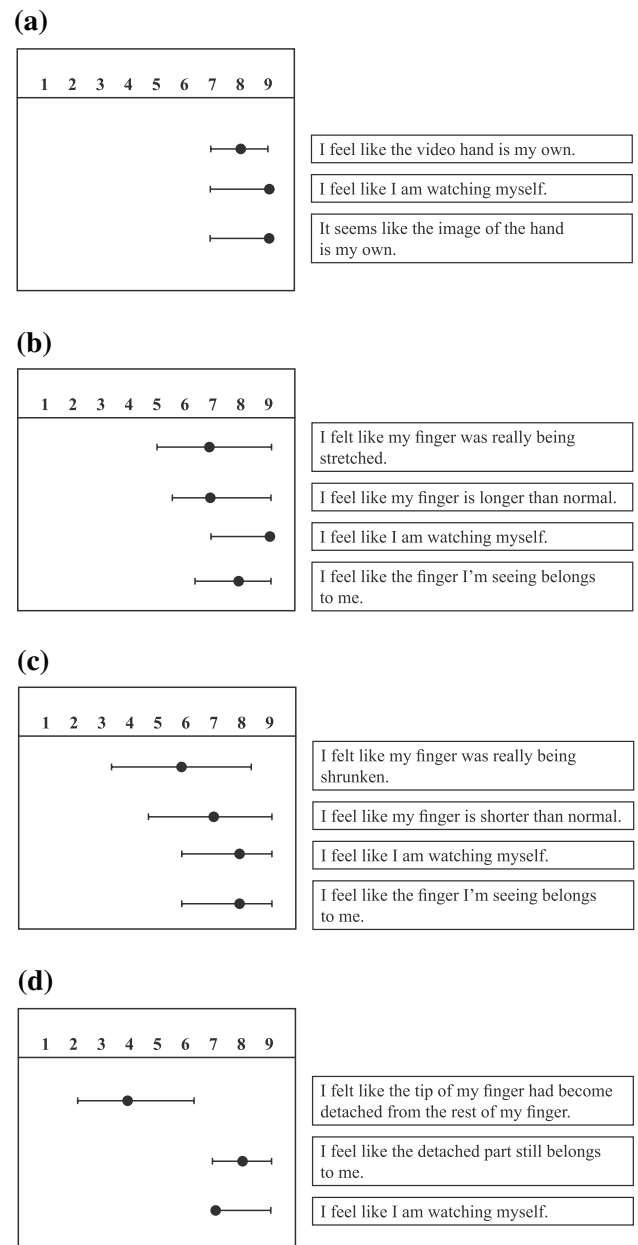


**Fig. 2** Medians and inter-quartile ranges for questionnaire ratings: **a** veridical baseline, **b** stretched finger, **c** shrunken finger and **d** detached finger

(touch-absent trials with a correct 'no' response). These were then used to calculate hit rates, false-alarm rates and the signal detection statistics $d'$ and $c$ respectively (MacMillan and Creelman 1991), with the log linear correction (Snodgrass and Corwin 1988), providing estimates of the participants' perceptual sensitivity ($d'$) and response bias ($c$, the tendency to report feeling the pulse regardless of whether or not one was present) in the presence and absence of light. Descriptive statistics for hit rates, false-alarm rates, sensitivity and response bias across all conditions are summarised in Table 1 below.

**Table 1** Mean ($\pm 1$ SD) hit rates, false-alarm rates and signal detection statistics for each illusion condition, in the presence and absence of light

| Condition | Hits (%) | False alarms (%) | $d'$ | $c$ |
|---|---|---|---|---|
| Veridical | | | | |
| Light | 53.1 (17.10) | 28.34 (19.59) | 0.76 (0.57) | 0.28 (0.48) |
| No light | 44.47 (17.52) | 21.43 (16.08) | 0.74 (0.63) | 0.53 (0.41) |
| Stretched finger | | | | |
| Light | 61.54 (12.77) | 30.49 (22.52) | 0.95 (0.83) | 0.15 (0.44) |
| No light | 51.38 (20.28) | 27.23 (20.66) | 0.75 (0.76) | 0.33 (0.50) |
| Shrunken finger | | | | |
| Light | 62.75 (17.36) | 25.58 (18.06) | 1.12 (0.83) | 0.21 (0.37) |
| No light | 57.53 (21.95) | 21.58 (18.70) | 1.19 (0.98) | 0.36 (0.60) |
| Detached finger | | | | |
| Light | 52.00 (15.39) | 22.20 (20.50) | 1.03 (0.91) | 0.46 (0.41) |
| No light | 41.09 (15.29) | 16.21 (15.71) | 0.94 (0.74) | 0.72 (0.42) |



**Fig. 3** Mean tactile sensitivity ($d'$) and response criterion ($c$) for each illusion condition. *Error bars* show standard error of the mean. *Asterisks* indicate the significant difference between the veridical baseline condition and illusion conditions (*$p < .05$)

A series of $2 \times 4$ repeated measures ANOVAs with light (2, present and absent) and condition (4, i.e. baseline, stretched, shrunken and detached) as within-subject factors were conducted to examine main effects and interactions on hit rates, false-alarm rates, tactile sensitivity ($d'$) and response criterion ($c$).

**Hit rates**

Hit rates were significantly higher in the presence of light [$F_{(1,30)} = 32.27$, $p < .001$, $\eta_p^2 = .518$]. A significant main effect of condition was also seen [$F_{(3,90)} = 6.83$, $p < .001$, $\eta_p^2 = .186$]. Planned comparisons revealed significantly higher hit rates in the stretched finger condition compared to the veridical baseline condition [$F_{(1,30)} = 5.58$, $p = .025$, $\eta_p^2 = .157$]. Hit rates were also significantly higher in the shrunken finger condition compared to the baseline condition [$F_{(1,30)} = 9.82$, $p = .004$, $\eta_p^2 = .247$]; however, no difference was seen between the detached finger condition and veridical baseline condition [$F_{(1,30)} = .38$, $p = .54$]. Light and condition were not found to interact [$F_{(3,90)} = .65$, $p = .59$]. The findings remained the same when controlled for STAI-T and SSAS.

**False-alarm rates**

False-alarm rates were not normally distributed, and a square root transformation was therefore applied to normalise the data. In the presence of the light, false-alarm rates were found to be significantly higher overall [$F_{(1,30)} = 12.70$, $p = .001$, $\eta_p^2 = .297$]. A significant main effect of condition was also found [$F_{(3,90)} = 6.20$, $p = .001$, $\eta_p^2 = .171$]. Planned comparisons revealed significantly lower false-alarm rates in the detached finger condition
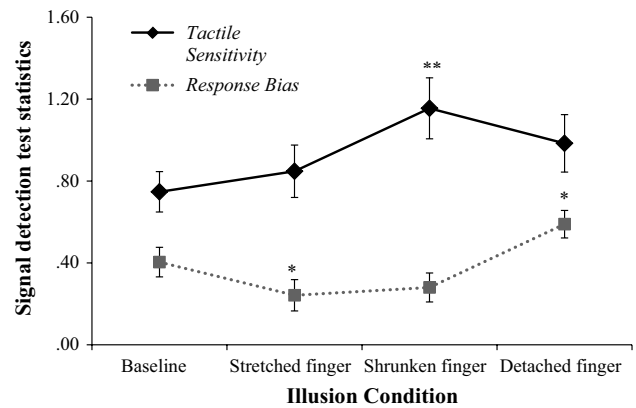
compared to the veridical baseline condition [$F_{(1,30)} = 7.49$, $p = .010$, $\eta_p^2 = .206$]. No differences were seen between the stretched and veridical baseline conditions [$F_{(1,30)} = 1.44$, $p = .24$] as well as the shrunken and veridical baseline conditions [$F_{(1,30)} = .62$, $p = .44$]. The interaction between light and condition were also not significant [$F_{(3,90)} = .76$, $p = .52$]. These findings remained the same when the STAI-T and SSAS were included as covariates.

**Tactile sensitivity ($d'$)**

A main effect of condition was found [$F_{(3,90)} = 3.63$, $p = .016$, $\eta_p^2 = .108$]. Planned comparisons indicated a significantly greater tactile sensitivity during the shrunken finger condition compared to the veridical baseline condition [$F_{(1,30)} = 9.41$, $p = .005$, $\eta p^2 = .239$]. A trend towards greater sensitivity was seen during the detached condition compared to the veridical baseline condition [$F_{(1,30)} = 3.76$, $p = .062$, $\eta_p^2 = .111$]. No difference between the stretched and veridical baseline conditions were seen [$F_{(1,30)} = .86$, $p = .36$]. No main effect of light [$F_{(1,30)} = 1.09$, $p = .31$] and no interaction were observed [$F_{(3,90)} = .98$, $p = .41$]. No difference was found when the STAI-T and SSAS were included as covariates. Figure 3 below shows mean tactile sensitivity across the four conditions in the presence and absence of light.

**Response criterion ($c$)**

Response criterion was significantly lower in the presence of light, suggesting that participants were more likely to report feeling a tactile pulse when the light was present [$F_{(1,30)} = 29.27$, $p < .001$, $\eta_p^2 = .494$]—regardless of whether or not a stimulus had been present. A significant main effect of condition was also seen [$F_{(3,90)} = 7.79$,

$p < .001$, $\eta_p^2 = 206$]; planned comparisons indicated that participants were more likely to report feeling the vibration during the stretched finger condition compared to the veridical baseline condition [$F_{(1,30)} = 4.20$, $p = .049$, $\eta_p^2 = .123$]. Participants were also significantly less inclined to report feeling the vibration during the detached finger condition [$F_{(1,30)} = 5.13$, $p = .031$, $\eta_p^2 = .146$], although there was no difference between the shrunken and baseline conditions [$F_{(1,30)} = 2.25$, $p = 1.44$]. Light and illusion condition were not found to interact [$F_{(3,90)} = .39$, $p = .76$]. The difference between the stretched finger and veridical baseline condition was reduced to a strong trend [$F_{(1,27)} = 4.00$, $p = .051$, $\eta_p^2 = .129$] when the STAI-T and SSAS were included as covariates.

## Discussion

The aim of the current study was to investigate how manipulating the perception of the finger through visuo-proprioceptive illusions would affect tactile detection. In line with previous studies (Kennett et al. 2001; de Vignemont et al. 2005), we expected illusory stretching and shrinking to have different effects on tactile perception. Instead, our findings suggested that both stretching and shrinking the finger significantly improved tactile perception compared to a veridical baseline condition. Although improved tactile detection during the stretched and shrunken conditions were found to be driven by response criterion effects and sensitivity, respectively, indicating separate underlying mechanisms, the absence of any significant increase in incorrect touch reports (false alarms) during the stretched condition suggests that the observed differences in response criterion could be largely attributed to the increase in correct touch reports rather than to a general tendency of reporting positively across all trials. The liberal response criterion seen during the stretched finger condition reduced to a strong trend when relevant covariates were included. This provides evidence for an overlap between somatosensation and subjective judgements of trait anxiety and tendencies of experiencing ambiguous sensory information as being particularly disturbing. Contrary to previous studies (Kennett et al. 2001; de Vignemont et al. 2005), the current findings also show an improvement in tactile detection following perceived shrinking of the finger. In contrast to two-point discrimination tasks used in previous studies (de Vignemont et al. 2005), the current study involved detection of near-threshold tactile stimuli with no spatial component which may have led to the observed difference. Indeed, perception of both above-threshold tactile stimuli with spatial components and near-threshold tactile stimuli with no spatial component has been reported to be different (Press et al. 2004). Additionally, while in previous studies

the precise mechanisms underlying changes in tactile perception as a result of changes in perceived body size are unclear, the current findings demonstrate that, for tactile detection at least, similar behavioural outcomes for stretching and shrinking are in fact driven by separate processes.

So how might distorting the perceived shape and size of the finger have affected tactile perception? Visuo-proprioceptive stretching may have temporarily altered cortical processing and increased activation of the visuo-proprioceptive bimodal neurones in the parietal regions resulting in increased tactile perception (Kennett et al. 2001; Schaefer et al. 2005, 2006). In the case of the shrunken finger, it is possible that the increase in tactile sensitivity we observed was due to the perceived reduction in visual detail; this resulted in a lower weighting of the incoming visual signal, causing a shift in sensory weighting (Ernst and Banks 2002) towards information unrelated to the appearance of the hand—which in this case was tactile information. Alternatively, given our constant exposure of our limbs growing in size, the shrunken condition may have been perceived negatively, leading to anxiety and stress. This would have increased firing of noradrenergic neurons (found to be associated with vigilance, alertness and selective attention to meaningful or novel stimuli; Southwick et al. 1999; Steimer 2002) in the locus ceruleus resulting in greater tactile sensitivity during this condition. In line with this, delusions of excessive body size are more commonly reported in psychiatric and neural conditions (Frederiks 1963; Mauguiere and Courjon 1978; Leker et al. 1996; Robinson and Podoll 2000), while experimental studies have sometimes reported asymmetric tendencies of ownership towards veridical and enlarged representations of the body (Pavani and Zampini 2007; Haggard and Jundi 2009), suggesting that enlarged representations are perhaps perceived more positively.

When the finger appeared to be detached, false-alarm rates were found to be significantly lower than in either stretched or shrunken conditions, as well as the veridical baseline condition, and response criterions were also more stringent for this condition. Surprisingly, ownership was still claimed over the detached finger, and illusion strength ratings indicated that participants felt this illusion the least (compared to the stretched and shrunken finger). It is not clear why this is the case, given that previous studies have continuously reported perceived discontinuity to result in reduced ownership over a body part (for example, Newport and Preston 2010; Perez-Marcos et al. 2011; Tieri et al. 2015); however, it should be noted that these previous studies measured ownership either when a body part was missing (e.g. the wrist, the forearm; Perez-Marcos et al. 2011; Tieri et al. 2015) rather than following disconnection or using different techniques such as time taken to elicit a virtual hand illusion (Perez-Marcos et al. 2011) and skin

conductance responses (Newport and Preston 2010). Newport and Preston (2010) used a similar illusion to that of the current study; however, ownership was assessed using skin conductance following virtual stabbing of the finger. Alternatively, it is also possible that demand characteristics (Nichols and Maner 2008) may have contributed to the unexpected high ownership ratings during this condition as participants may have believed that ownership over the detached finger was expected and therefore conformed to this expectation. This finding should therefore encourage future studies to incorporate control statements and/or obtain objective measures when assessing sense of ownership. During the detached condition, tactile attention may have been focused on the tip of the finger that appeared to be disconnected from the rest of the body rather than on whole finger more generally. This would have limited the influence from distracting internal bodily sensations (such as internal pulse sensations) as body-focused attention has been shown to increase awareness of internal bodily sensations (Rief and Barsky 2005; Deary et al. 2007; Rief and Broadbent 2007), which in the other conditions could be confused with the SSDT vibration. This may have had the effect of reducing tactile 'noise' and the ambiguity of the tactile signal in the detached condition, especially during vibration-absent trials.

Inclusion of the simultaneous task-irrelevant light was also found to significantly increase vibration reports regardless of whether or not one was present, leading to increases in both hit rates and false-alarm rates. This result replicates previous findings (Johnson et al. 2006; Lloyd et al. 2008; McKenzie et al. 2010; Mirams et al. 2010) and suggests that if visual information is available, participants incorporate it into decisions about ambiguous somatic events, even when such visual information is entirely task-irrelevant.

Previous studies using the SSDT have shown vision of the hand to increase false touch reports when it was non-informative, that is, when no additional helpful information about touch was provided (Mirams et al. 2010). This finding is in agreement with clinical models of medically unexplained symptoms that have suggested increased body-focused attention to increase awareness of benign internal bodily sensations (Rief and Barsky 2005; Deary et al. 2007; Rief and Broadbent 2007) that could be confused with the SSDT vibration (Mirams et al. 2010). Our findings therefore suggest that such an effect can be modulated by manipulating the visual appearance of the hand through multisensory illusions. These current results therefore extend previous studies that have reported discrepancies in pain perception following manipulated representations of the body (Ramachandran et al. 2009; Preston and Newport 2011) independent of the influence of pure response bias (Romano and Maravita 2014; Mancini et al. 2011).

In summary, the current findings highlight the plasticity and flexibility of the internal body image and suggest that somatosensation can be modulated by distorted representations of the body. While increasing and decreasing perceived body size enhanced detection of the SSDT vibration, this increase was found to be associated with a change in response criterion and greater sensitivity, respectively. Therefore, different underlying mechanisms may operate in interpreting somatic experiences when information relating to the shape and size of the body is altered. Given that sensory discrimination training has been used to resolve chronic pain in patients (Moseley et al. 2008a, b; Moseley and Wiech 2009), our results may be useful in understanding and managing somatic disturbances including knee osteoarthritis and CRPS.

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