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Brief body-scan meditation practice improves somatosensory perceptual decision making

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ABSTRACT

We have previously found that attention to internal somatic sensations (interoceptive attention) during a heart beat perception task increases the misperception of external touch on a somatic signal detection task (SSDT), during which healthy participants erroneously report feeling near-threshold vibrations presented to their fingertip in the absence of a stimulus. However, it has been suggested that mindful interoceptive attention should result in more accurate somatic perception, due to its non-evaluative and controlled nature. To investigate this possibility, 62 participants completed the SSDT before and after a period of brief body-scan mindfulness meditation training, or a control intervention (listening to a recorded story). The meditation intervention reduced tactile misperception and increased sensitivity during the SSDT. This finding suggests that the perceptual effects of interoceptive attention depend on its particular nature, and raises the possibility that body-scan meditation could reduce the misperception of physical symptoms in individuals with medically unexplained symptoms.

1. Introduction

Perception of internal bodily sensations (“interoception”) and external touch (“exteroception”, e.g., Sherrington, 1906)[1] contributes to our conscious experience of our bodies. Interoception has been defined as the sense of the physiological condition of the body (Cameron, 2001), including the perception of temperature, itch, muscular and visceral sensations, hunger, thirst, pain and other physical symptoms (Craig, 2002). Research suggests that interoceptive information is processed separately to exteroceptive information, via a dedicated cortical pathway (see Craig, 2002, 2003 for reviews). Interoceptive and exteroceptive perception are not solely based on incoming sensory information, rather they are influenced and potentially distorted by information from other sensory modalities and top-down factors, such as attention. As a result, somatic perception does not always reflect sensory reality. For example, hearing about an insect infestation might cause us to feel itch, or crawling sensations on our skin, in the absence of sensory stimulation. For some people, such somatic misperception can become more extreme and debilitating. People with medically unexplained symptoms (MUS), such as somatoform disorder patients, for example, experience subjectively compelling physical symptoms in the absence of any apparent medical pathology.

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[1] It could be argued that regardless of origin, all bodily sensations are “internal”. Indeed, the perception of external touch involves an interaction between environmental and bodily factors (i.e, an external stimulus contacts the skin). Nonetheless, a distinction can be made between sensations that originate from an external stimulus and sensations that originate within the body (e.g., Cameron, 2002; Leder, 1990).

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Using a recently developed paradigm, the somatic signal detection task (Lloyd, Mason, Brown, & Poliakoff, 2008), we have shown that healthy people also report feeling external touch in the absence of tactile stimulation. The SSDT involves detecting a near-threshold vibration presented to the fingertip on 50% of trials. Signal detection analysis is used to analyse the data from this task, to determine sensitivity (d'; i.e., the ability to distinguish between vibration and no vibration) and response criterion (c; i.e., the propensity to report feeling the vibration). Participants often report feeling the vibration when it was not presented (i.e., make false alarms), particularly when a light flashes next to the fingertip (which also occurs on 50% of trials). Individual differences in the tendency to misperceive the vibration are stable over time (McKenzie, Poliakoff, Brown, & Lloyd, 2010).

It is possible that increased attention towards the hand might contribute to tactile misperception during the SSDT by raising interoceptive awareness, leading to ambiguous internal bodily sensations (such as the feeling of the pulse in the fingertip) being mistakenly identified as vibrations (Lloyd et al., 2008). Consistent with this, subjective ratings of feeling the internal pulse in the fingertip during the SSDT tend to be correlated with false alarm rates (Katzer, Oberfeld, Hiller, & Witthoft, 2011) and tactile decision criteria have been shown to become more liberal following a heart beat perception task designed to increase attention to pulse sensations in the fingertip (Mirams, Poliakoff, Brown, & Lloyd, 2012, Experiment one). This could also account for the finding of increased false alarms in the presence of the light when the hand is visible during the SSDT, compared to when the hand is covered (but the light still visible; Mirams, Poliakoff, Brown, & Lloyd, 2010). When the hand is visible, the light might raise awareness of internal sensations in the finger that are then confused with the vibration. Indeed, recent research has shown that viewing the body raises awareness of 'spontaneous sensations' in the fingertips (Michael & Naveteur, 2011; Michael et al., 2012). False alarm responses on the SSDT are also associated with activity in the right insula and the anterior cingulate cortex (Poliakoff et al., in preparation), which are both associated with bodily attention and interoceptive perception (Craig, 2003; Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004).

The idea that attention to the body can increase sensory noise and lead to perceptual errors is consistent with clinical models of MUS (e.g., Brown, 2004; Deary, Chalder, & Sharpe, 2007; Rief & Barsky, 2005; Rief & Broadbent, 2007). These models suggest that attention raises awareness of ambiguous interoceptive sensations, which can lead to physical symptom reports if such sensations are misinterpreted as signalling illness. Indeed, people who report experiencing high numbers of physical symptoms also report being 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) and tend to make illness attributions for bodily sensations (Rief, Nanke, Emmerich, Bender, & Zech, 2004; Robbins & Kirmayer, 1991). In addition, both clinical and non-clinical participants reporting a high number of physical symptoms make more false alarms, and have a more liberal response criterion on the SSDT (Brown, Brunt, Poliakoff, & Lloyd, 2010; Brown et al., 2012).

Not all attentional manipulations increase tactile misperception during the SSDT, however. In one recent study, for example, focusing on exteroceptive sensations, in the context of a grating orientation task, led to a more stringent response criterion and a reduction in false alarms on the SSDT (Mirams et al., 2012, Experiment two), perhaps by reducing interference from interoceptive sensory noise. In the current study, we investigated the possibility that changing the nature of interoceptive attention could also reduce the misperception of touch during the SSDT. It has been argued, for example, that the type of interoceptive attention practised during mindfulness meditation should improve the accuracy of somatic perception (e.g., Khalsa et al., 2008). Mindfulness meditation involves paying attention to present moment experience including bodily sensations, thoughts, feelings and environmental stimuli, with an attitude of non-judgemental acceptance. Meditation practice is thought to increase mindfulness (i.e., the ability to focus attention on present moment experience) in everyday life, resulting in enhanced awareness of physical sensations, perceptions, affective states, thoughts and imagery (Grossman, Niemann, Schmidt, & Walach, 2004). Most meditation practices incorporate attention to internal body sensations such as the breath, the position of the joints, muscle tension and the heart beat. Such practice is thought to enhance interoceptive awareness (Khalsa et al., 2008) and improve perceptual clarity (Brown, Ryan, & Creswell, 2007; Grossman et al., 2004; MacLean et al., 2010; Rubia, 2009). As meditation commonly incorporates non-evaluative attention to internal and external stimuli it should result in more veridical perception (Grossman et al., 2004; Khalsa et al., 2008); that is, meditation should result in perceptions that are a more accurate account of sensory reality.

In line with this idea, meditation training has been found to reduce perceptual thresholds in a visual discrimination task (MacLean et al., 2010) and experienced practitioners of Tai Chi (a Chinese slow motion meditative exercise involving mindful attention to interoceptive sensations) show enhanced tactile acuity on grating orientation tasks compared to controls (Kerr et al., 2008). Meditation practice has also been found to reduce physical symptoms in participants with MUS (Eriksson, Moller, Soderberg, Eriksson, & Kurlberg, 2007; Landsman-Dijkstra, van Wijck, Groothoff, & Rispens, 2004) and dispositional mindfulness is negatively correlated with physical symptoms (Baer et al., 2008; Brown & Ryan, 2003) and health care utilisation (Brown & Ryan, 2003). Meditation practice is also associated with structural and functional changes in brain areas associated with attention, interoception and sensory processing (Farb et al., 2007; Lazar et al., 2005) including the right anterior insula. However, experienced meditators do not perform more accurately on heart beat perception tasks compared to controls (Khalsa et al., 2008; Nielsen & Kaszniak, 2006) and brief meditation training has not been found to improve heart beat perception ability (Parkin et al., submitted for publication). While heart beat perception ability may vary naturally between individuals (e.g., Dunn et al., 2010; Pollatos, Traut-Mattausch, & Schandry, 2009; Pollatos, Traut-Mattausch, Schroeder, & Schandry, 2007), it may not be amenable to modulation by training (c.f. Khalsa et al., 2008).

Given that we have previously found performance on the SSDT to be modulated by attention, the aim of the current study was to investigate whether meditation practice might impact on somatic perception during this task. We implemented a

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body-scan meditation exercise, which focuses on interoceptive attention. During the body-scan, attention is directed towards different areas of the body consecutively with an emphasis on noticing and experiencing any sensations, pain or muscle tension in each area, before intentionally disengaging and re-directing attention to the next body area. This cycle of attentional engagement, disengagement and shifting is repeated approximately 50 times during a 45 min body-scan exercise (Williams, 2010). In addition to improving the clarity of somatic perception (i.e., the ability to distinguish between signal and noise), this exercise might be expected to improve the ability to disengage attention from sensory noise and other distractions during the SSDT. Indeed, a growing body of evidence suggests that mindfulness meditation improves attentional control (see Cahn & Polich, 2006; Chiesa, Calati, & Serretti, 2011; Lutz, Slagter, Dunne, & Davidson, 2008 for reviews), including the ability to ignore distractions (e.g., Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007). By improving perceptual clarity and attentional control, body-scan practice was expected to improve the ability to distinguish between interoceptive sensations and the SSDT vibration and improve the ability to disengage attention from distracting somatic sensations, leading to a reduction in false alarms and an increase in sensitivity (d'). Meditation was not expected to change the general propensity to report feeling touch (meditation was expected to reduce false alarms, but not hits); therefore, we did not predict a change in response criterion (c).

We used a brief body-scan intervention, given that short meditation interventions have significant effects on mood (Zeidan, Johnson, Gordon, & Goolkasian, 2010c), cognition (Zeidan, Johnson, Diamond, David, & Goolkasian, 2010b) and sensory perception (Zeidan, Gordon, Merchant, & Goolkasian, 2010a). In these studies, participants completed just three or four twenty minute sessions of meditation practice. Short-term meditation training is also associated with functional changes in the brain: three hours of meditation practice increases activity in the anterior cingulate cortex compared to relaxation training (Tang et al., 2009).

2. Method

2.1. Participants

An advertisement was placed on the University of Manchester experimental participation scheme website, inviting participants to take part in 'an investigation into the effect of listening tasks on touch perception'. Meditation was not mentioned in the advert to avoid biasing the recruitment process in favour of participants interested in meditation. Sixty-two undergraduates (six male, mean age = 19.21 years, SD = .75) took part, in return for course credit or £5. Participants were required to be right-handed, not to have any impairment in the feeling or sensation of their hands, not to be a regular or experienced meditator and not to have a chronic or acute physical illness.

2.2. Design

A computer programme was used to pseudo-randomly allocate participants to the experimental or control group on their arrival to the first testing session, based on their participant number. The experimenter was unaware of group and counterbalancing allocation, which was pre-programmed by a colleague (as recommended by Schulz & Grimes, 2002), until they inputted the participant's number at the start of each testing session. Participants were aware that their task was either meditation, or story listening, but were unaware that they had been allocated to a particular group until debriefing. Participants attended two experimental sessions, 1 week apart, with a 6 day intervention period in between. In session one, participants completed the SSDT, followed by 15 min of meditation practice or story listening. In session two, participants completed 15 min of meditation practice or story listening, followed by the SSDT. During the intervention period, participants were instructed to complete 15 min of body-scan practice, or story listening each day. Fig. 1 illustrates the study design and procedure for each testing session.

2.3. SSDT design, materials and procedure

2.3.1. Materials

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 cm $\times$ 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.

2.3.2. Thresholding procedure

Before beginning the experimental trials of the SSDT, a threshold was found for each participant using a staircase procedure (Cornsweet, 1962) in which participants were presented with blocks of thirteen 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.

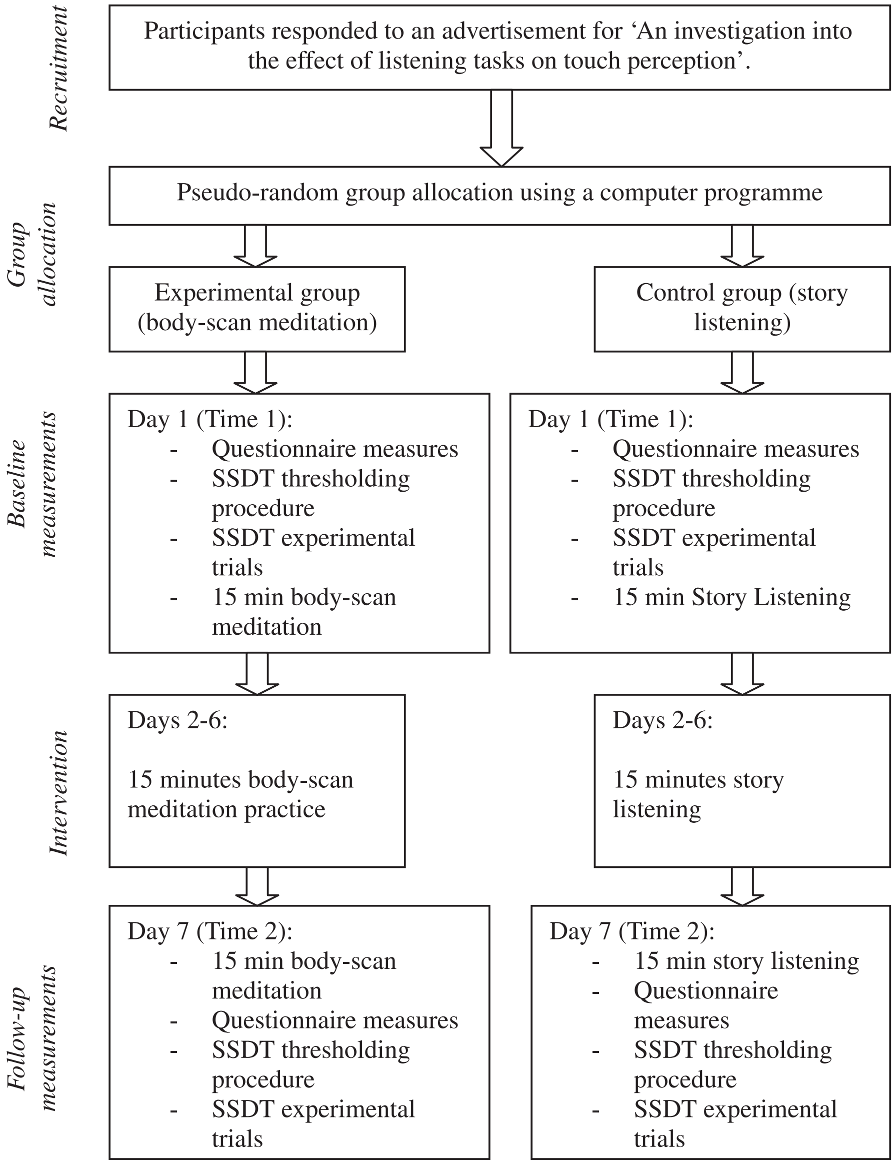

Fig. 1. Study design and procedure.

$18^\circ \times 7^\circ$ of the visual angle) pointing towards the participant's left index finger for 250 ms. This was followed by a stimulus period of 1020 ms. In tactile present trials, the 20 ms tactile pulse was delivered in the middle of the stimulus period; in tactile absent trials an empty 1020 ms period occurred. An onscreen 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 (.59 m/s) for all participants. If the vibration was perceived on more than 60% of the tactile present trials, the intensity was reduced by .16 m/s for the next thresholding block. If it was perceived on less than 40% of tactile present trials, the intensity was increased by .16 m/s.[2] 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 non-consecutive blocks at the same stimulus intensity. Immediately after completing the thresholding procedure, participants started the experimental trials of the SSDT.

[2] In pilot testing, we found that adjusting the strength of the vibration by .16 m/s was the most optimal adjustment for finding participants' tactile thresholds, as it resulted in a change in strength that was subtle, but perceptible.

Table 1
SSDT trial types and response classifications for signal detection analysis.

Trial types	Tactile pulse	Light	Number per block	Response[a]	Classification
Touch only	Present	Absent	20	"Yes"	Hit
				"No"	Miss
Catch	Absent	Absent	20	"Yes"	False alarm
				"No"	Correct rejection
Touch and Light	Present	Present	20	"Yes"	Hit
				"No"	Miss
Light only	Absent	Present	20	"Yes"	False alarm
				"No"	Correct rejection

[a] Please note, participants were only ever asked whether or not they felt the tactile pulse and never had to say whether or not they saw the light.

2.3.3. Experimental trials

The SSDT employed a 2(tactile present/tactile absent) $\times$ 2(light present/light absent) design and consisted of two, eighty trial blocks, with the following trial types: touch only (tactile present/light absent); touch and light (tactile present/light present); light only (tactile absent/light present); and catch (tactile absent/light absent) presented 20 times per block in a random order (see Table 1). The tactile stimulus was presented at the threshold level previously established. The experimental trials were identical to the threshold trials, apart from the addition of the light (which flashed in the middle of the 1020 ms stimulus period on 50% of trials) and the response prompt; this time, participants were required to indicate whether or not they felt the vibration after each trial, 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.).[3] To check that participants did not go off-threshold over the course of the experiment (i.e., that hit rates remained between 40% and 60% in the light absent condition), the experimenter checked a feedback screen, which displayed hit and false alarm rate at the end of block one, before allowing participants to move onto block two. Participants were instructed to keep their hand still throughout the experiment, including break and rest periods.

2.4. Experimental and control interventions

The meditation intervention was delivered using two fifteen minute audio recordings of a guided body-scan meditation exercise edited from a longer script (used previously by MacIver, Lloyd, Kelly, Roberts, & Nurmikko, 2008). Each recording started with a 2 min introduction to body-scan meditation. Participants were then instructed to focus their attention on sensations in different areas of the body in succession, starting with sensations of breathing in the chest, nostrils and throat. In version one, participants were instructed to direct their attention to their left and right legs, feet and toes, pelvis, hip bones, and abdomen, lower and upper back and chest. In version two, participants were instructed to direct their attention to their neck and shoulders, left and right arms, hands and fingers, the head and face, eyes and mouth. Throughout each recording, participants were encouraged to notice any sensations in each body area and to observe what was happening with their thoughts and their bodies, moment by moment, without judgement or criticism. Participants were reminded periodically to re-direct their attention back to the present moment, if their thoughts had begun to wander. Towards the end of each recording, participants were instructed to re-focus their attention on sensations of breathing. All participants listened to version one during the first testing session and version two during the second testing session. During the intervention period participants practised meditating once a day, alternating between the two versions across days. Thus participants listened to each version four times over the course of the study, completing eight fifteen minute meditation exercises in total.

Participants in the control group listened to eight successive 15 min clips of J.R.R Tolkien's "The Hobbit" (BBC Audiobooks Ltd., 1997; which was used in the control condition of Zeidan et al.'s 2010b study). Audio recordings of stories or educational texts have been used as control interventions in a number of other meditation studies (e.g., Cropley, Ussher, & Charitou, 2007; Erisman & Roemer, 2010). Participants listened to the first 15 min of the story in the first testing session, followed by seven subsequent 15 min clips (each clip told the next part of the story) during the intervention period and the second testing session. Before beginning the meditation or story listening task in each testing session, participants in both groups were instructed to pay attention as much as possible, to close their eyes throughout and not to fall asleep. Both interventions were delivered via headphones.

At the end of the first testing session, participants were given CD recordings of their intervention task, and an instruction handout. Participants in both groups were instructed to complete their intervention task for 15 min each day before the second testing session, in a private place where they were unlikely to be disturbed. The handout reminded participants to listen via headphones, to switch off their telephones and televisions, to pay attention as much as possible and to close their eyes. After completing the intervention task each day, participants were asked to complete a short questionnaire comprising four

[3] There were no significant effects of response key mapping group on any of the dependent variables (p's > .46).

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rating scales. Participants rated the difficulty of the task ('extremely easy' – extremely difficult'), effort taken to pay attention ('none at all' – 'a great deal') and frequency of distraction ('very rare' – 'extremely often'). The questionnaires were used to encourage adherence to the intervention. As a measure of adherence, participants were asked to rate the number of days they completed the intervention task during debriefing; it was made clear that this would not affect their credit or monetary compensation.

2.5. Questionnaire measures

Participants also completed the following questionnaire measures:

2.5.1. The Mindful Attention Awareness Scale (MAAS, Brown & Ryan, 2003) and the observe and act aware subscales of the Five Facets of Mindfulness Questionnaire (FFMQ, Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006)

The MAAS was completed at time one (T1; i.e., testing session one) and scores were used to control for baseline differences in trait mindfulness. The MAAS is a fifteen-item measure of the tendency to be inattentive to present moment experience in daily life. Participants rated how often they have experiences of being on automatic pilot ('I find myself doing things without paying attention'), being preoccupied ('I break or spill things because of carelessness, not paying attention, or thinking of something else') and not paying attention to the present moment ('I find it difficult to stay focused on what's happening in the present') on a scale from one ('almost always') to six ('almost never'). Scores range from fifteen to ninety with high scores indicating high mindfulness. The MAAS has acceptable internal consistency and test–retest reliability (Brown & Ryan, 2003). MAAS scores were also correlated with the Patient Health Questionnaire-15 (PHQ-15) scores (see Section 3.2), to investigate whether trait mindfulness was related to the experience of physical symptoms. MAAS, rather than FFMQ Observe and Act Aware scores were used to minimise the number of correlations.

The FFMQ was completed at T1 and time two (T2; i.e., testing session two) and scores were used to investigate whether the meditation intervention affected mindfulness. The FFMQ was developed from factor analyses of the combined pool of items from five other mindfulness questionnaires: the MAAS; the Freiburg Mindfulness Inventory (Buchheld, Grossman, & Walach, 2001; Walach, Buchheld, Buttenmuller, Kleinknecht, & Schmidt, 2006); the Kentucky Inventory of Mindfulness Skills (Baer, Smith, & Allen, 2004); the Cognitive and Affective Mindfulness Scale (Hayes & Feldman, 2004) and the Southampton Mindfulness Questionnaire (Chadwick et al., 2008). Participants completed the 'Observe' and 'Act Aware' subscales of this questionnaire, which were deemed to be most likely to be affected by body-scan practice. The Observe subscale includes eight items such as, 'when I am walking, I deliberately notice the sensations of my body moving', and 'when I take a shower or a bath, I stay alert to the sensations of water on my body'. The Act Aware subscale includes eight items including, 'when I do things, my mind wanders off and I am easily distracted' and 'I don't pay attention to what I'm doing because I'm daydreaming, worrying or otherwise distracted'. On both subscales, participants rate items on a scale from one ('never or very rarely true') to five ('very often or always true'). Scores on both subscales range from eight to forty with high scores indicating high mindfulness. The subscales have good internal consistency and scores on the FFMQ are correlated with meditation practice in long-term meditators (Baer et al., 2008) and increase with meditation training (Carmody & Baer, 2008).

2.5.2. The Attentional Control Scale (ACS, Derryberry & Reed, 2002)

The ACS is a twenty-item measure of perceived attentional control. Participants rate their ability to avoid distraction (e.g., 'my concentration is good even if there is music in the room around me'), disengage attention from distractions (e.g., 'after being interrupted or distracted, I can easily shift my attention back to what I was doing before') and switch attention (e.g., 'I can quickly switch from one task to another') on a scale from one ('almost never') to four ('always'). Scores range from twenty to eighty with high scores indicating higher perceived attentional control. The scale is internally consistent and scores are related to the ability to disengage attention from invalid visual cues (Derryberry & Reed, 2002). Participants completed the ACS at both time points to investigate whether the body-scan practice affected attentional control and T1 ACS scores were used to control for any baseline differences in attentional control.

2.5.3. The Patient Health Questionnaire-15 (PHQ-15, Kroenke, Spitzer, & Williams, 2002)

The PHQ-15 is a brief, self-administered measure of the frequency and severity of fifteen of the most commonly experienced physical symptoms (which account for more than 90% of symptoms seen in primary care, Kroenke et al., 2002). Scores range from one to thirty, with cut-off points of five and fifteen for low and high symptom severity in clinical populations (Kroenke et al., 2002). The PHQ-15 has good internal consistency (Han et al., 2009; Interian, Allen, Gara, Escobar, & Diaz-Martinez, 2006; Kroenke et al., 2002) and test–retest reliability (Han et al., 2009). To control for baseline differences in physical symptom reporting, which have previously been found to correlate with SSDT performance (Brown et al., 2012) and to investigate whether body-scan practice had any effect on physical symptom reporting, participants completed a modified version of the PHQ-15 at both time points. Participants rated how bothered they had been by fifteen common physical symptoms such as headaches, stomach pain, dizziness and fatigue over the previous week (rather than the past 4 weeks) on a scale of zero ('not bothered at all') to two ('bothered a lot').

2.5.4. State Trait Anxiety Inventory (STAI, Spielberger, 1983)

The state anxiety subscale (STAI-S) consists of twenty statements such as ‘I am worried’, ‘I am calm’ and ‘I feel nervous’ which respondents rate on a scale from one (not at all) to four (very much so) according to how they *presently* feel. The trait anxiety subscale (STAI-T) consists of the same twenty statements that respondents rate according to how they *generally* feel. Scores range from twenty to eighty with higher scores indicating higher anxiety. The STAI-T was completed at T1 only and scores were used to control for any baseline differences in trait anxiety. The STAI-S was completed at both time points to investigate the effects of each intervention on state anxiety, and to control for any changes in anxiety from T1 to T2.

3. Results

3.1. Data analysis

‘Definitely’ and ‘maybe’ responses on the SSDT were combined and grouped into ‘yes’ and ‘no’ responses, which were then classified as hits (correct reports of feeling the touch on tactile present trials), misses (reports of not feeling the touch on tactile 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, see Table 1). Collapsing the data gave similar false alarm rates as those found in previous studies using a dichotomous scale (e.g., Lloyd et al., 2008). 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)[4] and used to calculate the signal detection theory test statistics d' [z(Hits) − z(False alarms)] and c [$-.5 \times z$(HIT) + Z(False alarms)] (Macmillan & Creelman, 1991). This provided estimates of each participant’s perceptual sensitivity (d'), and response criterion (c) at each time point.

Inspection of box plots revealed outlying scores (with z-scores > 1.96) in the hit rate (two scores), false alarm rate (10 scores), sensitivity (one score) and response criterion (four scores) data. To minimise the impact of these scores, they were changed to the next highest (or lowest) score plus .01. Despite doing so, the hit rate data (in the presence of the light at T2) and false alarm rate data in each condition remained non-normally distributed. The hit rate data were normalised using logarithm transformations. It was not possible to transform the false alarm rate data, therefore these data were analysed non-parametrically.

To investigate whether body-scan practice improved sensitivity during the SSDT, a mixed design ANOVA was conducted to analyse the sensitivity data with time (T1, T2) and intervention group (experimental, control) as factors[5]. SSDT light condition was originally included as a factor, but did not interact with group or time and therefore was removed from the model to increase statistical power. A time × group interaction was predicted for the sensitivity data, with a significant increase in sensitivity from T1 to T2 for the meditation group. A second ANOVA was conducted to investigate whether the meditation intervention affected response criterion; we did not anticipate a main affect of time or a group x time interaction for response criterion. ANOVAs were conducted without, then with MAAS, T1 PHQ-15 and T1 ACS deviation (i.e., mean-centered) scores as covariates (in line with Delaney & Maxwell, 1981) to control for baseline differences in mindfulness, attentional control and the propensity to experience physical symptoms.

To investigate whether biases in the thresholding procedure accounted for any between group differences in sensitivity at T2, vibration strength (which was non-normally distributed, and could not be normalised using transformations) and the number of vibrations perceived during the last block of thresholding trials at T1 and T2 were compared within and between intervention groups using Wilcoxon and Mann–Whitney tests. Statistical analyses were conducted using SPSS version 15.0 (SPPS Inc., Chicago, IL).

3.2. Intervention adherence and group comparability

All participants reported completing the meditation task or listening to the story for the full 15 min each day during the intervention period. Table 2 shows questionnaire data for each participant group at T1 and T2. The T1 and T2 PHQ-15 and STAI-S data were non-normally distributed. The STAI-S and the T1 PHQ-15 data were normalised using square root transformations. It was not possible to normalise the T2 PHQ-15 data, therefore these data were analysed non-parametrically.

The meditation and control groups did not differ in baseline MAAS scores ($t(60) = .49$, $p = .63$, $d = .13$) or STAI-T scores ($t(60) = .08$, $p = .94$, $d = .02$). To determine whether participant groups were comparable on the other questionnaire measures at baseline and to investigate whether the meditation intervention affected self-reported state anxiety, attentional control, or mindfulness, a series of mixed design ANOVAs were conducted with group (meditation, control) and time (T1, T2) as factors and either STAI-S, ACS, FFMQ-Observe or FFMQ-Act Aware scores as the dependent variable. There were no effects of

[4] 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.

[5] It has been argued that ANCOVA, comparing the performance of experimental and control groups at T2, controlling for T1, should be used to compare baseline and follow-up data in randomised controlled trials (Vickers & Altman, 2001). A mixed design ANOVA was chosen in the current study to determine, not only if the meditation and control groups differed at T2, but also which group showed a significant change from T1 to T2. The use of a mixed design ANOVA reduced the number of statistical tests required to obtain a clear account of experimental effects, reducing the chance of Type I errors. However, the slight changes that the use of ANCOVA makes to the results are shown in footnotes below.

Table 2
Means (and SDs) of PHQ-15, STAI-S, STAI-T, ACS, MAAS, FFMQ Act Aware and Observe scores at each time point for each intervention group.

Measure	Time		Experimental group (meditation)	Control group (story listening)
PHQ-15	1[a]	Original	6.00 (5.00)	4.00 (3.00)
		Transformed	2.56 (.71)	2.31 (.61)
	2[a]		6.00 (5.00)	4.00 (5.00)
STAI-S	1[a]	Original	32.00 (10.00)	31.00 (9.00)
		Transformed	*1.50 (.15)*	*1.49 (.10)*
	2	Original	33.00 (15.00)	32.00 (11.00)
		Transformed	*1.51 (.12)*	*1.50 (.12)*
STAI-T	1		35.19 (10.13)	35.00 (8.59)
ACS	1		51.16 (9.05)	48.39 (5.82)
	2		49.42 (9.56)	47.61 (7.11)
MAAS	1		4.04 (.85)	3.95 (.63)
FFMQ Act Aware	1		26.90 (5.37)	25.68 (5.29)
	2		26.03 (5.17)	23.90 (5.96)
FFMQ Observe	1		23.94 (5.49)	24.06 (5.88)
	2		22.90 (5.68)	22.94 (6.45)

Medians and inter-quartile ranges are shown for non-normally distributed data (marked with [a]positive skew).

Table 3
Means (and SDs) of hit rates, d' and c before and after the intervention for each intervention group.

	Time		Hit rates (original)	Hit rates (transformed)	False alarm rates[b]	Sensitivity (d')	c
Experimental (meditation)	1	Light	62.27 (17.96)	11.68 (5.92)	18.29 (24.00)	1.22 (.87)	.24 (.34)
		No light	53.27 (17.53)	11.10 (5.67)	15.85 (15.00)	1.13 (.91)	.47 (.35)
		Overall	*57.77 (16.11)*	*11.39 (5.26)*	*17.07 (18.00)*	*1.17 (.87)*	*.36 (.28)*
	2	Light	75.29 (15.56)[a]	14.10 (5.33)	15.85 (20.00)	1.83 (1.05)	.15 (.41)
		No light	64.08 (20.00)	12.23 (6.61)	10.98 (20.00)	1.65 (1.06)	.40 (.35)
		Overall	*69.69 (15.79)*	*13.16 (5.29)*	*15.24 (17.00)*	*1.74 (1.01)*	*.27 (.33)*
Control (story)	1	Light	69.98 (17.81)	14.35 (5.82)	15.85 (24.00)	1.54 (.99)	.17 (.41)
		No light	58.13 (17.78)	12.61 (6.03)	10.98 (15.00)	1.49 (.99)	.52 (.44)
		Overall	*64.02 (16.76)*	*13.48 (5.56)*	*14.63 (16.00)*	*1.51 (.95)*	*.35 (.39)*
	2	Light	68.96 (15.66)[a]	11.90 (10.01)	10.98 (.20)	1.71 (.96)	.30 (.33)
		No light	59.01 (17.27)	10.39 (5.77)	8.54 (17.00)	1.53 (1.01)	.50 (.33)
		Overall	*63.99 (15.23)*	*11.15 (5.09)*	*13.41 (18.00)*	*1.62 (.96)*	*.40 (.31)*

Median and inter-quartile range is shown for non-normally distributed false alarm rate and hit rate data (marked with [a]negative skew, [b]positive skew).

intervention group (p's > .13) and no interactions between intervention group and time (p's > .15); intervention groups did not differ at T1 or T2 on any of the questionnaire measures. However, there was a significant main effect of time on ACS ($F(1,60) = 5.43$, $p = .02$, $d = .42$) and FFMQ Act Aware scores ($F(1,60) = 8.90$, $p = .00$, $d = .54$) and a tendency towards a main effect of time on FFMQ Observe scores ($F(1,60) = 3.25$, $p = .08$, $d = .33$). Scores on each measure decreased from T1 to T2 in both groups (both groups showed a reduction in self-reported attentional control and mindfulness).

T1 PHQ-15 scores (square root transformed) did not differ between intervention groups ($t(60) = 1.57$, $p = .14$, $d = .41$), nor did T2 PHQ-15 scores ($U = 423.50$, $p = .42$, $r = .10$). Wilcoxon tests showed that PHQ-15 scores did not change from T1 to T2 for the experimental ($T = 157.00$, $p = .44$, $r = .14$) or control group ($T = 108.50$, $p = .22$, $r = .22$). Trait mindfulness was related to the experience of physical symptoms as MAAS scores were negatively correlated with T1 PHQ-15 scores (*Spearman's* $r = -.39$, $p = .00$).

3.3. Did body-scan practice affect SSDT performance?

Table 3 shows descriptive statistics for each SSDT outcome measure at each time point and in each light condition, in the meditation and control groups.

3.3.1. Sensitivity (d')[6]

Sensitivity increased from T1 to T2 ($F(1,60) = 10.16$, $p = .00$, $d = .58$). There was a significant time × group interaction ($F(1,60) = 4.63$, $p = .04$). Groups did not differ in sensitivity at T1 ($t(60) = 1.46$, $p = .15$, $d = .38$) or T2 ($t(60) = -.49$, $p = .63$, $d = .13$). In the control group, sensitivity did not change from T1 to T2 ($t(30) = .71$, $p = .48$, $d = .18$); in the meditation group, however, sensitivity significantly increased from T1 to T2 ($t(30) = -3.89$, $p = .001$, $d = 1.00$). The main effect of intervention

[6] An ANCOVA showed a trend for higher sensitivity in the meditation compared to the control group ($p = .06$) at T2, controlling for T1 performance (due to an increase in sensitivity from T1 to T2 in the meditation group).

group was not significant ($p = .36$). These findings remained the same with T1 PHQ-15 and T1 ACS deviation scores included as covariates. With MAAS deviation scores included as a covariate, there was a tendency towards an interaction between time and MAAS scores ($F(1,58) = 3.83$, $p = .06$), indicating the assumption of homogeneity of regression slopes was violated (i.e., MAAS scores related differently to d' at different levels of time). Therefore, it was not appropriate to use MAAS scores as a covariate for this dependent variable. In the control group, MAAS scores were positively correlated with sensitivity change scores (T2–T1 sensitivity, $r = .38$, $p = .04$). In the meditation group, MAAS scores were not correlated with sensitivity change scores, $r = 26$, $p = .16$).

A Wilcoxon test suggested that the increase in sensitivity from T1 to T2 in the meditation group was due to a decrease in false alarms from T1 to T2 ($T = 101.50$, $p = .01$, $r = .45$). Hit rates (log transformed) did not change significantly from T1 to T2 in this group ($t(60) = -1.52$, $p = .14$, $d = .39$). To investigate whether this decrease in false alarm rates was related to self-reported physical symptoms or trait mindfulness in the meditation group, T1 PHQ-15, T1 ACS and MAAS deviation scores were correlated with false alarm rate change scores. False alarm rate change scores were not correlated with T1 PHQ-15, T1 ACS or MAAS deviation scores (p's > .13).

3.3.2. Response criterion (c)[7]

There was no effect of time ($F(1,60) = .12$, $p = .73$, $d = .04$), group ($F(1,60) = .68$, $p = .41$, $d = .13$) and no interaction between time and group ($F(1,60) = 2.44$, $p = .12$). Findings remained the same with T1 PHQ-15, T1 ACS and MAAS deviation scores included as covariates.

3.3.3. Could systematic differences in the thresholding procedure account for the increase in d′ in the meditation group?

SSDT vibration strength did not change from T1 to T2 for the meditation ($T = 114.50$, $p = .47$, $r = .13$) or control group ($T = 130.50$, $p = .39$, $r = .16$) and did not differ between groups at T1 ($U = 475.00$, $p = .94$, $r = .01$) or T2 ($U = 434.50$, $p = .52$, $r = .11$). There was no change in the number of perceived vibrations on the last block of thresholding trials from T1 to T2 in the meditation ($T = 91.00$, $p = .86$, $r = .03$) or control group ($T = 91.50$, $p = .39$, $r = .15$). The number of perceived vibrations did not differ between groups at T1 ($U = 410.50$, $p = .29$, $r = .19$) or T2 ($U = 461$, $p = .77$, $r = .05$).

4. Discussion

Our aim was to investigate whether mindfulness meditation would reduce tactile misperception and increase sensitivity during the SSDT, via an improvement in perceptual clarity (i.e., an improved ability to distinguish between sensory noise and the SSDT vibration) and attentional control. In line with this hypothesis, participants who completed a brief, self-administered body-scan intervention showed an increase in sensitivity during the SSDT, compared to a control group who listened to a recorded story. As expected, neither group showed a change in response criterion.

The meditation group had lower false alarm rates at T2 compared to T1, suggesting that the body-scan intervention significantly decreased tactile misperception during the SSDT. This finding supports the assumption that meditation practice improves the veridicality of perceptions (e.g., Grossman et al., 2004). The decrease in false alarm rates in the meditation group was unrelated to baseline mindfulness and physical symptom reports, which suggests that the intervention, rather than pre-existing individual differences, accounted for this change. This reduction in false alarm rates from T1 to T2 was reflected in increased sensitivity (d') in the meditation group, suggesting an improved ability to distinguish between signal (the SSDT vibration) and noise (e.g., ambiguous interoceptive sensations). This increase in sensitivity was not accounted for by systematic differences in the thresholding procedure, as the number of perceived vibrations during the last thresholding block and approximate vibration strength were not affected by participant group or time. On average, the vibration was no stronger or weaker at T2 compared to T1 for either participant group. Rather than reducing the average tactile detection threshold in the meditation group (enabling participants to detect weaker vibrations), the body-scan intervention decreased the number of detection errors (i.e., reduced false alarms). An improved ability to recognise ‘true’ and ‘false’ perceptions could potentially have implications for health and cognition. It has been argued, for example, that accurate conscious perception of sensory and mental events permits more flexible, objectively informed psychological and behavioural responses and that mindfulness might impact on well-being through this mechanism (Brown et al., 2007, p212, see also Brown & Ryan, 2003).

The results of the current study contrast with our previous finding that interoceptive attention during a heart beat perception task leads to increased tactile misperception and a more liberal criterion for reporting touch during the SSDT (Mirams et al., 2012, Experiment one). Performing a heart beat perception task (which involved counting internal pulse sensations in the fingertip) may have raised levels of sensory noise, increasing the propensity to report touch, regardless of whether or not the vibration was present. In contrast, body-scan practice improved the accuracy of somatosensory decision making; suggesting that different types of interoceptive attention have different perceptual effects. This finding is in line with proposals that changing the nature of bodily attention has implications for somatic perception (e.g., Mehling et al., 2009). For example, although non-mindful interoceptive attention might exacerbate somatic misperception in MUS (e.g., Brown, 2004; Deary et al., 2007; Rief & Broadbent, 2007), practicing unbiased, flexible and non-reactive interoceptive

[7] An ANCOVA showed a trend for a more liberal response criterion in the meditation group compared to the control group ($p = .10$) at T2, controlling for T1 performance (however, follow-up t-tests showed that response criterion did not change significantly from T1 to T2 for either group, p's > .20).

attention during mindfulness meditation (see Baer, 2007) improved the accuracy of somatic perception in the current study. It is possible that body-focused meditation practice could reduce the misperception of physical symptoms in patients with MUS, by improving their ability to distinguish between signal (i.e., physical symptoms) and noise (i.e., ambiguous bodily sensations). The finding of a negative correlation between trait mindfulness and physical symptom reports in the current study is in line with this idea. Given that there are likely to be differences between the effects of short versus long term meditation (c.f. Williams, 2010), caution should be taken before applying these results clinically, i.e., longer-term, more intensive meditation practice might be necessary to reduce physical symptoms in patients with MUS. It is encouraging, however, that even brief body-scan practice had a large effect on sensitivity (Cohen's $d = 1$) in the current study.

It is possible, however, that the body-scan exercise had a different effect to the heart beat perception task in our previous study for reasons other than mindfulness. For example, the heart beat perception task involved focusing attention on interoceptive sensations solely in the fingertip, whereas the body-scan exercise involved focusing attention on interoceptive sensations in various parts of the body. There is a possibility, therefore, that it was this difference that accounted for the different effects of these two manipulations, rather than differences between mindful and non-mindful interoceptive attention. It is also not clear whether the effects of meditation in the current study were due to the somatic nature of body-scan practice, or whether a meditation technique unrelated to the body would have had a similar effect. Meditative techniques that involve focussing attention on external auditory stimulation could also potentially improve the ability to disengage attention from interoceptive sensations. Future studies could include a control group who practice non-body-related meditation to clarify this issue.

Story listening was chosen as a control for the body-scan exercise following previous meditation intervention studies (e.g., Cropley et al., 2007; Erisman & Roemer, 2010; Zeidan et al., 2010b). Participants in the control group showed no change in sensitivity from T1 to T2, which is consistent with previous findings that SSDT performance remains stable when participants are tested twice over a week (McKenzie et al., 2010). Story listening matched the body-scan in format (both tasks involved paying attention to speech, via headphones) and duration (both tasks involved listening for 15 min, on eight occasions), but did not involve a mindfulness component, or attention to the body. However, the two tasks differed in other ways, which limits their comparability. For example, the story might have elicited greater emotional responding than the body-scan, depending on participants' enjoyment. Future studies could implement alternative control tasks, such as listening to educational texts or music (c.f., MacCoon et al., 2012).

It was suggested in the introduction that body-scan practice might impact on SSDT performance via improved attentional control, as well as an improved ability to distinguish between signal and noise. Indeed, brief meditation training has been found to improve the ability to sustain attention (e.g., Zeidan et al., 2010b). Although body-scan practice did not affect self-reported attentional control, it is possible that it had a more specific effect on interoceptive attentional control. One way of exploring this possibility would be to investigate whether body-scan practice reduces interference when participants perform the SSDT after a heart beat perception task (i.e., by improving the ability to disengage attention from distracting internal pulse sensations).

Unexpectedly, body-scan practice did not reduce state anxiety (from T1 to T2). This may have been because the STAI-S was only completed once during each testing session, rather than before and after the intervention tasks. In addition, the meditation intervention did not increase self-reported mindfulness on the Observe or Act Aware subscales of the FFMQ. This contrasts with findings from previous studies that have used brief meditation interventions (e.g., Zeidan et al., 2010a; Zeidan et al., 2010b). Different meditation exercises (mindfulness of the breath rather than the body-scan) were implemented in these studies, however, and the interventions were delivered in person by experienced instructors, rather than self-administered. It is possible that, despite reporting full adherence to the intervention tasks, not all participants engaged fully with the body-scan exercises in the current study. An additional measure of adherence or a personally delivered, live intervention could be implemented in future studies, to address this limitation.

Zeidan and colleagues also used the Freiburg Mindfulness Inventory (Buchheld et al., 2001; Walach et al., 2006), which is intended for use with novice meditators. The FFMQ (which was chosen for its emphasis on attentional control and mindfulness of bodily sensations) may be more suitable for use with experienced meditators. Furthermore, the FFMQ measures trait as opposed to state mindfulness, so short-term changes in mindfulness may not have been detected (c.f. Parkin et al., submitted for publication; Schmertz, Anderson, & Robins, 2009). It has been argued that brief meditation interventions should not be expected to increase self-reported mindfulness, a trait likely to take more time to consolidate (c.f. Williams, 2010). However, brief meditation interventions might still lead to short-term increases in mindfulness, which would be more likely to be detected using state versions of the MAAS and FFMQ. It is also possible that meditation practice, or completing measures of mindfulness, initially makes people aware of a lack of attentional control and awareness, which could account for why FFMQ scores decreased from T1 to T2 in the current study. Although brief meditation interventions may not increase trait mindfulness, the short-term effects of meditation can still impact performance on cognitive tasks (see Williams, 2010). However, it might be more appropriate to consider brief meditation interventions as cognitive manipulations rather than as mindfulness training (c.f. Arch & Craske, 2006).

4.1. Conclusions

A brief, unsupervised body-scan meditation intervention reduced tactile misperception and improved sensitivity during the SSDT, perhaps via improved perceptual clarity. This finding suggests that mindful interoceptive attention benefits somatosensory perceptual decision making. This contrasts with our previous finding that non-mindful interoceptive attention increases somatic misperception during the SSDT; different types of interoceptive attention seem to have different consequences for subsequent somatic perception. The current results also raise the possibility that a body-scan meditation intervention could be useful for patients with MUS. Studies investigating whether body-scan practice can reduce tactile misperception in participants who report a high number of physical symptoms are warranted.

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