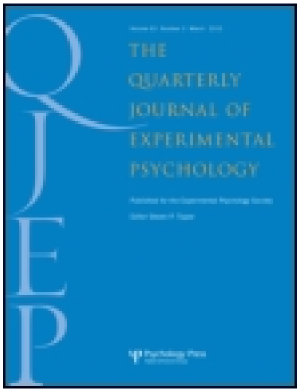

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Interoceptive and exteroceptive attention have opposite effects on subsequent somatosensory perceptual decision making

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Interoceptive and exteroceptive attention have opposite effects on subsequent somatosensory perceptual decision making

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Evidence suggests that interoceptive and exteroceptive attention might have different perceptual effects. However, the effects of these different types of body-focused attention have never been directly compared. The current research investigated how interoceptive and exteroceptive attention affect subsequent performance on the somatic signal detection task (SSDT). In Experiment 1, 37 participants completed the SSDT under usual testing conditions and after performing an interoceptive heartbeat perception task. This task led to a more liberal response criterion, leading to increased touch reports in the presence and absence of a target vibration. This finding is consistent with suggestions that attending internally contributes to physical symptom reporting in patients with medically unexplained symptoms (MUS). In Experiment 2, 40 participants completed the SSDT before and after an exteroceptive grating orientation task. This task led to a more stringent response criterion, leading to decreased touch reports in the presence and absence of the target, possibly via a reduction in sensory noise. This work demonstrates that internal and external body-focused attention can have opposite effects on subsequent somatic perceptual decision making and suggests that attentional training could be useful for patients reporting MUS.

Keywords: Attention; Exteroception; Interoception; Signal detection analysis; Somatization.

Interoception has recently been defined as the sense of the physiological condition of the body, and includes the perception of temperature, pain, itch, muscular and visceral stimuli, hunger, and thirst (Craig, 2002). Interoception is considered to be distinct from exteroception, the perception of external tactile stimulation[1] (e.g., Sherrington, 1906). Indeed, interoceptive and exteroceptive

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[1] It could be argued that regardless of the origin of a bodily sensation, all bodily sensations are "internal" by nature. For example, the perception of external touch involves an interaction between environmental and bodily factors (i.e., an external stimulus exerts pressure on the surface of the skin). Nonetheless, a distinction can be made between bodily sensations that originate from some external stimulus and bodily sensations that originate within the body (e.g., Cameron, 2002; Craig, 2003; Leder, 1990).

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information are processed separately, via a dedicated cortical pathway (see Craig, 2002, 2003, for reviews).

Evidence suggests that focusing one's attention on interoceptive and exteroceptive information might have different perceptual effects. For example, instructing participants to attend preferentially to stimulation in the tactile modality or increasing the number of tactile targets within a task (i.e., exteroceptive attention) results in faster reaction times to tactile targets (Spence, Nicholls, & Driver, 2001) and speeds the perceived arrival of tactile stimuli (relative to stimulation in other modalities) in temporal order judgement tasks (Spence, Shore, & Klein, 2001; Vibell, Klinge, Zampini, Spence, & Nobre, 2007). It has been suggested that attention enhances tactile perception by amplifying responses to tactile stimuli in the somatosensory cortex (Burton & Sinclair, 2000) and also by decreasing neuronal responses to distractor stimuli (Johansen-Berg & Lloyd, 2000).

In contrast, clinical models have suggested that focusing attention on interoceptive information can lead to an increase in perceptual errors, including the tendency to report physical symptoms in the absence of medical pathology (i.e., medically unexplained symptoms, MUS; e.g., Brown, 2004; Deary, Chalder, & Sharpe, 2007; Rief & Barsky, 2005; Rief & Broadbent, 2007). It is known that people who habitually report high numbers of physical symptoms are highly aware of internal bodily sensations more generally (e.g., Barsky, Brener, Coeytaux, & Cleary, 1995; Duddu, Chaturvedi, & Isaac, 2003; Haenen, Schmidt, Schoenmakers, & van den Hout, 1997), but are rarely more accurate on objective measures of interoception, such as heartbeat perception (HBP; Ehlers, Mayou, Sprigings, & Birkhead, 2000; Fairclough & Goodwin, 2007; Mussgay, Klinkenberg, & Ruddel, 1999). Instructions to attend to "the body" and attending to body-related information also increase self-reported awareness of bodily sensations (Haenen, Schmidt, Kroeze, & van den Hout, 1996; Pennebaker & Lightner, 1980), typically without improving interoceptive accuracy (see Silvia & Gendolla, 2001, for a review). Thus, it seems that whereas exteroceptive attention improves accuracy of exteroceptive perception, interoceptive attention increases the *quantity* of information available to perception but not necessarily its *quality* (cf. Pennebaker, 1982; Silvia & Gendolla, 2001). However, the perceptual effects of interoceptive and exteroceptive attention have never been directly compared.

In the current research, we investigated whether interoceptive and exteroceptive attention differentially affect the subsequent propensity to report feeling ambiguous external tactile stimulation during the somatic signal detection task (SSDT; Lloyd, Mason, Brown & Poliakoff, 2008). This task involves detecting a near-threshold vibration on the fingertip presented on 50% of trials. Signal detection theory is used to analyse the data from this task, making it possible to determine whether a manipulation affects tactile sensitivity (i.e., an individual's ability to distinguish signal from noise), response criterion (c—an individual's propensity to report feeling touch), or both. In healthy participants, simultaneously presenting a visual stimulus (light flash) improves detection of the vibration and also increases false reports of feeling the vibration when it is absent (Lloyd et al., 2008). This could be because the light increases attentional orienting towards the hand, which might raise awareness of internal bodily sensations that become confused with the vibration (Lloyd et al., 2008).

We have previously found that both clinical and nonclinical participants reporting a high number of physical symptoms have a more liberal criterion for reporting external touch and make more "false alarms" (reports of feeling touch in the absence of tactile stimulation) on this task (Brown, Brunt, Poliakoff, & Lloyd, 2010; Brown et al., 2011). We have also found that viewing the hand increases false alarms on the SSDT in light-present trials compared to when the hand is covered (but the light still visible; Mirams, Poliakoff, Brown, & Lloyd, 2010). It may be that the light increased tactile attention towards the hand when it was visible, leading participants to mistakenly class sensory noise (from tactile afferents on the skin or internal pulse sensations) as signal (vibration), thereby increasing false alarms. This finding contrasts with previous findings that viewing the body enhances tactile perception (e.g., Kennett, Taylor-Clarke, & Haggard, 2001; Serino, Padiglioni, Haggard, & Ladavas, 2009; Tipper et al., 1998) and demonstrates the value of taking into account both sensitivity and response criterion when evaluating attentional effects.

EXPERIMENT 1: THE EFFECT OF INTERNAL BODY-FOCUSED ATTENTION ON SOMATIC PERCEPTION

To test the hypothesis that sensory noise in the fingertip contributes to false alarms during the SSDT, we investigated how prior performance of an interoceptive task affects subsequent decision making during the SSDT. A version of Schandry's (1981) mental tracking task was used to direct attention towards internal sensations in the fingertip. This task has been used widely to measure interoceptive ability (e.g., Mussgay et al., 1999; Pollatos, Traut-Mattausch, & Schandry, 2009). Unlike other HBP tasks, participants attend solely to internal heartbeat sensations in this paradigm, counting the number of heartbeats they can feel in different time intervals. Participants' counts are then compared with electrocardiogram (ECG) recordings of heartbeats to calculate accuracy. In this study, participants concentrated on internal pulse sensations in their fingertip. The HBP task was expected to induce a state of raised interoceptive awareness, which was expected to have a carry-over effect on subsequent SSDT performance. As a consequence, participants were expected to be more likely to report feeling the experimental vibration (have a more liberal response criterion) after completing the HBP task, due to increased confusion between internal bodily sensations in the fingertip and the vibration. This confusion was also predicted to decrease confidence in touch reports.

Method

Participants

Forty undergraduate students were initially recruited; however, data were removed from one participant who did not complete the study and two participants who were unable to feel a countable pulse during the HBP task. The final sample consisted of 37 right-handed participants (assessed using the Edinburgh Handedness Inventory; Oldfield, 1971) aged 19 to 48 years (mean = 21.97 years, *SD* = 4.00; 30 female). All participants gave informed consent prior to participating in the study, which was approved by the local Ethics Committee at the University of Manchester. All participants had normal or corrected-to-normal vision, and none reported any tactile sensory deficits.

Design

A repeated measures design was implemented with HBP task condition (HBP task vs. no HBP task) and SSDT light condition (light present vs. light absent) as within-subject variables. Participants attended two experimental sessions, one week apart. In one session they completed the SSDT; in another they completed the HBP task, then the SSDT. The order of sessions was counterbalanced, and participants attended Session 1 on the same day of the week and time as Session 2.

SSDT materials and procedure

Participants sat in a light-attenuated room approximately 60 cm in front of a stimulus array. This consisted of a polystyrene block into which was mounted a 4-mm red light-emitting diode (LED) and a bone conductor with a 1.6 × 2.4-cm vibrating surface (Oticon Limited, B/C 2-PIN) to which the participant's left index finger was fixed with a double-sided adhesive pad. Tactile pulses (20 ms, 100-Hz vibrations) were produced by sending amplified sound files, controlled via E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA, USA), to the bone conductor. Instructions were delivered on a monitor. Participants listened to white noise via headphones throughout the experiment to mask any informative sounds from the bone conductor.

Before beginning the SSDT, a threshold was found for each participant using a staircase procedure (Cornsweet, 1962) in which participants were presented with blocks of 13 trials: 10 tactile present and 3 tactile absent. The beginning of each trial was signalled by the appearance of a green arrow cue on the monitor (subtending approx. 18 ° × 7 ° of the visual angle) pointing towards the participant's left index finger for 250 ms. This was followed by a stimulus period of 1,020 ms. In tactile-present trials, the 20-ms tactile pulse was delivered with a delay of 500 ms on either side; in tactile-absent trials, an empty 1,020-ms period occurred. An on-screen prompt then appeared, and participants were asked to report whether they had perceived a pulse ("yes") or not ("no") by pressing keys labelled "Y" or "N" on the computer keyboard. The tactile stimulus was initially presented at the same intensity (0.59 m/s, as measured by an accelerometer attached to the bone conductor) for all participants. If the vibration was perceived on more than 60% of the tactile-present trials, the intensity was reduced by 0.16 m/s for the next thresholding block. If it was perceived on less than 40% of the tactile-present trials, the intensity was increased by 0.16 m/s. This procedure was repeated until the stimulus intensity approached the participant's 50% threshold (the intensity necessary for participants to perceive the vibration on 40–60% of trials). Participants had to score within this range for two consecutive blocks, or for three nonconsecutive blocks at the same stimulus intensity. Participants were instructed to keep their hand still throughout the experiment, including break and rest periods.

The SSDT consisted of two 80-trial blocks, with the following trial types: light only (light present/touch absent); light and touch (light present/touch present); touch only (light absent/touch present); and catch (light absent/touch absent) presented 20 times per block in a random order. The tactile stimulus was presented at the threshold level previously established. Each SSDT trial was preceded by the appearance of the green arrow cue on the monitor for 250 ms. In touch only trials, a 20-ms vibration occurred with a delay of 500 ms on either side. Catch trials consisted of an empty 1,020-ms interval. In light and touch trials, the LED flashed for 20 ms at the same time as the vibration. In light only trials, the LED flashed for 20 ms. Participants were not told anything about the light and were only required to indicate whether or not they felt the tactile stimulus after each trial, this time using one of four response options: "definitely yes", "maybe yes", "maybe no", "definitely no". Half of the participants were instructed to press keyboard buttons labelled "1" for "definitely yes", "2" for "maybe yes", "3" for "maybe no", or "4" for "definitely no". The other half received the reverse instructions (i.e., "1" for "definitely no", "2" for "maybe no", etc.).

HBP task design, materials, and procedure

The mental tracking task has good test–retest reliability (Mussgay et al., 1999). Performance on time estimation tasks and self-reported knowledge of heart rate have not been found to be associated with tracking task performance (e.g., Ehlers et al., 2000; Zoellner & Craske, 1999), suggesting that participants do not simply guess the number of heartbeats based on these factors. As the aim of the current study was to investigate the effect of interoceptive attention, rather than HBP ability, the mental tracking task was altered in four ways. First, participants were instructed to attend to pulse sensations specifically in their left index fingertip. Secondly, the task was made easier by applying pressure to the fingertip using a pulse monitor to make pulse sensations more noticeable. Thirdly, to encourage engagement with the task, participants were given feedback about their performance after each interval. Finally, to ensure raised interoceptive awareness, the task was repeated so that participants completed six, rather than three, intervals of the task.

After participants had read the written instructions, the fingertip pulse monitor was attached to the left index finger (no measurements were taken from this). Three disposable silver/silver chloride (Ag/AgCl) electrodes were then attached to both wrists and the right ankle, and ECG was registered using ADInstruments PowerLab equipment and Chart software (version 5.4, ADInstruments, Pty Limited) with a sampling rate of 400 Hz. The PowerLab software provided an instant count of the number of heartbeats that occurred during each interval. Participants were instructed to concentrate on feelings in their fingertip until they could feel their pulse; if necessary, the tightness of the fingertip pulse monitor was adjusted. Participants were then asked to count silently the number of pulses they could feel in their fingertip during 25-, 35-, and 45-s intervals. The start and finish of each interval was verbally signalled by the experimenter, who simultaneously started and stopped the ECG recording. At the end of each interval, participants verbally reported how many beats they had counted, and the experimenter gave them accuracy feedback (the absolute difference between actual and counted beats). Participants were not given a signed error to prevent them from using nonperceptual strategies to count pulse sensations, such as guessing in accordance with whether they previously under- or overestimated the number of pulses.

Participants completed each time interval twice, in a random order, completing six intervals overall. Participants were unaware of the duration of each interval and were instructed not to take their pulse or try any other physical manipulations that might facilitate the detection of heartbeats. Participants listened to white noise via headphones throughout to mask any distracting sounds. The task took approximately 6 minutes.

Participants completed the SSDT after the HBP task. To check that the HBP task raised awareness of internal sensations in the fingertip, participants were asked; "Were you more aware of the feelings in your fingertip after you had done the heartbeat perception task?" at the end of the testing session. No other instructions were given, and participants were naïve as to the true purpose of the study.

Data analysis

SSDT. Responses were classified as hits (correct reports of feeling the touch on touch-present trials), misses (reports of not feeling the touch on touch-present trials), false alarms (erroneous reports of feeling the touch on touch-absent trials) or correct rejections (reports of not feeling the touch on touch-absent trials). "Definitely" and "maybe" responses were combined and grouped into "yes" and "no" responses.[2] Hit rates [hits + 0.5/(hits + misses+1)] and false-alarm rates [false alarms + 0.5/(false alarms + correct rejections +1)] were calculated using the log–linear correction (Snodgrass & Corwin, 1988)[3] and were used to calculate the signal detection theory test statistics d' [z(hits) − z(false alarms)] and c [–0.5 × (zHIT + zFA)] (where HIT is hit rate, and FA is false-alarm rate, Macmillan & Creelman, 1991). This provided estimates of each participant's perceptual sensitivity (d'), and response criterion (c) in each light and HBP condition. Statistical analyses were conducted using SPSS Version 15.0 (SPSS Inc., Chicago, IL).

HBP task. Interoceptive accuracy was calculated for each participant as the mean score across the six HBP intervals using the formula (following Mussgay et al., 1999; Pollatos, Traut-Mattausch, Schroeder, & Schandry, 2007):

$$Accuracy = \frac{1}{6}\sum\left(1 - \frac{[\text{recordedbeats} - \text{countedbeats}]}{\text{recordedbeats}}\right)$$

This provides a pulse detection score from 0 to 1 with high scores indicating small amounts of error. The highest accuracy achieved on any time period of the HBP task was also recorded. Effect sizes were calculated using Cohen's d. Effects of 0.10, 0.25, and 0.40 are thought to indicate small, medium, and large effects in analysis of variance (ANOVA), and effects of 0.20, 0.50, and 0.80 are thought to indicate small, medium, and large effects in t tests (Cohen, 1992).

Results

HBP task performance

Average accuracy on the HBP task ranged from .35 to .99 ($M = .81$, $SD = .14$), suggesting that participants were engaged with the task. At the end of the

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[2] Collapsing the data gave similar false-alarm rates to those found in previous studies (e.g., Lloyd et al., 2008).

[3] Applying the log–linear correction (the addition of 0.5 and 1) eliminates values of zero in the hit and false-alarm rate data, which is necessary in order to calculate d' and c.

experiment 85% of participants stated that they were more aware of feelings in their fingertip after they had done the HBP task.

Normality and outliers for SSDT data

Inspection of box plots revealed outlying scores in the sensitivity and response criterion data. As no participant had outlying scores in both testing sessions, outlying scores were changed to the next highest (or lowest) score plus .01 (cf., Field, 2005). After doing so, the response criterion data were normally distributed. As the sensitivity data (in the HBP condition) remained positively skewed, logarithm transformations were used to normalize these data.

The effect of the HBP task on SSDT performance

Table 1 shows descriptive statistics for each SSDT outcome measure in each HBP and light condition. To test the hypothesis that the HBP task would lead to a more liberal response criterion during the SSDT, a 2 (HBP condition) × 2 (light condition) repeated measures ANOVA was performed with *c* as the dependent variable. Paired or independent samples *t* tests were used to elucidate any interactions. The main effect of HBP condition was not significant, $F(1, 36) = 1.56$, $p = .22$, Cohen's $d = 0.21$, but there was a significant interaction between HBP condition and light, $F(1, 36) = 8.58$, $p = .01$ (see Figure 1). Response criterion was lower in light-present trials than in light-absent trials both with, $t(36) = 2.62$, $p = .01$, Cohen's $d = 0.62$, and without the HBP task, $t(36) = 4.85$, $p < .001$, Cohen's $d = 1.14$. There was no difference in response criterion between the two HBP conditions in light-present trials ($p = .69$). However, in light-absent trials, response criterion was significantly lower with the HBP task than without it, $t(36) = 2.28$, $p = .03$, Cohen's $d = 0.54$. To see whether the light had a smaller effect on response criterion after the HBP task, difference scores (*c* light-present − *c* light-absent) in each HBP condition were compared. The light had a significantly smaller effect on response criterion with the HBP task (mean difference = .11) than without it (mean difference = .33), $t(36) = 2.93$, $p = .01$, Cohen's $d = 0.69$.

To test the hypothesis that confidence in touch-present decisions during the SSDT would be lower after the HBP task, paired samples *t* tests were

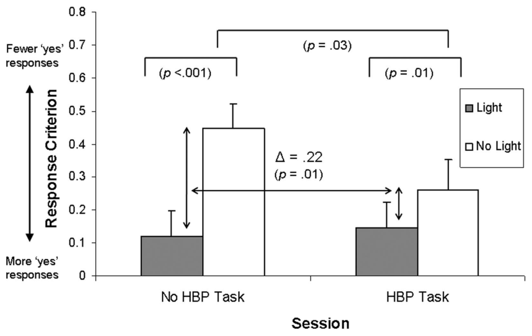

Figure 1. *The effect of heartbeat perception (HBP) condition and light on response criterion in Experiment 1. Vertical arrows indicate differences between light and no-light conditions. Response criterion was lower (participants were more likely to report feeling the vibration) in light-absent trials in the HBP testing session than in light-absent trials in the testing session without the HBP task. Error bars reflect + standard error of the mean.*

Table 1. *Means of hit rates, false-alarm rates, d′, and c in each HBP and light condition in Experiment 1*

HBP condition	*Light condition*	*Hits (%)*	*False alarms (%)*	*d′*	*d′ (logarithm transformed)*	*c*
No HBP task	Light	63.71 (21.03)	30.28 (22.33)	1.08 (1.04)	.26 (.24)	.12 (.45)
	No light	49.80 (20.92)	25.99 (23.02)	0.88 (0.90)	.20 (.23)	.45 (.56)
HBP task	Light	62.00 (18.81)	32.95 (24.20)	0.96 (1.08)	.22 (.28)	.15 (.46)
	No light	54.89 (20.38)	29.23 (21.79)	0.79 (0.86)	.21 (.20)	.26 (.47)

Note: HBP = heartbeat perception; *d′* = perceptual sensitivity; *c* = response criterion. Standard deviations in parentheses.

conducted comparing certainty ratings (proportion of "definitely yes" compared to "maybe yes" responses) for hit and false-alarm responses before and after the HBP task. The HBP task did not affect confidence in either hit, $t(36) = 0.87$, $p = .39$, Cohen's $d = 0.25$ or false-alarm responses, $t(31) = -0.517$, $p = .61$, Cohen's $d = 0.12$.

To rule out the possibility that the HBP task affected sensitivity during the SSDT, a 2 (HBP condition) × 2 (light condition) repeated measures ANOVA was performed with d' (logarithm transformed data) as the dependent variable. There was no effect of light, $F(1, 36) = 2.70$, $p = .11$, Cohen's $d = 0.22$, or HBP task, $F(1, 36) = 0.28$, $p = .60$, Cohen's $d = 0.09$, and no interaction between light and HBP task, $F(1, 36) = 1.77$, $p = .19$.

Discussion

The aim of Experiment 1 was to investigate the effect of interoceptive attention on the subsequent tendency to report external touch during the SSDT. The HBP task was expected to raise awareness of internal pulse sensations during the SSDT, leading to confusion between internal pulse sensations and the vibration. This confusion was expected to manifest in a more liberal response criterion. As expected, the HBP task significantly reduced response criterion (made participants more likely to report feeling touch)[4] in light-absent (but not light-present) trials, resulting in higher hit and false-alarm rates after the HBP task. Although the HBP task affected the number of touch reports in light-absent trials, it did not affect the accuracy of tactile perception (sensitivity did not change after the HBP task) or confidence in yes responses. This finding is consistent with the proposed role of overinterpretation of bodily sensations in MUS (e.g., Brown, 2004; Deary et al., 2007; Rief & Barsky, 2005; Rief & Broadbent, 2007). Interoceptive attention may increase the amount of somatic information that we are aware of and lead us to mistake sensory noise for "signal".

It should be noted that attending internally only made participants more willing to report feeling the touch in the absence of the light. The HBP task may have affected performance in light-absent rather than light-present trials because, in such trials, internal pulse sensations occurring at any time between the offset of the cue and onset of the response screen could potentially be mistaken for the vibration. In contrast, only internal pulse sensations occurring at the same time as the light could be mistaken for the vibration on light-present trials.

Alternatively, the visual stimulation in light trials may have overridden the effect of heightened interoceptive awareness after the HBP task. Visual information has been found to dominate and alter touch perception, particularly when visual and tactile inputs provide incongruent information (see, for example, Johnson, Burton, & Ro, 2006).

EXPERIMENT 2: THE EFFECT OF EXTERNAL TACTILE ATTENTION ON SOMATIC PERCEPTION

In Experiment 2, we investigated the effect of performing an exteroceptive task on subsequent SSDT performance. Whereas the HBP task in Experiment 1 may have increased the ratio of noise (i.e., distracting bodily sensations) to signal (i.e., vibration) during the SSDT, an exteroceptive task was expected to have the opposite effect, by amplifying neuronal responses to the vibration and by reducing interference from sensory noise. A grating orientation task was chosen to manipulate attention to external tactile stimulation. Such tasks are a reliable, well-validated, and widely used measure of tactile acuity (e.g., Sathian & Zangaladze, 1996; Van Boven, Hamilton, Kauffman, Keenan, & Pascual-Leone, 2000). In grating orientation tasks, acuity gratings (domes with grooves cut into them) are applied to the skin in either a transverse or longitudinal orientation. Participants report the orientation they feel on each trial. A task involving spatial discrimination, rather than simple detection of tactile stimulation, was chosen to ensure that the task

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[4] As criterion was >0, participants were still more likely to say no than yes after doing the HBP task. However, they were more likely to say yes after the HBP task than in the no HBP task condition.

engaged sufficient processing resources and also to make the task equivalent in difficulty to the interoceptive attention manipulation (HBP task) in Experiment 1. To allow comparison with the HBP task, an additional counting task was added to the usual grating orientation task procedure, and ECG recordings were taken during the task to control for any extraneous effects of the ECG procedure in Experiment 1.

The grating orientation task was expected to increase sensitivity (d') during the SSDT, increasing correct touch reports (hit rates) relative to incorrect touch reports (false alarms). Participants were also expected to be more confident in their touch-present decisions after the grating orientation task.

Method

Participants

Forty undergraduate students were initially recruited; however, data were subsequently removed from one participant who was above threshold (with a hit rate of $>90\%$ in light-absent trials) during the SSDT. The final sample consisted of 39 right-handed participants aged 19 to 45 years (mean $= 23.94$ years, $SD = 5.28$; 22 female).

Design

A repeated measures design was implemented with grating orientation task condition (before vs. after grating orientation task) and SSDT light condition (light present vs. light absent) as within-subjects variables. We have previously found that SSDT performance remains largely constant with repeated experience (McKenzie, Poliakoff, Brown, & Lloyd, 2010). Therefore for pragmatic reasons, participants attended just one experimental session, during which they completed the SSDT before and after the grating orientation task. The procedure for the SSDT was the same as that in Experiment 1.

Grating orientation task materials and procedure

Participants were seated behind a desk and were given written instructions for the task. The participant's left hand was placed palm side up onto a foam pad, to which their left index finger was secured using tape to prevent movement. Electrodes were attached for ECG measurement as in Experiment 1. A wooden screen prevented vision of the hand. The tactile stimuli for the task were 10 plastic grating domes (Tactile Acuity Gratings, JVP Domes, Med-Core) with grooves of a different width (ranging from 0.25 mm to 3.5 mm) cut into each one. In pilot testing, most people began to make errors in grating orientation discrimination at the 1.5-mm grating; therefore, this grating was used initially in the thresholding procedure.

During thresholding, the experimenter applied the 1.5-mm grating dome to the participant's left index finger for 1 second, 10 times vertically (along the fingertip) and 10 times horizontally (across the fingertip) in a predetermined pseudorandom order, which was the same for each participant. Participants verbally reported which orientation they felt after each presentation. If the participant was correct less than 80% of the time, the task was repeated using a wider grating width; if the participant was correct more than 80% of the time, the task was repeated using a narrower grating width, until a grating width was identified at which the participant correctly identified the orientation 80% of the time. The thresholding procedure took approximately 3 minutes.

The grating width identified during the thresholding procedure was used in the counting task. The participant received blocks of 25, 35, and 45 presentations (participants were not informed of the number of presentations in each block). In each block, domes were manually applied by the experimenter for 1 second in either the vertical or horizontal orientation, in a predetermined pseudorandom order. Participants were instructed to keep a mental count of the number of either vertical or horizontal gratings (target type was counterbalanced) in each block. The proportion of target gratings (horizontal or vertical) varied between 40 and 60% in each presentation block. At the end of each block, participants verbally reported how many target orientations they had counted, and the experimenter gave them accuracy feedback (the absolute difference between actual and counted targets). Participants completed five presentation blocks (2×25, 2×35, 1×45). This made the task equivalent in duration to the HBP task, which involved six counting intervals, but no thresholding procedure. Throughout the counting task, participants listened to white noise via headphones to mask any distracting sounds.

Data analysis

SSDT. As in Experiment 1, hit and false-alarm rates were used to calculate signal detection measures of sensitivity (d') and response bias (c), this time in each grating orientation task and light condition.

Grating orientation task. Exteroceptive accuracy was calculated for each participant using the same formula as that used to calculate interoceptive accuracy in Experiment 1.

Results

Grating orientation task data

Average accuracy on the grating orientation task was 81% ($SD = 10.45$), suggesting that the task was equivalent in difficulty to the HBP task. Grating discrimination thresholds ranged from 1.2 mm to 3.5 mm (mean = 2.11, $SD = 0.53$).

Normality and outliers for SSDT data

Inspection of box plots revealed outlying scores in the criterion data. To minimize the impact of these scores, they were changed to the next highest (or lowest) score plus .01. This procedure normalized the criterion data.

The effect of the grating orientation task on SSDT performance

Table 2 shows descriptive statistics for each SSDT outcome measure in each grating orientation and light condition. To test the hypothesis that the grating orientation task would lead to an increase in sensitivity during the SSDT, a 2 (grating orientation condition) × 2 (light condition) repeated measures ANOVA was performed with d' as the dependent variable. There was no effect of the grating orientation task, $F(1, 38) = 0.16$, $p = .69$, Cohen's $d = 0.07$, and no interaction between grating orientation task and light condition, $F(1, 38) = 0.97$, $p = .33$. Sensitivity was significantly higher in light-present than in light-absent trials, $F(1, 38) = 28.18$, $p < .001$, Cohen's $d = 0.86$, see Table 2.

To test the hypothesis that confidence in touch-present decisions during the SSDT would be lower after the grating orientation task, paired samples t tests were conducted comparing certainty ratings (proportion of "definitely yes" compared to "maybe yes" responses) for hit and false-alarm responses in each grating orientation condition. The grating orientation task did not affect confidence in either hits, $t(38) = 0.24$, $p = .81$, Cohen's $d = 0.06$, or false alarms, $t(38) = 1.08$, $p = .29$, Cohen's $d = 0.23$.

To investigate whether the grating orientation task affected response criterion during the SSDT, a 2 (grating orientation condition) × 2 (light condition) repeated measures ANOVA was performed with c as the dependent variable. Response criterion was significantly higher (participants made significantly fewer yes responses) after the grating orientation task than before, $F(1,$

Table 2. *Means of hit rates, false-alarm rates, d′, and c in each grating orientation and light condition in Experiment 2*

Grating orientation condition	*Light condition*	*Hits (%)*	*False alarms (%)*	d'	c
Before grating orientation task	Light	71.20 (19.26)	21.74 (21.71)	1.66 (1.22)	.16 (.46)
	No light	58.82 (20.92)	16.56 (15.18)	1.41 (1.12)	.45 (.36)
After grating orientation task	Light	69.89 (18.89)	20.05 (20.38)	1.67 (1.17)	.24 (.40)
	No light	53.38 (19.90)	14.65 (14.36)	1.31 (0.94)	.60 (.35)

Note: d' = perceptual sensitivity; c = response criterion. Standard deviations in parentheses.

38) = 6.00, $p = .02$, Cohen's $d = 0.39$.[5] There was no interaction between grating orientation task and light condition, $F(1, 38) = 1.67$, $p = .20$. Response criterion was significantly lower in light-present than in light-absent trials, $F(1, 38) = 24.86$, $p < .001$, Cohen's $d = 0.81$, see Table 2.

Did SSDT performance remain stable over time?

To rule out the possibility that practice effects accounted for the change in response criterion in Experiment 2, Time 1 (first SSDT performance) and Time 2 (second SSDT performance) data from each experiment were combined. Paired samples *t* tests showed that time (i.e., SSDT practice) did not affect sensitivity—averaged across light conditions, $t(75) = 0.03$, $p = .98$, Cohen's $d = 0.00$—or response criterion—averaged across light conditions, $t(75) = 0.11$, $p = .92$, Cohen's $d = 0.02$.

Discussion

In Experiment 2, attending to external tactile stimulation during the grating orientation task was expected to heighten subsequent exteroceptive sensitivity during the SSDT, resulting in increased hits relative to false alarms. The grating orientation task did not affect sensitivity, however, but led to a more stringent response criterion with participants being less likely to report feeling a touch after the task. This increase in response criterion led to lower hit and false-alarm rates after the grating orientation task, across light conditions. The grating orientation task did not affect confidence in touch reports.

The grating orientation task may not have affected sensitivity as the strength of the SSDT vibration was set to be at threshold each time the task was performed. This may have prevented any increase in hit rates during the SSDT. Nevertheless, the grating orientation task may have reduced levels of sensory noise, which could account for the change in response criterion. As noted in the introduction, attention is thought to act in two ways: by amplifying neuronal responses to attended stimuli, and by decreasing interference from distracting stimuli in the same or different sensory modalities (see, for example, Johansen-Berg & Lloyd, 2000), thereby improving the signal to noise ratio (e.g., Hillyard, Vogel, & Luck, 1998). This could account for the reduction in false alarms, as participants classed sensory noise as signal less often on touch-absent trials, and could also account for reduction in hits, as participants classed sensory noise as signal less often on touch-present trials. A reduction in the number of accidental hits may have prevented any increase in sensitivity after the grating orientation task, despite a decrease in sensory noise.

GENERAL DISCUSSION

The aim of this research was to investigate whether interoceptive and exteroceptive attention have different effects on somatic perception. In Experiment 1, attending to internal bodily sensations during a HBP task increased the subsequent propensity to report external touch during the SSDT. Raised interoceptive awareness may have caused confusion between signal and noise, reducing the criterion for reporting sensations. A similar process may be responsible for increased symptom reports in patients with MUS. In Experiment 2, performing an exteroceptive task had the opposite effect on participants' subsequent criterion for reporting external touch, perhaps by reducing levels of sensory noise.

We suggest that performing the HBP and grating orientation tasks had carry-over effects to SSDT performance, by increasing awareness of interoceptive or exteroceptive information. It could be argued that the current findings are better accounted for by a modality shift effect—that is, a cost in processing targets after switching from one sensory modality to another (e.g.,

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[5] When the response criterion data from Experiments 1 and 2 were combined and analysed in a 2 (manipulation condition) × 2 (light condition) × 2 (experiment) mixed design ANOVA, there was an interaction between light, manipulation, and experiment, $F(74) = 10.03$, $p = .002$.

Spence, Nicholls, et al., 2001). Whilst there may have been a cost in switching from the interoceptive to the exteroceptive modality in Experiment 1, which would not arise in Experiment 2, the switching did not occur during the SSDT itself. Moreover, evidence suggests that the modality shift effect is very short lived (Miles, Brown, & Poliakoff, 2011), making it an unlikely explanation for our results. It may be that we have demonstrated a modality shift effect of a different nature, however, whereby switching attention from the interoceptive modality incurs a cost for subsequent exteroceptive perception, due to the sustained effects of increased sensory noise.

A limitation of the current research is that Experiments 1 and 2 differed in their design. Experiment 2 took place over one testing session, with all participants completing the SSDT before, then after the grating orientation task. Experiment 1 took place over two testing sessions, with half of the participants completing the SSDT before (Testing Session 1), then after the HBP task (Testing Session 2) and half completing the SSDT after the HBP task (Testing Session 1), then without the HBP task (Testing Session 2). This could account for the higher false-alarm rates and lower tactile sensitivity, even without the HBP task, in Experiment 1. After experiencing confusion between internal pulse sensations and the experimental vibration in the HBP testing session, participants who did the HBP task in the first testing session might have been more likely to notice internal pulse sensations the second time they completed the SSDT. However, the order in which participants completed testing sessions in Experiment 1 did not account for the effect of the HBP task. When condition order was included as a between-subjects variable, the light and HBP task interaction for response criterion remained significant.

It is also possible that differences between the participant groups may have affected the findings. For example, average baseline sensitivity was much lower in Experiment 1 ($M = 0.98$) than in Experiment 2 ($M = 1.54$), suggesting that the participants in Experiment 1 may have been less able to distinguish between signal and noise. Indeed, the SSDT thresholding procedure took significantly longer ($p < .001$) for participants in Experiment 1 (M number of blocks = 5.15) than for participants in Experiment 2 ($M = 4.08$). Therefore, this group may have been particularly susceptible to interference by the HBP task. However, as there was little difference in baseline response criterion in Experiment 1 ($M = .29$) and Experiment 2 ($M = .31$), we think it is unlikely that group differences account for the differential changes in response criterion in the two experiments.

We have found that changing the *direction* of body-focused attention alters the subsequent propensity to report feeling touch. This raises the possibility that attentional training could be useful for individuals with MUS, by facilitating disengagement of attention from bodily sensations. Indeed, attending to auditory stimulation has been found to decrease physical symptom reports in hypochondriasis patients (Papageorgiou & Wells, 1998). Changing the *nature* of interoceptive attention might also benefit individuals with MUS (cf. Mehling et al., 2009). In particular, encouraging mindful body-focused attention could help people to shift their attentional focus away from worrying bodily sensations. Mindfulness meditation has previously been found to reduce psychosomatic symptoms (e.g., Landsman-Dijkstra, van Wijck, Groothoff, & Rispens, 2004) and improve attentional control (see Lutz, Slagter, Dunne, & Davidson, 2008, for a review). We are currently investigating whether a meditation technique known as the "body-scan" affects performance during the SSDT.

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