1   **Spatial attention modulates tactile change detection**

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1   **ABSTRACT**

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3   People often fail to detect changes between successively-presented tactile patterns, a
4   phenomenon known as tactile change blindness. In this study, we investigated whether
5   changes introduced to tactile patterns are detected better when a participant's attention
6   is focused on the location where the change occurs. Across two experiments,
7   participants ($N = 55$) were instructed to detect changes between two consecutively-
8   presented tactile patterns. In half of the trials, the stimulated body sites in the two
9   patterns were identical. In the other half of the trials, one of the stimulated body locations
10   differed between the two patterns. Endogenous (or voluntary) attention was manipulated
11   by instructing participants which new bodily location was most likely to be stimulated. We
12   found that changes at the attended location were detected more accurately than changes
13   at bodily locations that were unattended. This finding demonstrates that attention can
14   effectively modulate tactile change detection. We discuss the value of this experimental
15   paradigm for investigating excessive attentional focus or hypervigilance to particular
16   regions of the body in various clinical populations.

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18   **Keywords:** Change detection, tactile perception, spatial attention, hypervigilance.

1. Introduction

In daily life, a wide variety of information is presented to our tactile receptors, such as, for example, the contact between our back and the chair that we happen to be sitting on, the wooden desk on our skin while we are working, or the clothing that we wear (Graziano et al. 2002). A remarkable observation is that even when tactile information is changing (thus becoming potentially relevant) we can still be unaware of it (Gallace and Spence 2008). Empirical support for this notion mainly comes from research using a tactile change detection paradigm (Gallace et al. 2006a). In a prototypical experiment, participants are repeatedly presented with two successive tactile patterns consisting of the simultaneous presentation of several tactile stimuli on different body sites (see Figure 1). In half of the trials, the stimulated body sites in the two tactile patterns are identical. In the other half of the trials, one of the stimulated body locations differs between the two tactile patterns. After each trial, participants have to judge whether the locations that were stimulated in the two patterns were the same or not (Gallace et al. 2006a). Although, to date, the studies that have been published have differed on a number of parameters (e.g., the inter-stimulus interval, the presence versus absence of masking stimuli, the number of stimuli, and the complexity of the display used), the results have consistently demonstrated that people often fail to detect changes between successively presented tactile patterns, an observation that, by analogy with a similar phenomenon previously reported in the visual (e.g., Simons and Levin 1997; Triesch et al. 2003) and auditory (e.g., Demany and Pressnitzer 2011) modality, has been referred to as “tactile change blindness” (Gallace, Auvray et al. 2006; Gallace et al. 2006a, 2007; Pritchett et al. 2011). It is noteworthy that similar mechanisms might be involved in the detection of changes in visual, auditory, and tactile stimuli, which have been linked to a cortical network with both modality-specific and multisensory components. In a study by Downar and colleagues (2000), brain regions responsive to stimulus change included unimodal

1 areas such as the visual, auditory, and somatosensory cortices, as well as multimodally-
2 responsive areas, comprising a right-lateralized network consisting of the
3 temporoparietal junction, inferior frontal gyrus, insula, and the supplementary motor
4 areas.

5 One can imagine that for certain individuals the detection of subtle changes in a
6 particular body part may be especially relevant for their current goals or concerns. For
7 instance, it is assumed that some patients (e.g., those suffering from chronic back pain,
8 panic disorder, heart disease, skin disease, etc.) are often preoccupied with bodily cues
9 signaling potential physical harm (Crombez et al. 2005; Eifert et al. 2000; Karsdorp et al.
10 2007; Schmidt et al. 1997; Verhoeven et al. 2008). Such a preoccupation may lead to an
11 excessive attentional focus (i.e., hypervigilance) on the affected region of the body and,
12 consequently, to an increased sensitivity for bodily changes in that region. Although
13 empirical evidence is accumulating that the anticipation of physical threat is associated
14 with an overall increase in attention to bodily sensations (for a review, see Van Damme
15 et al. 2010), the question of whether a strong focus of attention on a specific bodily
16 location increases sensitivity for bodily changes at that location remains unanswered.

17 The main aim of the present study was to investigate whether focusing attention on
18 one particular bodily location improves tactile change detection at that location in healthy
19 volunteers. There are two reasons why one might expect that attention would affect
20 performance in a tactile change detection task. First, in a typical tactile change detection
21 task, attention needs to be divided between multiple locations. It is likely that in the
22 limited time period that the tactile patterns are activated (typically for not longer than
23 200ms), not all of the stimulated locations can enter the focus of a participant's attention
24 (see Gallace et al. 2006b; Johansen-Berg and Lloyd 2000; Lakatos and Shepard 1997),
25 thus making it difficult for participants to judge whether or not the two tactile patterns
26 differed. Indeed, tactile information is likely to be processed serially, as research has

1 shown that subitizing (i.e., an enumeration process in which a small number of items are
2 processed rapidly, accurately, and pre-attentively; Mandler and Shebo 1982) does not
3 occur in the tactile modality (Gallace et al. 2006b; but see Riggs et al. 2006). Second,
4 research has demonstrated that focusing attention on a specific body location results in
5 enhanced processing of tactile stimuli presented at that location as compared to an
6 unattended location (Spence and Gallace 2007; Spence and Parise 2010; Yates and
7 Nicholls 2009, 2011). Tactile attention is thought to affect processing in the
8 somatosensory cortex through amplification of responses to relevant stimulus features
9 and suppression of responses to irrelevant features (Burton and Sinclair 2000; Forster
10 and Eimer 2005; Johansen-Berg and Lloyd 2000; Jones et al. 2007; Sambo and Forster
11 2011).

12 To date, only one study has investigated attentional processing in the context of
13 tactile change detection. Pritchett and his colleagues (2011) replicated the typical
14 findings concerning tactile change blindness, but additionally examined whether the
15 detection of a change between two successively-presented tactile patterns was
16 accompanied by a shift of spatial attention to the location where the change had taken
17 place. For this purpose, the presentation of the second pattern was followed shortly
18 thereafter (100-300ms) by a single tactile stimulus presented at the location where the
19 change had taken place, or else at a different location. Participants were instructed to
20 make a speeded response to that single tactile stimulus. Faster responses were
21 expected when the stimulus was presented at the location of the change than when it
22 was presented elsewhere, but no such effect was found, suggesting that the detection of
23 a change is not necessarily associated with heightened attention to the location where
24 the change occurred (Pritchett et al. 2011). Note, however, that one other possible
25 explanation for this finding might be that simple detection latencies in touch aren't
26 necessarily all that sensitive to shifts of spatial attention, whereas clearer spatial cuing

effects tend to emerge when using other (e.g., discrimination) tasks (see Spence and McGlone 2001). Nonetheless, this study did not measure whether focusing attention on a specific body location facilitates the detection of tactile changes at that location.

The present study was designed to address this issue in two similar tactile change detection experiments in which the focus of participants' spatial attention was explicitly manipulated. Tactors (i.e., tactile stimulators) were attached to six possible locations on the arms and legs of the participant (see Figure 1). In each trial, two tactile patterns consisting of the simultaneous activation of three stimulus locations were presented. The participants had to judge whether the stimulus locations that were activated during the first pattern were identical to those locations that were activated during the second pattern. A difference always implied a re-location of one tactile stimulus to another location of the body which was not previously activated. In order to manipulate spatial attention experimentally, the participants were informed that 75% of the change trials a pattern change would imply a repositioning of one tactile stimulus to a specified location (either the left or the right forearm, counterbalanced across blocks). In the remaining trials, a pattern change would involve a re-location of one tactile stimulus to another (invalid) location of the body. In fact, the location to which the change would occur was validly indicated in 2/3 of the trials (valid trials), and invalidly on the remaining 1/3 of the trials (invalid trials). Changes toward the indicated location occurred from all body locations, except for the locations toward which attention was directed in the different blocks. These different trial types were presented randomly throughout the experiment. We hypothesized that the ability of participants to detect the change would be better when their attention was focused on the location of change as compared to when the change occurred outside of the focus of their spatial attention.

INSERT FIGURE 1

2. Materials and methods

2.1. Participants

Twenty-three healthy undergraduate psychology students (12 females, 11 males; mean age=18.8 years, range 18-25 years) took part in Experiment 1 in order to fulfil their course requirements. In Experiment 2, 36 healthy undergraduate students (30 females, 6 males; mean age=22 years, range 19-30 years) were paid to take part in the experiment. The study protocol was approved by the local ethical committee and was performed according to the ethical standards laid down in the declaration of Helsinki. The participants were informed that the experiment consisted of a computer-controlled task in which tactile stimuli would be administered to the arms and legs. All participants provided informed consent and were free to terminate the experiment at any time should they so desire. One participant was excluded from Experiment 2 because she reported nerve damage to the left lower arm. The remaining participants reported normal tactile perception at all tactor locations and normal or corrected to normal visual perception.

2.2. Apparatus and materials

In both experiments, vibrotactile stimuli (200 ms) were presented by means of seven resonant-type tactors (C-2 TACTOR, Engineering Acoustics, Inc.) consisting of a housing that was 3.05 cm in diameter and 0.79 cm high, with a skin contactor that was 0.76 cm in diameter. All stimulus characteristics (amplitude and frequency) were entered through a self-developed software program that was used to control the tactors. The stimuli were administered to the dorsal aspects of six different body locations (see Figure 1). In Experiment 1, these locations included the forearm (left and right), the upper arm (left and right), and the area just above the ankle (left and right). In Experiment 2, the tactor

locations consisted of the forearm (left and right), the area just above the ankle (left and right), and the area just below the knee (left and right). Mean factor intensities for each body site are given in Table 1. The tactors were attached directly to the skin surface by means of double-sided tape rings and were driven by a custom-built device at 200 Hz. Participants wore noise-cancelling headphones (PXC 350 Sennheiser) in order to prevent any interference from environmental noise. Prior to the start of the experiment, the stimulus intensities at each tactor were individually matched, as there is evidence for variation in sensitivity depending on the body site stimulated (e.g., Weinstein 1968). In order to accomplish this, a standardized matching procedure was used for each participant. First, a tactile stimulus (reference stimulus, $Power = 0.04$ watts) was presented just below the participant's right elbow, a location that was irrelevant during the rest of the experiment. Next, tactile stimuli were presented separately at each relevant location, and participants had to say whether the intensity was lower, higher, or equal to the intensity of the reference stimulus. The reference stimulus was presented repeatedly before moving to another tactor location, in order to make sure that participants remembered the intensity of the reference stimulus correctly. The intensity of each tactor was varied until it was reported that the subjective intensity of each stimulus was perceived as being equal to the subjective intensity of the reference stimulus.

INSERT TABLE 1

2.3. *Tactile change detection task*

The paradigm was programmed and controlled by Inquisit Millisecond software (Inquisit 2.0) on a PC laptop (HP Compaq nc6120) with a keyboard. The participants were instructed to keep their eyes on the black-coloured screen for the duration of the experiment. Each trial started with a white fixation cross that appeared in the center of

the screen for 500ms. Next, the first stimulus pattern was presented for 200ms, followed by an empty stimulus interval of 110ms, after which the second stimulus pattern was presented for 200ms. Tactile patterns always consisted of three simultaneously-presented tactile stimuli. The different pattern combinations were randomly presented during the experiment. In half of the trials, the second pattern was identical to the first. In the other half of the trials, the two patterns differed, as one of the stimulated locations of the first tactile pattern shifted toward another location in the second tactile pattern. So, one of the three factors that were active during the first pattern was inactive during the second pattern, and a factor positioned at another body location became active instead. The participants were instructed to detect whether the first and the second tactile pattern differed, and to respond 'yes' or 'no' by pressing the corresponding response keys (respectively "4" and "6" on an AZERTY-keyboard) with the index and middle finger of their right hand. There was 2500ms response time, and it was stressed that accuracy, rather than speed, was of importance.

2.4. Procedure

Before engaging in the tactile change detection task, the participants were instructed that each trial consisted of the presentation of two tactile patterns that could either be identical or not. In order to manipulate spatial attention experimentally, the participants were informed that 75% of the change trials would occur at a specified body location. As such, there were only two different block types, which were counterbalanced. In one block type, the participants were instructed that in 75% of the change trials a pattern change would imply a re-location of one tactile stimulus to the right forearm. In the other block type, participants were instructed that, in 75% of the change trials, a pattern change would imply a repositioning of one tactile stimulus to the left forearm. In the remaining trials, a pattern change would involve a re-location of one tactile stimulus to

another (invalid) location of the body. This change never occurred from an 'indicated' location to this other location. In fact, the location to which the change would occur was validly indicated in 2/3 of the trials (valid trials), and invalidly on the remaining 1/3 of the trials (invalid trials). In Experiment 2, the indicated locations involved the left and right leg just below the knee. Before each block, a picture (see Figure 1) indicated on which arm (Experiment 1) or leg (Experiment 2) a change was most likely to occur. A re-location of one tactile stimulus to another body location could occur from all body locations - except for the locations toward which attention was directed in the different blocks. There was an equal proportion of trials in which a change implied a relocation from the left or right arm or leg to the indicated body locations. These different trial types were presented randomly throughout the course of the experiment. In order to become familiar with the task, the participants first performed a practice phase, consisting of 16 trials. In the experimental phase, the participants completed a total of 288 trials, divided into four experimental blocks of 72 trials (36 'same' trials, 24 valid 'different' trials, and 12 invalid 'different' trials).

2.5. *Statistical analysis*

The data were analyzed using repeated measures analysis of variance (ANOVA) on the percentage correctly detected changes (i.e., accuracy). To obtain an objective and standardized measure of the magnitude of the observed effects, namely a standardized difference between two means, effect sizes (Cohen's *d*) for independent samples were calculated using Morris and DeShon's (2002, in Borenstein et al. 2009) formula. The 95% Confidence Interval (95% CI) was also calculated. Cohen's *d* is an effect size that is not design-dependent and conventional norms are available (Field, 2005). We determined whether Cohen's *d* was small (0.20), medium (0.50), or large (0.80) (Cohen 1988).

3. Results

Three participants were excluded from further statistical analyses. In Experiment 1, one participant failed to respond on more than 50% of the trials and therefore was removed from further analysis. Analyses were performed on the remaining 22 participants. In Experiment 2, one participant was excluded because she reported nerve damage to the left lower arm (see Methods section), one participant was unable to feel tactile stimuli on the legs, and for one of the participants, technical problems led to a faulty administration of the stimuli. The data from the remaining 33 participants were considered appropriate for further statistical analyses. Trials in which participants failed to give a response (on average 2% of the trials) were excluded from all statistical analyses. On average, the participants failed to detect changes in 27.95% of the change trials. The results revealed that the participants also made a few errors on trials in which the patterns did not change ($M=0.11$, $SD=0.15$).

As the design of the two experiments was the same with the exception of the indicated locations, the data from both experiments were analysed together. A repeated measures ANOVA was performed with trial type (valid, invalid) as the within-participants variable, indicated location (arm, leg) as the between-participants variable, and accuracy (i.e., the percentage of correctly detected changes) as the dependent variable. Analysis of the data revealed a significant main effect of trial type as well as a large effect size ($F(1,53)=52.41$, $p<.001$, $d = 1.24$, 95% CI [0.75, 1.72]), indicating a higher accuracy for detecting changes at the attended location ($M=0.83$, $SD=0.17$) as compared to changes at unattended locations ($M=0.62$, $SD=0.17$). There was no main effect of indicated location ($F(1,53)<1$, $p=.35$, $d = 0.25$, 95% CI [-0.29, 0.79]), demonstrating that accuracy did not differ when the indicated locations concerned the arms ($M=0.74$, $SD=0.11$) or the

legs ($M=0.71$, $SD=0.13$). Furthermore, the interaction between trial type and indicated location just failed to reach statistical significance ($F(1,53)=3.94$, $p=.052$).

4. Discussion

The current study investigated whether the focus of a participant's spatial attention can modulate tactile change detection. In the two experiments reported here, participants' attention toward a specific location was manipulated during a typical tactile change detection paradigm (Gallace et al. 2006a). The participants were instructed to detect changes between two consecutively-presented tactile patterns, each consisting of the simultaneous presentation of three tactile stimuli. In half of the trials, one of the stimulated locations of the first tactile pattern shifted toward another location in the second tactile pattern, and, in the other half of the trials, the two patterns were identical. In each block of trials, attention was directed toward a specified bodily location by means of a visual cue that indicated the location where a change in the position of the stimuli was most likely to occur during that block.

The results revealed that participants were more accurate in detecting changes to the attended location than in detecting changes to unattended locations. Our findings thus suggest that attention can play a role in change detection. This is unlike the results of Pritchett et al.'s (2011; see above) study, but as mentioned before they did not investigate the same process as in our experiment. It has been shown that information processing is not only dependent upon bottom-up (exogenous or stimulus-driven) attention, but also upon top-down (endogenous or goal-driven) attention (Corbetta and Shulman 2002; Folk et al. 1992; Yantis 1998), and our findings demonstrate that top-down attention can effectively modulate tactile change detection performance. It has been proposed that individuals adopt 'attentional control settings' including certain stimulus features or characteristics (such as location) that are relevant for their goals and

1 that will receive more attention if they are present in the environment (Corbetta and
2 Shulman 2002; Folk et al. 1992; Yantis 1998). By indicating that a pattern change would
3 most likely involve, for example, the left arm, the features 'tactile' and 'left arm' might
4 have become activated in the participants' attentional set, resulting in more attention
5 being devoted to that specific location as compared to the other body locations. Whereas
6 Pritchett et al. (2011) showed that the detection of changes in successively-presented
7 tactile patterns was not accompanied by (involuntary) attention to the location where the
8 change had taken place, the current study rather examined whether explicitly directing
9 attention to a specific location improves the detection of changes at that location.

10 Another interesting question following on from this concerns what might happen if
11 attention is directed towards one side of the body instead of towards a specific location.
12 One could argue that this particular side of the body might become an active feature in
13 the attentional set, resulting in better performance for detecting pattern changes that
14 involve this body side. Alternatively, if there are multiple possible stimulus locations
15 within this body side, this might again result in competition between different spatial
16 locations (Johansen-Berg and Lloyd 2005), which might then lead to a decreased
17 performance when trying to detect pattern changes involving this body side as compared
18 to a situation in which there is no attentional competition. Moreover, as there are
19 indications that in some clinical populations the altered processing of tactile information
20 is not linked to the specific body part itself but rather to the location of this body part
21 (Moseley et al. 2009, Moseley, Gallace et al. 2012), it might be especially interesting to
22 investigate whether heightened sensitivity for detecting changes in tactile information
23 might be best understood within a somatotopic or rather a spatial frame of reference.
24 Future research will help to provide a better insight into this topic.

25 A number of issues with regard to this study deserve further discussion. First, one
26 could raise the issue that the attention manipulation used in our experiment might have

1 resulted in participants using a strategy of only attending to the presence or absence of a
2 stimulus at the indicated location, making this a signal detection task rather than a
3 change detection task. Other studies have already suggested that the propensity to
4 report the presence of single weak tactile stimuli in a somatic signal detection task is
5 affected by attention (Lloyd et al. 2008; Mirams et al. 2012). However, the participants in
6 the present study were clearly instructed to detect changes between the two tactile
7 patterns. Our results confirmed that they indeed followed these instructions properly as
8 even in the invalid trials, participants were still able to correctly respond on 61% of these
9 trials. We can therefore conclude that the task is not simply a signal detection task in
10 which the presence versus absence of a tactile stimulus at the cued location has to be
11 detected in a situation with simultaneous distractors. Second, the current experiment
12 consisted of valid trials, in which attention was directed to the location of change, and
13 invalid trials, in which attention was directed away from the location of change. There
14 were, however, no 'neutral' trials (e.g., a block type in which no information was provided
15 concerning the location of the pattern changes) in which attention was equally divided
16 between all body locations. As such, the current study cannot clarify whether the
17 difference between valid and invalid trials is due to a benefit from correctly directing
18 spatial attention to the indicated location, or to a cost from incorrectly directing spatial
19 attention to the indicated location. Using both RTs and event-related potentials, Forster
20 and Eimer (2005) investigated the mechanisms underlying tactile spatial attention. They
21 showed that costs were found to be larger than benefits. Based upon these findings, one
22 might rather expect a cost for detecting invalid changes more than a benefit for detecting
23 valid changes. Further research will, however, be needed in order to clarify this matter.
24 Third, it is worth pointing out that the typical tactile change detection task only allows one
25 to measure sensitivity for the detection of changes in pattern locations. Future research

1 may consider using alternative approaches in which sensitivity for changes in the nature
2 of a tactile stimulus (such as its intensity or frequency) could be assessed.

3 The current study is the first to demonstrate that focusing attention on a specific
4 region of the body improves tactile change detection in that region. This experimental
5 paradigm may be useful for investigating excessive attentional focus or hypervigilance to
6 particular regions of the body in various clinical populations. One particular benefit of the
7 current paradigm involves the focus on accuracy rather than RTs. It has been
8 demonstrated that certain clinical populations such as chronic pain patients are
9 characterized by cognitive dysfunction and psychomotor slowing (e.g., Dick et al. 2002;
10 Glass 2009; Veldhuijzen et al. 2012). Because this may lead to slower RTs and
11 increased RT variability, paradigms relying on response speed may prove less reliable in
12 these populations (Van Damme et al. 2008). There are some studies (e.g., Brown et al.,
13 2010) that have used tactile paradigms in order to investigate illusory touch experiences
14 in persons with somatoform symptoms, showing that these persons have a tendency to
15 erroneously report tactile signals. Our approach, on the other hand, was specifically
16 developed to investigate the intriguing – but largely unexplored idea - of an excessive
17 attentional focus or hypervigilance to particular regions of the body in various clinical
18 populations such as patients with lower back pain (Crombez et al. 2005, Moseley,
19 Gallagher et al. 2012) or chronic itch (Van Laarhoven et al. 2010). Specific hypotheses
20 can be tested when using this paradigm in clinical populations. Change detection
21 performance on one body location that is relevant (or threatening) to the condition of a
22 patient can be compared to change detection performance on irrelevant body locations,
23 with increased attentional processing being reflected in a higher detection performance
24 for changes involving the relevant location. When applying the change detection
25 paradigm to a group of patients with lower back pain, for example, one might expect
26 them to be more accurate in detecting pattern changes that involve the back location as

1 compared to pattern changes that involve other bodily locations - if they are indeed more
2 attentive to the back region (Crombez et al. 1998; but, see Moseley, Gallagher et al.
3 2012).

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1   **Figure legends**

2

3   *Figure 1.* An illustration of the different factor locations used in Experiments 1 and 2.

4   During the experiment, these illustrations acted as cues representing the location at

5   which a change was most likely to occur.