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Somatosensory hypervigilance and pain: An experimental approach

Lore Van Hulle

Promotor: Prof. dr. Stefaan Van Damme
Copromotor: Prof. dr. Geert Crombez

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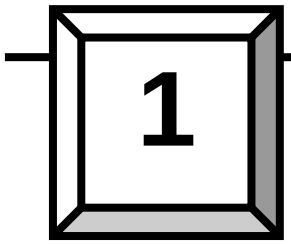

GENERAL INTRODUCTION

CHRONIC PAIN: IN A NUTSHELL

The experience of aversive bodily sensations such as pain is a common feature of everyday life. Studies examining the prevalence of acute pain (i.e., pain of a duration of less than three months) in primary care observed that approximately one third of the patients reported pain complaints, half of which consisted of acute pain complaints (Hasselström, Liu-Palmgren, & Rasjö-Wraak, 2002; Koleva, Krulichova, Bertolini, Caimi, & Garattini, 2005). A common distinction is made between nociceptive and neuropathic pain (Serpell, Makin, & Harvey, 1998; Woolf, 2010). Nociceptive pain results from somatosensory or visceral tissue damage. While somatosensory nociceptive pain is experienced as alarming, sharp, and easy to localize, visceral nociceptive pain is perceived as dull and difficult to localize. Neuropathic pain, on the other hand, results from nerve damage. This pain is often described as 'burning' or 'electrical', and is felt in the part of the body from where the nerve impulses originate. Here, the intensity of the pain is no longer in proportion to the nature of the stimulus (Serpell et al., 1998; Woolf, 2010). Although pain is often transient, in a number of people pain persists and becomes chronic. Studies documenting the prevalence of chronic pain in Europe have reported a prevalence of 19% (Breivik, Collett, Ventafridda, Cohen, & Gallacher, 2006; Reid et al., 2011). However, a review of the literature has revealed a large variability between prevalence estimates, ranging from 10.5% to 55.2% (Ospina & Harstall, 2002). This inconsistency can to a large extent be explained by the lack of consensus about the definition of chronic pain (Ospina & Harstall, 2002). For example, pain has been considered to be chronic when it persists for more than three months (e.g., Reid et al., 2011), or for more than six months (e.g., Breivik et al., 2006; Gureje, Von Korff, Simon, & Gater, 1999). Also, when the severity of the chronic pain problem is taken into account lower prevalence estimates, approximately 11% in adults, have been reported (e.g., Ospina & Harstall, 2002; Von Korff, Dworkin, & Le Resche, 1990). Undoubtedly, chronic pain is a major healthcare problem. The high socioeconomic costs associated with chronic pain mainly originate from the more frequent health care utilization, sick leave and work loss (Breivik et al., 2006; Von Korff et al., 1990). On an individual level, chronic pain has been related to lower quality of life, more disability, and distress (Bingefors & Isacson, 2004; Breivik et al., 2006; Lamé, Peters, Vlaeyen, Van Kleef, & Patijn, 2005). Chronic pain interferes with daily

activities and causes psychological impairment (Gureje et al., 1999; Reid et al., 2011; Von Korff et al., 1990). Moreover, a significant number of individuals experiencing chronic pain show symptoms of anxiety and depression (Breivik et al., 2006; McWilliams, Cox, & Enns, 2003; Von Korff, Ormel, Keefe, & Dworkin, 1992). Taken together, these facts highlight the importance to increase our knowledge about chronic pain and its causal, maintaining, and exacerbating mechanisms.

In both theory and practice, pain is now approached from a biopsychosocial perspective. For a long time, however, a biomedical, dualistic vision dominated the field of pain, presuming that there was a direct and unique link between tissue damage, pain experience, and disability (Gatchel, Peng, Peters, Fuchs, & Turk, 2007; Waddell, 1992). Yet, this reductionistic vision could not account for a number of observations. Pain can, for example, be experienced in the absence of tissue damage (e.g., Nikolajsen & Jensen, 2001). Also, it has been found that placebos may alter the experience of pain (Wager et al., 2004). Loeser (1980) already stated that pain is associated with four dimensions, namely nociception, pain, suffering, and pain behavior. He argued that nociception does not necessarily result in the subjective experience of pain. Similarly, nociception is not always related to suffering or pain behavior. Indeed, individuals reporting a similar pain intensity may vary in the amount of disability they demonstrate (Flor & Turk, 1988; Von Korff et al., 1992; Waddell, 1992), as such showing that there is no one-to-one relationship between pain intensity and disability. The gate-control theory of Melzack & Wall (1965) is generally considered as the major breakthrough in the evolution from a biomedical toward a biopsychosocial vision on pain. The authors argued that nociceptive signals are filtered and modulated at each level of the central nervous system. Critically, they assumed that physical, affective-motivational and cognitive factors are able to influence the pain experience. In the subsequent decades, this theory has nourished research investigating the role of psychological factors on the experience and management of pain (Gatchel et al., 2007). Now, it is widely acknowledged that pain and disability result from an interaction between biological, social, and psychological variables. This vision, highlighting the absence of an absolute relationship between pain, pathology, and disability can also be retrieved in the definition of pain according to the International Association for the Study of Pain, which describes pain as "*… an*

unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage" (Merskey, 1986).

In the past decades, a number of psychological variables - such as pain catastrophizing, pain-related fear, coping, etc. - have been put forward as influencing the subjective experience of pain and disability (e.g., Eccleston & Crombez, 2007; Keefe et al., 1987; Sullivan, Lynch, & Clark, 2005; Vlaeyen & Linton, 2000). Here, we narrow our focus to one factor that has gained particular interest in understanding and treating pain, namely attention.

PAIN AND ATTENTION

It is intuitively assumed that attention influences the experience of pain (Leventhal, 1992). While distracting attention away from pain is generally considered to reduce the experience of pain, focused attention has been thought to increase the perception of painful sensations (Barsky, Goodson, Lane, & Cleary, 1988; McCaul & Mallot, 1984; Eccleston, 1995). Nevertheless, studies that have investigated the modulating effect of attention on pain have yielded mixed results (Seminowicz & Davis, 2007a; Villemure & Bushnell, 2002). Indeed, several studies support the assumption that distraction reduces, and focused attention increases, pain (e.g., James & Hardardottir, 2002; Tracey et al., 2002; Veldhuijzen, Kenemans, de Bruin, Olivier, & Volkerts, 2006), but others have found no (e.g., Hadjistavropoulos, Hadjistavropoulos, & Quine, 2000; Roelofs, Peters, van der Zijden, & Vlaeyen, 2004), or even opposite effects (e.g., Cioffi & Holloway, 1993; Goubert, Crombez, Eccleston, & Devulder, 2004; Keogh, Hatton, & Ellery, 2000; Masedo & Esteve, 2007). There is, however, increasing consensus that differences between individuals and contexts may influence whether or not pain is modulated by attention (Eccleston, 1995; Van Ryckeghem, Crombez, Van Hulle, & Van Damme, 2012).

In the context of chronic pain, a popular hypothesis states that individuals with chronic pain are excessively attentive (i.e., hypervigilant) to somatosensory information, which may then result in an amplified perception of somatosensory sensations (Chapman, 1978; Crombez, Van Damme, & Eccleston, 2005; Van Damme, Legrain, Vogt, & Crombez, 2010). The concept of hypervigilance is omnipresent in various theoretical models on chronic pain (e.g., Eccleston &

Crombez, 2007; Rollman, 2009; Vlaeyen & Linton, 2000). Consequently, hypervigilance is also targeted in the development of psychological treatments for chronic pain, such as attention management (Elomaa, Williams, & Kalso, 2009) or attention bias modification (Sharpe et al., 2012). Yet, despite its popularity in both theory and clinical practice, evidence for a heightened attentional processing of somatosensory information in chronic pain is scarce (Crombez, Van Ryckeghem, Eccleston, & Van Damme, 2013; Van Damme et al., 2010). Moreover, hypervigilance theory and research are plagued by inconsistent conceptualization and operationalization (Van Damme et al., 2010). In the following sections, we aim to elucidate this concept. First, attention is defined and its function is described, thereby exploring the relation between pain and attention. Next, the possible role of hypervigilance in chronic pain is discussed. Finally, we shed light on the different conceptualizations and operationalizations of hypervigilance, and the difficulties which ensue from this. From this, we expound our view on hypervigilance.

A Bottom-Up/Top-Down Interaction

Attention can be defined as the selection of information for action (Wu, 2011). It allows us to maintain relatively stable behavior in a context in which we are constantly confronted with a mass of incoming sensory information that is competing for a limited attentional capacity. Whether or not a stimulus becomes the focus of attention is thought to result from an interaction between bottom-up and top-down mechanisms (Corbetta & Schulman, 2002; Desimone & Duncan, 1995). Stimuli can be selected in a bottom-up way as a result of specific characteristics of the stimulus such as its novelty or intensity, but also by means of top-down processes. These enhance neuronal responses to stimulus features on the basis of their relevance to current goals that are active in working memory, while inhibiting the selection of irrelevant information (Desimone & Duncan, 1995). From a functional perspective, attention thus functions to both (1) protect our focus of attention from irrelevant demands in order to maintain ongoing behavior (‘goal shielding’, Goschke & Dreisbach, 2008), and (2) allow this attentional focus to be interrupted by more important information in order to allow adequate action (Allport, 1989).

Pain demands attention and interrupts ongoing behavior. According to the cognitive-affective model of the interruptive function of pain developed by Eccleston and Crombez (1999), the bottom-up capture of attention by pain in an environment with multiple demands is evolutionary adaptive, as pain informs us about potential bodily damage, and urges an adequate (re)action. The attention-demanding character of pain has mostly been investigated by means of the primary task paradigm (Crombez, Baeyens, & Eelen, 1994; Eccleston, 1994). In this paradigm, participants engage in an attention-demanding primary task, while occasionally a painful stimulus is administered. A number of studies using this task (Crombez, Eccleston, Baeyens, & Eelen, 1996, 1997; Vancleef & Peters, 2006) have observed a deterioration in primary task performance during the administration of a painful stimulus, thereby demonstrating an attentional interruption by pain. Several neurological studies have also documented the attentional capture by pain (Dowman & ben-Avraham, 2008; Legrain et al., 2009; Seminowicz & Davis, 2007b). The model of Eccleston and Crombez (1999) further states that the interruption by pain is not absolute, but is modulated by several factors, among which a number of characteristics of the pain stimulus (Eccleston & Crombez, 1999), such as the intensity (Eccleston, 1994), predictability (Crombez et al., 1994), and novelty (Legrain, Guérit, Bruyer, & Plaghki, 2002; Legrain, Bruyer, Guérit, & Plaghki, 2003) of the stimulus.

However, pain does not always attract attention in a bottom-up fashion. The idea that stimulus-selection occurs on the basis of a bottom-up/top-down interaction, originally stemming from visual attention literature (Desimone & Duncan, 1995; Corbetta & Shulman, 2002), has also been applied to the field of pain (Legrain et al., 2009; Van Damme et al., 2010). According to the neurocognitive model of attention to pain of Legrain et al. (2009; see Figure 1), the bottom-up capture of attention by pain is unintentional, but can be modulated by an individual's ongoing goals, thoughts and intentions. It is generally assumed that this top-down processing occurs through active representations in working memory (Allport, 2011), such as 'attentional load' and 'attentional set'. Attentional load reflects the amount of attention that one investigates in a task. The higher the attentional load required for a task, the less attention there is to invest in task-irrelevant stimuli. Applied to pain, research has for example demonstrated that when attention is strongly engaged in a task, pain interruption is decreased

(Legrain, Bruyer, Guérit, & Plaghki, 2005). Attentional set refers to a mental set of stimulus characteristics that are relevant to the individual's goals (Legrain et al, 2009; Yantis, 2000). The allocation of attention is then facilitated to stimuli that match one ore more of these features (Corbetta & Shulman, 2002; Folk & Remington, 2008; Legrain et al., 2009; Soto, Hodsoll, Rotshtein, & Humphreys, 2008). Accordingly, it could be hypothesized that if one has thoughts or concerns that are related to pain, attention may be facilitated toward pain stimuli since these match active pain features in working memory (Legrain et al., 2009; Van Damme et al., 2010). A number of findings are in line with this theory. The results of Crombez, Eccleston, Baeyens, and Eelen (1998b) and Van Damme, Crombez, and Eccleston (2004), for example, showed that higher levels of pain catastrophizing lead to more attentional intteruption. Also, research has demonstrated that the attention-demanding character of pain further increases when participants are threatened with the possible administration of a painful stimulus of a high intensity (Crombez, Eccleston, Baeyens, & Eelen, 1998a). However, catastrophizing thoughts may not only facilitate the processing of painful information. Imagine, for example, a person who is experiencing low back pain. He or she may be worried that there is damage. This thought may activate certain stimulus representations in working memory, such as location or modality features, e.g., 'lower back' and 'somatensory sensation', in working memory. As a result, this person may notice even non-painful somatosensory stimuli at the back, because these stimuli match both location and modality features that are active in his or her attentional set. Indeed, certain stimuli may also become the focus of one's attention because they share some features with active representations in working memory. Supporting this idea are research findings showing that the same brain regions are involved in the attentional processing of both nociceptive and non-nociceptive stimuli (Corbetta & Shulman, 2002; Tracey & Mantyh, 2007; Ploner, Pollok, & Schnitzler, 2004). More specifically, it has recently been suggested that there exists a salience detection system in the brain through which attention is oriented and monitored to salient auditory, somatosensory or visual information (Legrain, Iannetti, Plaghki, & Mouraux, 2011; Moseley, Gallace, & Spence, 2012). Interestingly, there is evidence that cortical activation in response to somatosensory stimuli does not differ regardless of whether these stimulati are nociceptive or non-nociceptive in nature, but seems to be somatosensory-specific

(Haggard, Iannetti, & Longo, 2013; Mouraux, Diukova, Lee, Wise, & Iannetti, 2011).

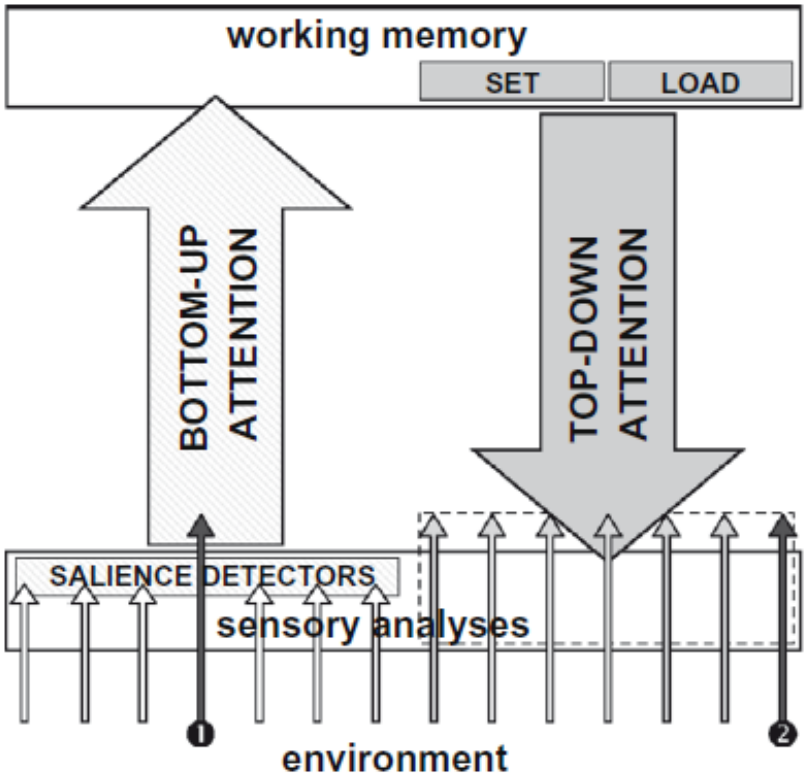

Figure 1. The neurocognitive model of attention to pain of Legrain et al. (2009). The figure shows that environmental stimuli are processed by means of both bottom-up processes, which select stimuli on the basis of their saliency (arrow 1), and top-down processes, which facilitate the processing of relevant stimuli (arrow 2) while inhibiting irrelevant stimuli.

Chronic Pain and Hypervigilance

Generally, the accurate detection and localization of pain and bodily threats is an adaptive ability, as it allows protection of the body against actual or potential damage by triggering defensive behaviors (Dowman & ben-Avraham, 2008; Haggard et al., 2013). However, in some individuals pain persists, and the pain loses its warning function. Yet, it may still demand attention. A popular hypothesis states that as a result of an enduring fearful appraisal of pain, individuals with chronic pain become hypervigilant for or over-attentive to somatosensory signals,

thus facilitating the processing of cues signaling potential pain or bodily harm (Chapman, 1978; Crombez et al., 2005; Rollman, 2009; Vlaeyen & Linton, 2000). One model that presumes the role of hypervigilance in chronic pain is the model of misdirected problem-solving (Eccleston & Crombez, 2007). This theory assumes that the interruptive quality of pain leads to worrying about pain, which results in hypervigilance to bodily sensations and urges an individual to look for a solution. When the pain problem cannot be solved, which is the case in a number of chronic pain conditions, individuals may become stuck in repeated attempts to solve the problem, which leads to increased worrying and hypervigilance. Another model that has gained a particular interest in the field of chronic pain is the fear-avoidance model of Vlaeyen and Linton (2000; see Figure 2).

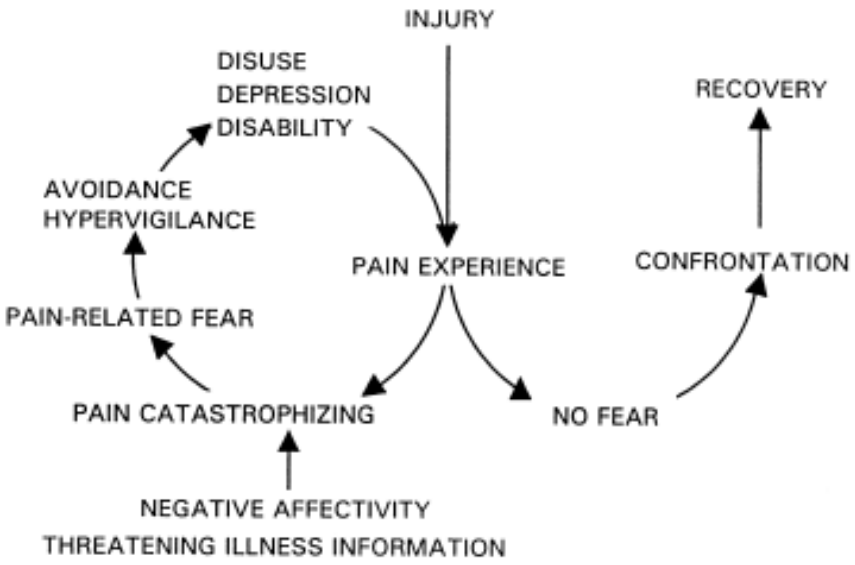

Figure 2. Fear-avoidance model of Vlaeyen and Linton (2000).

According to this model, the way in which pain is interpreted determines whether it leads to disability or to recovery. More specifically, it is assumed that a catastrophizing interpretation of pain, i.e. interpreting pain as extremely threatening (Sullivan, Bishop, & Pivik, 1995), evokes pain-related fear. As a consequence, individuals may become hypervigilant, i.e. excessively attentive, to bodily signals that signal potential harm, and may engage in avoidance behaviour.

This may further lead to disability, disuse, and depression, factors that are, in turn, thought to affect the experience of pain (Vlaeyen & Linton, 2000). A large amount of studies have supported this model by showing that pain-related fear and pain catastrophizing are consistently associated with disability in individuals with chronic pain (e.g., Gheldof et al., 2010; Goubert, Crombez, & Van Damme, 2004; Sullivan et al., 2005; Swinkels-Meewisse, Roelofs, Oostendorp, Verbeek, & Vlaeyen, 2006; Turner, Mancl, & Aaron, 2004). However, although hypervigilance is assumed to mediate this relationship, and has often been studied by means of questionnaires and attentional bias paradigms (e.g., Goubert et al., 2004; Roelofs, Peters, & Vlaeyen, 2002; Asmundson, Carleton, & Ekong, 2005), research evidence remains inconsistent (Leeuw et al., 2007; Van Damme et al., 2010).

Hypervigilance: Conceptualization

As mentioned before, 'hypervigilance' has been conceptualized and operationalized in a variety of ways. Etymologically, hypervigilance can be split up into: 'hyper-', which means 'over, above, beyond, exceedingly', and 'vigilance', meaning 'sustained alertness'. Hypervigilance thus refers to a state of excessively sustained alertness. Historically, the concept of hypervigilance was first applied to the context of pain by Chapman (1978), who stated that persons with chronic pain show a tendency to scan the body for somatosensory signals of pain and that this results from a fearful appraisal of pain. Since then, roughly two different lines of conceptualization can be distinguished. First, several authors explicitly or implicitly define hypervigilance as a hypersensitivity for all types of sensory information (Hollins et al., 2009; McDermid, Rollman, & McCain, 2009; Rollman, 2009). Rollman (2009) even questioned whether the concept hypervigilance would not be better composed of a number of elements, including "… *a greater sensitivity to stimuli, a high degree of monitoring of internal and external events, attribution of bodily signs to physiological causes rather than to environmental or psychological factors, maladaptive coping in dealing with elevated anxiety about bodily signs, and perhaps, a biological predisposition to respond to negative experiences and thoughts with bodily reactions such as localized or widespread muscle tension*." According to this view, hypersensitivity to pain, increased somatic focus, and health anxiety are all aspects of hypervigilance. As a result, evidence for an

excessive attentional focus (i.e., hypervigilance) toward pain and pain-related information has often been derived from studies demonstrating that individuals with chronic pain, such as fibromyalgia or chronic low back pain, show an increased sensitivity to painful information, i.e. lower pain thresholds and lower levels of pain tolerance, and even to non-painful stimuli, as compared to individuals without a chronic pain condition (Blumenstiel et al., 2011; Flor, Diers, & Birbaumer, 2004; Geisser et al., 2003; Hollins et al., 2009; Kosek, Ekholm, & Hansson, 1996; Lautenbacher, Rollman, & McCain, 1994; McDermid et al., 1996; Puta et al., 2012).

A second group of authors stays close to the etymological and original definition of hypervigilance, describing it solely in terms of an attentional process (Crombez et al., 2005; Lautenbacher et al., 2009; Tiemann et al., 2012; Van Damme et al., 2009; Van Damme et al., 2010). Hypervigilance is defined here as the prioritized processing of somatosensory information in the context of multiple attentional demands (Crombez et al., 2005), and therefore is highly similar to the term ‘attentional bias’ (see Crombez et al., 2013). According to this view, hypervigilance is explicitly distinguished from hyperalgesia, allodynia and hyperresponsitivity (Crombez et al., 2005; Gonzáles et al., 2010; Van Damme et al., 2009, 2010), as such differentiating the process of attention from the possible products resulting from elevated attention. Such a parsimonious conceptualization allows the development of testable hypotheses and specific guidelines for treatment (Van Damme et al., 2009). Indeed, hypervigilance is only one mechanism that may account for research findings demonstrating hypersensitivity in, for example, fibromyalgia patients. Other processes, such as central sensitization (e.g., Arendt Nielsen & Henriksson, 2007; Staud, Robinson, & Price, 2007), have also been hypothesized to account for lowered pain threshold and tolerance levels in persons with fibromyalgia. It is therefore recommended not to simply equate hypervigilance with hypersensitivity (Crombez et al., 2005; Van Damme et al., 2009).

Hypervigilance: Operationalization

Where are we now?

Starting from the idea that hypervigilance is conceived as the prioritization of attention to certain information, a large number of studies have examined whether individuals with chronic pain are more attentive toward pain and pain-related information as compared to healthy individuals. First, the hypervigilance hypothesis has been supported by research showing that individuals with chronic pain tend to show higher scores on self-report measures of hypervigilance, such as the Pain Vigilance and Awareness Questionnaire (PVAQ; McCracken, 1997), than healthy controls (Crombez et al., 2004; Peters, Vlaeyen, & van Drunen, 2000; Roelofs, Peters, McCracken, & Vlaeyen, 2003; Tiemann et al., 2012). Moreover, it has been suggested that hypervigilance to pain is dependent upon catastrophic thinking and pain-related fear (Crombez, Eccleston, Baeyens, Van Houdenhove, & Van den Broeck, 1999; Goubert et al., 2004). Nevertheless, it has been argued that the scores on these self-report measures in individuals with chronic pain may be, at least partly, confounded by the continuous presence of pain and other somatic symptoms, perhaps rather reflecting the presence of multiple somatic complaints than an excessive attentional focus on these sensations (Crombez, Eccleston, Van den Broeck, Goubert, & Van Houdenhove, 2004). Therefore, it is recommended to investigate hypervigilance by means of behavioral measures that are less susceptible to such report bias.

Second, hypervigilance in individuals with chronic pain has been studied by means of several attentional bias paradigms, which are described here shortly. In the *modified Stroop paradigm*, participants are presented with pain-related and neutral words which are administered in different colors, and are instructed to rapidly name the color of each word. It is hypothesized that pain words will automatically demand attention, which is thought to result in slower color-naming of pain-related words as compared to neutral words. Chronic pain patients are expected to show more pain-related interference as compared to individuals without a chronic pain condition (Roelofs et al., 2002). In the *dot-probe paradigm*, a pain word and a neutral word are simultaneously presented on a screen. One of these two words is then replaced by a dot, and participants are instructed to indicate the location where the dot appeared. It is expected that response times will be faster when the dot replaces a pain word as compared to a neutral word.

Moreover, this effect is thought to be more pronounced in chronic pain patients as compared to healthy controls (Asmundson et al., 2005). Another paradigm that has been used to investigate the attentional processing of pain-related information is the *modified spatial cueing task*, originally developed by Posner (1978) as the exogenous cueing task. In this task, participants have to detect visual targets that are presented on the left or right side of the screen. Before each target, a pain-related cue is briefly presented at either the same (congruent) or opposite (incongruent) spatial position. Slower reaction times to incongruent as compared to incongruent trials reflect exogenous orienting, and this seems to be increased when pain-related cues are used (Van Damme et al., 2004; Van Damme, Crombez, & Lorenz, 2007; Van Damme, Eccleston, Crombez, & Koster, 2006; Van Ryckeghem et al., 2013). Again, it is assumed that the attentional bias toward pain-words is more pronounced in individuals with chronic pain as compared to healthy controls (e.g., Chapman & Martin, 2011). Despite the large number of studies, evidence for an increased attentional processing of pain-related information in individuals with chronic pain as compared to healthy controls is far from convincing (see Pincus and Morley, 2001; Van Damme et al., 2010). Moreover, a recent meta-analysis by Crombez et al. (2013) indicated that there was an attentional bias to pain-related information in chronic pain patients, but that this effect was only small, and, importantly, not significantly different from healthy controls. Furthermore, attentional bias did not seem to be associated with pain-related fear or catastrophizing about pain. It has been argued that the visual stimulus material used in these studies might not be sufficient to activate 'schemata' of bodily threat, as these are only semantic representations of pain (Crombez et al., 2013; Van Damme et al., 2010). Indeed, research investigating the idea of heightened attention to pain-related information is mainly limited to studies comparing the deployment of attention to pain-related and neutral words or pictures (e.g., Asmundson et al., 2005; Haggman, Sharpe, Nicholas, & Refshauge, 2010; Liossi, Schoth, Bradley, & Mogg, 2009). Therefore, it has been recommended that future studies should shift to somatosensory attention paradigms (Crombez et al., 2013; Van Damme et al., 2010).

Where are we going?

From the previous sections, we may conclude that clear evidence for the presence of hypervigilance in individuals with chronic pain is lacking. Future studies should evolve to the use of more ecologically valid attentional bias paradigms. Below, a number of directions toward a new approach of hypervigilance are highlighted.

First, somatosensory hypervigilance is defined here as the prioritized processing of somatosensory information in the context of multiple attentional demands (Crombez et al., 2005). This definition stresses that crucial to infer the presence of hypervigilance is the demonstration that pain-related features are prioritized by the attention system at the expense of other information (Crombez et al., 2005; Van Damme et al., 2010). It is expected that in this situation potential attentional preferences will become prominent, as this would lead to the prioritized processing of relevant stimuli as compared to irrelevant information.

Second, this definition implies that *somatosensory* versions of attentional bias paradigms should be used. It can be argued that somatosensory stimuli, being administered directly to the participants' skin, might be both personally relevant and ecologically valid, in comparison with visual words (Crombez et al., 2013; Van Damme et al., 2010). Indeed, it may be argued that somatosensory stimuli may have a higher potential to activate a threat value. Still, studies investigating somatosensory hypervigilance in chronic pain populations are rare. In a study of Tiemann et al. (2012) participants with fibromyalgia and control participants engaged in a visual reaction time task during which painful stimuli were administered. In contrast to what was expected, participants with fibromyalgia did not show a greater increase in reaction time on the task when a painful stimulus was administered as compared to the control group. This suggested that participants with fibromyalgia did not prioritize painful information more than individuals without a chronic pain condition. However, the use of painful stimuli in an experimental context may have activated pain-related thoughts in both the chronic pain and the control group, as pain has an intrinsic attention-demanding quality (Eccleston & Crombez, 1999). Consequently, prior existing differences in the prioritization of attention to somatosensory information may not become visible. Therefore, the use of innocuous, rather than painful, somatosensory stimuli may be preferred to investigate somatosensory

hypervigilance in individuals with and without chronic pain. According to the neurocognitive model of Legrain et al. (2009), it can easily be hypothesized that individuals with chronic pain maintain features of painful expectations within their attentional set, consequently leading to more attention to somatosensory stimuli. One can easily call to mind the situation of an individual with low back pain, who is worried about a potential injury, and continuously scans his back in order to detect signals of potential harm. It is likely that, as a result of such strong focus of attention on the back, this person will notice even non-painful somatosensory changes in that body region. More specifically, from this model, it may be expected that individuals with chronic pain will be particularly attentive to the specific region of the body where their pain problem is situated. Studies investigating this idea are however lacking.

Third, hypervigilance is commonly assumed to be induced by fear of movement or (re)injury (Crombez et al., 1999; Roelofs et al., 2007; Vlaeyen & Linton, 2000, 2013). There is evidence that certain movements may acquire a threat value through associative learning processes (Meulders, Vansteenwegen, & Vlaeyen, 2011; Moseley & Hodges, 2005), and it has been proposed that these processes may also underlie movement-related fear in individuals with chronic low back pain (Meulders & Vlaeyen, 2013). As it has been theorized that attention is oriented and monitored toward potential bodily threats (Haggard et al., 2013; Legrain et al., 2011; Van Damme et al., 2010), it may be expected that, during a threatening movement, attention will be focused on the body part where pain is anticipated, leading to increased perception of somatosensory information in that body part. Remember the individual with chronic low back pain. Especially in the situation in which he/she is about to bend over to lift up a heavy bag, a fearful anticipation that this movement will cause (further) damage, or worsen the pain, may arise. From this, it may be hypothesized that hypervigilance only emerges in a specific context. Therefore, studies should investigate the prioritization of somatosensory information in individuals with chronic pain in a context in which they are required to perform a movement that activates a threat value. Such a threat value may be absent when they are in rest.

Fourth, certain clinical populations such as chronic pain patients are characterized by cognitive dysfunction and psychomotor slowing (e.g., Dick, Eccleston, & Crombez, 2002; Glass, 2009; Veldhuijzen, Sondaal, & Oosterman,

2012). Because this may lead to slower RTs and increased RT variability, paradigms relying on response speed, such as the Stroop task or dot probe task, may prove less reliable in these populations (Van Damme, Crombez, & Notebaert, 2008). As a result, an approach in terms of accuracy measures was favoured above traditional reaction time paradigms.

AIM AND OUTLINE OF THE STUDIES

The aims of this PhD thesis were (1) to develop paradigms allowing assessment of somatosensory hypervigilance, (2) to investigate the assumption that bodily threat leads to attentional prioritization of non-painful somatosensory information, and (3) to investigate whether individuals with chronic pain are characterized by somatosensory hypervigilance in comparison with healthy controls.

In **Part I**, we investigated the utility of several somatosensory attention paradigms to measure the prioritization of somatosensory information in a context of multiple demands. Attention was either manipulated to a specific modality, if the task considered the detection of stimuli in different modalities, or to a specific location of the body, if the task consisted of the detection of somatosensory stimuli on different locations of the body. Focused attention should be reflected in the facilitated processing of relevant as compared to irrelevant information. All the reported studies were carried out in student samples.

In ***Chapter 2***, the value of the modality cued signal detection task in assessing the attentional prioritization of somatosensory as compared to auditory information was investigated. This task consisted of an un-speeded detection task in which weak (individually calibrated) somatosensory or auditory stimuli were administered. The focus of attention was manipulated by the presentation of a visual cue (the word “warmth” or “tone”), which was predictive of the corresponding target in 2/3 of the trials, at the start of each trial. Focused attention toward a specific modality was expected to lead to a better detection of stimuli in the attended modality as compared to stimuli in the unattended modality.

In ***Chapter 3*** we investigated whether the tactile change detection paradigm, which is based upon the tactile change blindness paradigm (Gallace,

Tan, & Spence, 2006), was sensitive to detect the attentional prioritization of body locations. In this task, participants were instructed to detect changes between two consecutively-presented tactile patterns that were presented on multiple locations of the body. In half of the trials, the stimulated body sites in the two patterns were identical. In the other half of the trials, one of the stimulated body locations differed between the two patterns. Usually, people experience difficulties in detecting such subtle changes in tactile information (Gallace et al., 2006). It was investigated whether the manipulation of attention toward a specific location of the body resulted in a better detection of tactile changes that occurred at the attended location as compared to changes at body locations that were unattended.

Chapter 4 investigated the value of the sensory suppression paradigm to assess the attentional prioritization of body locations during movement execution. For this purpose, participants simultaneously engaged in a movement task, in which they were required to execute a back-bending movement or keep still, and a perceptual task, which consisted of the detection of subtle tactile stimuli administered to their upper or lower back. The focus of participants' attention was manipulated by raising the probability that one of the back locations would be stimulated. Typically, tactile perception is reduced during movement (e.g., Juravle, Deubel, & Spence, 2011; Williams & Chapman, 2000, 2002). We tested whether focused attention would lead to a better detection of somatosensory stimuli that were presented at the attended as compared to the unattended body location.

Part II consists of two studies that build upon two of the paradigms developed in Part I. Here, we examined whether bodily threat induces a spontaneous state of somatosensory hypervigilance toward the body part where the pain is expected.

In ***Chapter 5***, it was investigated whether the threat of experimental pain on a specific body location facilitates the detection of tactile changes on that particular body location by experimentally inducing pain anticipation at one location of the body. Healthy participants engaged in a tactile change detection task (see Chapter 3), in which they had to detect changes between two consecutively presented tactile patterns while, occasionally, a painful stimulus was administered to one of the stimulated locations. It was hypothesized that this threat manipulation would

result in an attentional focus to the threatened body location, consequently leading to a better detection of tactile changes occurring at that location.

Chapter 6 examined whether the expectation of pain during movement execution would lead to a reduced sensory suppression of tactile information on the body part where pain was expected. Healthy participants engaged in a movement-detection task in which they were instructed to (1) move both arms either to the left or to the right, or keep them at rest, and (2), at the same time, detect the presence or absence of a tactile stimulus on the left or the right forearm. One movement was made threatening by occasionally associating it with the administration of a painful stimulus on either the left or the right forearm. If a threatening movement leads to heightened attention on the body part where the pain is expected, this should lead to a better detection of tactile stimuli on the threatened body part during a threatening as compared to a neutral movement, indicating reduced sensory suppression as a result of pain anticipation.

Part III contains two studies investigating somatosensory hypervigilance in individuals with chronic pain.

In ***Chapter 7***, the presence of somatosensory hypervigilance in a sample of patients with fibromyalgia as compared to a matched control group was investigated by means of a multi-method approach using both self-report questionnaires and a behavioral measure of somatosensory hypervigilance. The behavioral measure consisted of the tactile change detection task (Chapter 3 and 5). The task was performed under two conditions. In the divided attention condition, tactile changes occurred equally often at all possible body locations. In the focused attention condition, participants were informed about which body location would be most likely to be involved in tactile changes. First, it was expected that self-reported hypervigilance would be higher in individuals with fibromyalgia than in matched controls. Second, it was hypothesized that somatosensory hypervigilance would be reflected by a more accurate detection of tactile changes in the divided attention condition, and that in the focused attention condition, patients with fibromyalgia would be better than matched controls in detecting tactile changes at unattended locations. That is, we expected that the habit to scan the body for signals of potential threat in individuals with fibromyalgia

would interfere with the task instruction to attend to one particular location of the body.

Chapter 8 examined whether individuals with chronic low back pain exhibit heightened attention to somatosensory information during the execution of movements that are related to the painful body part. For this purpose, both participants with chronic low back pain and control participants engaged in a sensory suppression task in which they were instructed to (1) perform an arm movement, a back movement, or no movement, and (2), at the same time, detect the presence or absence of a subtle tactile stimulus on the chest, the arm, or the back. It was hypothesized that, if individuals with chronic low back pain are indeed particularly attentive to the back region during the execution of the back movements, this would be reflected in a decreased sensory suppression of somatosensory information at the back during the execution of back movements, in comparison with the control group.

Finally, in ***Chapter 9***, the results of the previously described studies are discussed in the light of the hypotheses, and suggestions for future research are presented.

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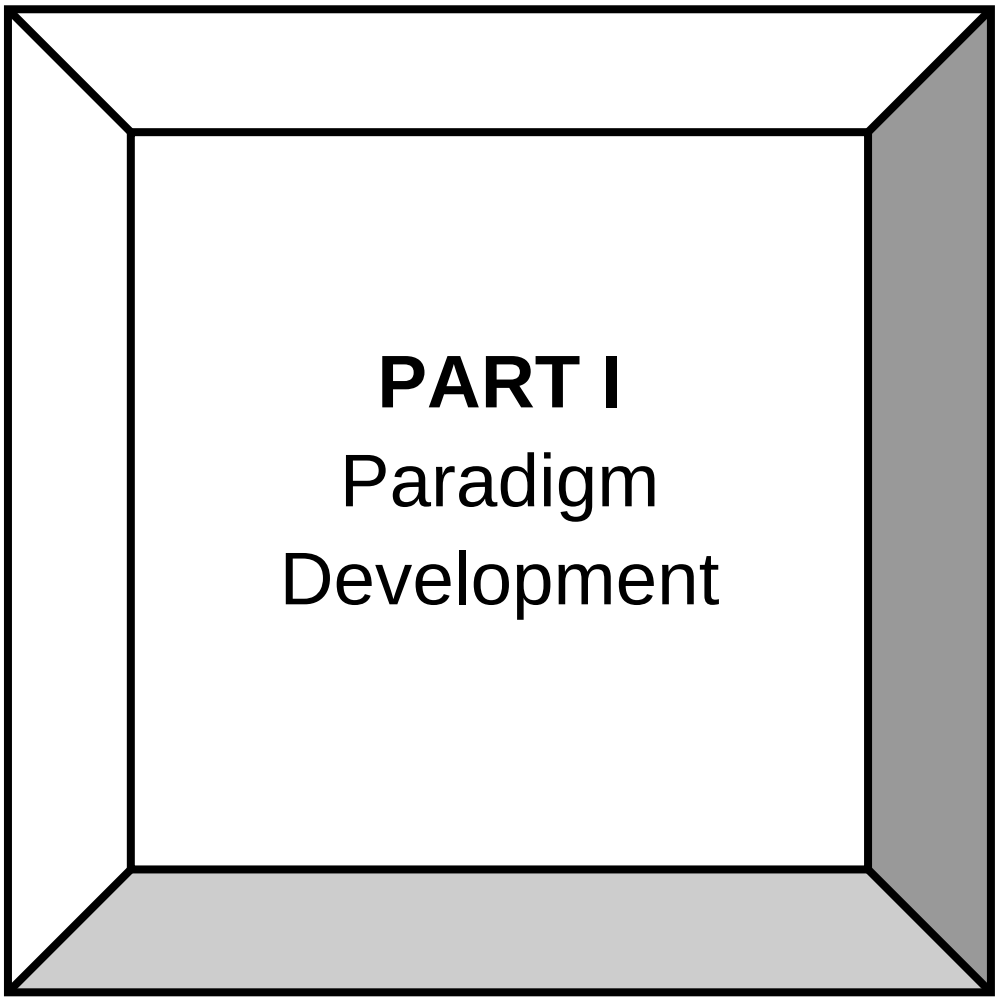
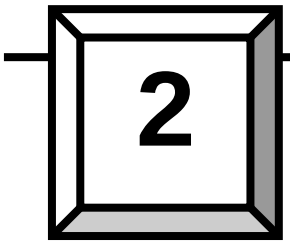

PART I
Paradigm
Development



VALID CUES FOR AUDITORY OR SOMATOSENSORY TARGETS AFFECT THEIR PERCEPTION: A SIGNAL DETECTION APPROACH[1]

ABSTRACT

The present study investigated the effects of focusing attention towards auditory or somatosensory stimuli on perceptual sensitivity and response bias using a signal detection task. Participants (*N* = 44) performed an unspeeded detection task in which weak (individually calibrated) somatosensory or auditory stimuli were delivered. The focus of attention was manipulated by the presentation of a visual cue at the start of each trial. The visual cue consisted of the word "warmth" or the word "tone". This word cue was predictive of the corresponding target on 2/3 of the trials. As hypothesized, the results showed that cueing attention to a specific sensory modality resulted in a higher perceptual sensitivity for validly cued targets than for invalidly cued targets, as well as in a more liberal response criterion for reporting stimuli in the valid modality than in the invalid modality. The value of this experimental paradigm for investigating excessive attentional focus or hypervigilance in various non-clinical and clinical populations is discussed.

[1] Van Hulle, L., Van Damme, S., & Crombez, G. (2013). Valid cues for auditory or somatosensory targets affect their perception: A signal detection approach. *Perception, 42*, 223-232.

INTRODUCTION

In a typical naturalistic environment we are often overwhelmed with a mass of sensory stimuli entering our senses (e.g., visual, auditory, somatosensory) competing for cognitive processing (Spence & Driver, 1997). In order to make sure that our actions are adequately accomplished, and are not repeatedly interrupted by stimuli from the environment, this multitude of sensory information has to be reduced. One way to achieve such reduction is by the selection of sensory inputs that are considered as relevant or informative for the current goal or concern (Corbetta & Shulman, 2002; Klinger & Cox, 2008; Yantis, 1998). Indeed, stimuli that are related to a currently activated goal have been shown to be prioritized by the attention system (Folk, Remington, & Johnston, 1992; Notebaert, Crombez, Van Damme, De Houwer, & Theeuwes, 2011; Vogt, De Houwer, Moors, Van Damme, & Crombez, 2010).

One can imagine that for certain individuals the detection of bodily sensations may be especially relevant for their current goals or concerns. For instance, it is assumed that persons with a variety of clinical disorders (e.g., chronic pain, panic disorder, heart disease, skin disease) are often preoccupied with bodily cues signaling potential physical harm (Crombez, Van Damme, & Eccleston, 2005; Eifert, Zvolensky, & Lejuez, 2000; Van Laarhoven, Kraaimaat, Wilder-Smith, & Evers, 2010). Such preoccupation may then lead to an excessive focus of attention (i.e., hypervigilance) to bodily sensations and, consequently, to an increased chance that even weak innocuous somatosensory inputs enter consciousness. Although empirical evidence is accumulating that the anticipation of physical threat is associated with an overall increase in attention to body-related information (for a review, see Van Damme, Legrain, Vogt, & Crombez, 2010), the assumption that a strong tendency to focus attention on bodily sensations increases the chance of becoming aware of weak somatosensory inputs, remains largely uninvestigated (but, see Peters, Vlaeyen, & van Drunen, 2000).

One possible way to test this idea is by means of behavior paradigms in which participants have to correctly detect weak stimuli in different sensory modalities (including the somatosensory modality) that are presented in an unpredictable sequence. In such paradigm, focusing attention endogenously to one modality by means of instructions (Spence, Shore, & Klein, 2001) or cues (Lloyd, Bolanowski, Stanley, Howard, & McGlone, 1999; Spence, Nicholls, &

Driver, 2001; Spence, Pavani, & Driver, 2000; Van Damme, Crombez, & Eccleston, 2002) has been found to lead to shorter reaction times to target stimuli in the attended modality as compared to targets in the unattended modality. However, reaction time paradigms may be problematic for a number of reasons. First, many clinical populations, such as chronic pain patients, are typically characterized by cognitive impairment and psychomotor slowing (e.g., Veldhuijzen, Sondaal, & Oosterman, 2012), which may lead to large reaction time variability and decreased sensitivity for identifying attentional effects (Van Damme, Crombez, & Notebaert, 2008). Second, one could expect that a strong focus of attention on one modality may not only increase the chance that weak stimuli in that modality are more often detected than weak stimuli in other sensory modalities (perceptual sensitivity), but also that stimuli in that modality may be simply reported more often irrespective of its perceptual effect (response bias) (Mirams, Poliakoff, Brown, & Lloyd, 2012). Reaction times are less suitable if one wants to measure these effects independently (see Spence & Parise, 2010; Spence, Nicholls et al., 2001).

The main aim of the present study is to investigate the effects of focusing attention endogenously to one sensory modality on both perceptual sensitivity and response bias using a signal detection task with stimuli from different sensory modalities. Healthy participants are asked to report the presence or absence of weak (individually calibrated) somatosensory and auditory targets. The focus of attention is experimentally manipulated on a trial-to-trial basis by means of a cue signaling the most likely modality of the upcoming stimulus (see also Lloyd et al., 1999; Spence, Nicholls et al., 2001; Spence et al., 2000). Using signal detection theory on correct hits and false detections, measures of perceptual sensitivity and response bias can be calculated for both validly and invalidly cued somatosensory and auditory stimulation. It is expected that cueing a modality will result in (1) a higher perceptual sensitivity, i.e., a more adequate detection of validly cued stimuli than invalidly cued stimuli, and (2) a more liberal response criterion to report stimuli from the valid modality than stimuli from the invalid modality irrespective of actual sensory input (see, Mirams et al., 2012; Soto-Faraco, Sinnett, Alsius, & Kingstone, 2005).

METHODS

Participants

Forty-four healthy undergraduate psychology students (37 females, 7 males; mean age = 20.09 years, range 18-35 years) participated to fulfil course requirements. The study protocol was approved by the ethical committee of the Faculty of Psychology and Educational Sciences of Ghent University. All participants gave informed consent and were free to terminate the experiment at any time. Two participants were removed for further analysis because of technical problems. All data from the remaining 42 participants were considered appropriate for further statistical analysis.

Apparatus and Stimulus Material

Somatic stimuli were thermal stimuli (300 ms), administered on the left wrist by means of a CHEPS thermode (Medoc Pathway, Medoc). Auditory stimuli (300 ms; pink noise, Audacity) were administered through a noise-cancelling headphone (PXC 350 Sennheiser). The baseline temperature of the CHEPS thermode was set at 32°C (see also Jones & Berris, 2002; Meier, Berde, DiCanzio, Zurakowski, & Sethna, 2001). In order to reduce the influence caused by environmental noise, an auditory baseline was created, namely a constant white noise at 42.4 Db, which exceeded the variable noise resulting from the Medoc. The intensity of both the thermal and auditory stimuli was individually calibrated in order to approach perceptual threshold by means of a simple staircase method. For this purpose, a series of 10 stimuli with decreasing intensity were presented. After each stimulus participants were asked to indicate whether they perceived it or not. This procedure was done once with ten thermal stimuli (intensities ranging from 37.5 °C to 32.5 °C) and once with ten auditory stimuli (intensities ranging from 54 Db to 42.6 Db). To determine the intensity of the thermal stimulus, a staircase was used with a step size of 0.5°C. The staircase to determine the intensity of the auditory stimulus started with a maximum intensity of 54 dB (approximately, as this intensity was measured with a dB-meter). The volume of this original auditory stimulus of 54 dB was decreased stepwise in order to obtain different stimulus intensities. Importantly, the size of each step corresponded to the logarithmic hearing characteristic of the ear. Accordingly, the step size

between the lowest intensity and one intensity higher was smaller than the step size between the highest intensity and one intensity lower.

For each modality, the last stimulus intensitity a participant was able to perceive was selected. When the responses altered between yes and no within a certain range of stimulus intensities, the perceptual threshold was calculated by taking the average of the stimulus intensities within that range. The average intensity selected for the auditory stimulus was a volume of 43.55 Db (*SD* = 0.54 Db, range 42.60-45.40), and the average intensity selected for the thermal stimulus was 33.25 °C (*SD* = 0.51 °C, range 32.50-34.50].

Modality Cued Signal Detection Task

The paradigm was programmed and controlled by Inquisit Millisecond software (Inquisit 2.0) on a laptop (HP Compaq nc6120) with keyboard. In a typical signal detection task, participants are asked to detect the presence or absence of a sensory target. The present study made use of a modified version of a signal detection task. The task consisted of an un-speeded detection of weak (individually calibrated) somatosensory and auditory stimuli. In order to experimentally manipulate attention endogenously, each trial started with a visual cue, i.e., the word “warmth” or the word “tone”, which was presented on the screen for 500 ms (for a similar manipulation see Van Damme et al., 2002). Both somatic and auditory targets were preceded by a valid cue in 2/3 of the trials and by an invalid cue in the other 1/3 of the trials. Previous studies have used cues that informed participants about the probability of a specific event in order to endogenously direct attention toward a specific location or modality (e.g., Lloyd et al., 1999; Spence et al., 2000; Spence, Nicholls et al., 2001). Immediately after the presentation of the cue, either a somatic stimulus, an auditory stimulus or no stimulus at all was administered. Next, a question appeared on the screen, i.e., “*Did you perceive a heat stimulus?*” (only after ‘no stimulus’ trials or heat trials) or “*Did you perceive an auditory stimulus?*” (only after ‘no stimulus’ trials or auditory trials)[2]. Trials in which the target was actually administered are referred to as signal trials, whereas trials in which no target was administered are referred to as

[2] This procedure was used in order to calculate distinct signal detection measures, namely perceptual sensitivity and response bias, for the auditory and somatosensory trials.

noise trials. The participants were instructed to respond to this question by pressing ‘yes’ or ‘no’ on the proper response keys (respectively “4” and “6” on an AZERTY-keyboard) with the index and middle finger of their right hand. There was ample time (3500 ms) to respond, and it was stressed that accuracy, rather than speed, was of importance.

As such, there were four conditions: Modality (auditory, somatosensory) x Cue type (valid, invalid). The order of the trials was randomized across participants. Table 1 provides an overview of the different trial types used in the experiment and the number of trials within each trial type.

Table 1

Number and type of trials during the practice and the experiment phase.

Condition	Practice trials	Experimental trials	Cue	Target
Aud. Valid	2	40	Aud.	Aud.
	2	40	Aud.	No stimulus
Aud. Invalid	1	20	Som.	Aud.
	1	20	Som.	No stimulus
Som. Valid	2	40	Som.	Som.
	2	40	Som.	No stimulus
Som. Invalid	1	20	Aud.	Som.
	1	20	Aud.	No stimulus

Procedure

Pre-experimental phase. Participants were informed about the nature of the stimuli that would be administered and gave their informed consent. Next, participants’ individual perceptual thresholds for both the auditory and the thermal stimuli were determined separately.

Experimental phase. Participants were instructed to respond to the targets as accurately as possible. In order to manipulate attention, they were informed that the target stimuli were mostly preceded by a valid cue. To become familiar with the task, participants first performed a practice phase. In the experimental phase,

participants completed a total number of 240 trials, divided in 10 experimental blocks of 24 trials (for a schematic overview, see Table 1). After each block, the location of the thermode was slightly changed to prevent potential habituation effects.

Post-experimental phase. As a manipulation check, participants were asked immediately after the experiment was terminated to rate by means of 11-point numerical graphical rating scales from zero ("not at all") to ten ("very") to what extent they expected that the stimulus modality was predicted by the cues (1), how intensely they perceived the auditory and thermal stimuli (2), and how much attention they payed to the the stimuli (3).

Data-analyses

Signal detection theory was used in order to calculate the hit and false alarms rates, which allowed further differentiation between perceptual sensitivity and response bias (Macmillan & Creelman, 2005; Stanislaw & Todorov, 1999; Wickens, 2002). A signal trial is a trial in which a stimulus is delivered, whereas a noise trial is a trial in which no stimulus is delivered. Hit and false alarm rates were computed, separately for (in)valid auditory and (in)valid somatosensory and auditory trials (see Table 1). The hit rate is calculated by dividing the number of times a participant correctly reported the presence of a signal, by the number of signal trials. Similar, the false alarm rate is calculated by dividing the number of times a participant incorrectly reported the presence of a signal, by the number of noise trials. Next, indexes of perceptual sensitivity (*A'*) and response bias (*c*) were calculated based upon these hit and false alarm rates.

$$A' = 0.5 + [sign(H-F)(H-F)^2+|H-F|] / [4max(H,F)-4HF] \quad (1)$$

$$c = -(\Phi^{-1}(H)+ \Phi^{-1}(F))/2^3 \quad (2)$$

[3] Φ represents the 'phi' score used to convert *z* scores into probabilities.

Values of *A'* range between zero and one, with values above 0.5 indicating that perceptual sensitivity exceeds chance level, thus that participants are able to distinghuish signals from noise. *A'* has been proposed as a measure of sensitivity as this (nonparametric) measure does not rely on assumptions of normality and equal variance (in contrast to *d'*, and as such is unaffected by or not dependent on response bias (Macmillan & Creelman, 2005; Stanislaw & Todorov, 1999; Wickens, 2002). In this study, the sign of *c* was reversed in order to ease interpretation. Therefore, a value of zero here indicates no response bias, a positive value indicates a bias for 'yes'-responses (i.e., a bias to respond that a signal was present), and a negative value a bias for 'no'-responses (i.e., a bias to respond that no signal was present). One-sample *t*-tests were used to investigate participants' belief in the predictive value of the cues, and to test whether perceptual sensitivity differed from chance level and whether response bias was present. A 2 (Cue: valid, invalid) x 2 (Modality: somatosensory, auditory) analysis of variance (ANOVA) with repeated measures was performed on perceptual sensitivity and response bias measures. Effect sizes for independent samples were calculated using Morris and DeShon's (2002, as cited in Borenstein, Hedges, Higgins, & Rothstein, 2009) formula. The 95% Confidence Interval (95% CI) was also calculated. We determined whether Cohen's *d* was small (0.20), medium (0.50) or large (0.80) (Cohen, 1988).

RESULTS

Self-report Data

One-sample *t*-tests were used to check whether participants' belief in the predictive value of both the thermal and the auditory cues differed significantly from zero. Results showed that (resp. $t(41) = 20.44$, $p < .001$ and $t(41) = 12.08$, $p < .001$), indicating that the attention manipulation was successful. Noteworthy, this belief was stronger for thermal cues ($M = 5.26$, $SD = 1.68$) than for auditory cues ($M = 4.02$, $SD = 2.16$), $t(41) = 3.35$, $p < 01$. Mean post-experiment intensity ratings were also higher for thermal stimuli ($M = 4.90$, $SD = 2.59$) than for auditory stimuli ($M = 2.38$, $SD = 2.19$), $t(41) = 6.02$, $p < .001$). Nevertheless, participants did not report to attend more to thermal stimuli ($M = 6.95$, $SD = 1.75$) than to auditory stimuli ($M = 6.81$, $SD = 1.94$), $t(41) = .33$, $p = .74$.

Repeated-measures Analyses

Perceptual accuracy. Overall, perceptual sensitivity measures significantly differed from chance level (for means, standard deviations, and one-sample *t*-tests, see Table 2). A 2 (Cue: valid, invalid) x 2 (Modality: somatosensory, auditory) analysis of variance (ANOVA) with repeated measures was performed on perceptual sensitivity measures. There was a significant main effect of Cue ($F(1,41) = 8.48$, $p = .01$, $d = 0.33$, 95% CI [0.06,0.60]), indicating a higher perceptual sensitivity for stimuli in the validly cued trials ($M = 0.85$, $SD = 0.14$) as compared to stimuli in the invalidly cued trials ($M = 0.80$, $SD = 0.16$). Furthermore, a significant main effect of Modality was found ($F(1,41) = 31.62$, $p < .001$; $d = 0.87$, 95% CI [0.52,1.22]), showing a higher perceptual sensitivity for somatosensory stimuli ($M = 0.89$, $SD = 0.13$) as compared to auditory stimuli ($M = 0.75$, $SD = 0.18$). The Cue x Modality interaction was not significant ($F(1,41) = 0.25$, $p = .62$).

Response bias. One sample *t*-tests showed response bias measures to be significantly different from zero. As the overall bias was negative, this indicated that participants overall had a conservative response criterion in reporting the presence of a stimulus (for means, standard deviations, and one-sample *t*-tests, see Table 2). Another 2 (Cue: valid, invalid) x 2 (Modality: somatosensory, auditory) analysis of variance (ANOVA) with repeated measures was performed on response bias measures. There was a significant main effect of Cue ($F(1,41) = 38.20$, $p < .001$; $d = 0.61$, 95% CI [0.40,0.81]), indicating that participants used a less stringent criterion (i.e., were less conservative) to report the presence of a stimulus in the validly cued trials ($M = -0.43$, $SD = 0.43$) as compared to the invalidly cued trials ($M = -0.71$, $SD = 0.48$). Also the main effect of Modality was significant ($F(1,41) = 21.71$, $p = .00$; $d = 0.74$, 95% CI [0.36,1.13]), indicating that participants used a less stringent criterion to report a somatosensory stimulus ($M = -0.32$, $SD = 0.43$) as compared to an auditory stimulus ($M = -0.74$, $SD = 0.65$). The Cue x Modality interaction failed to reach statistical significance ($F(1,41) = 3.02$, $p = .09$).

Table 2

Hit (H) and false alarm (F) rates for each condition together with means and standard deviations for perceptual sensitivity (A') and response bias (c). One sample t-tests were used to assess whether perceptual sensitivity exceeded chance level (A'>0.50) and whether there was any indication of response bias (c≠0).

	A'				*c*				*H*	*FA*
	M	*SD*	*t*(41)	*p*	*M*	*SD*	*t*(41)	*p*		
Aud. Valid	0.76	0.19	8.87	<.001	-0.66	0.66	6.53	<.001	.50	.14
Aud. Invalid	0.71	0.18	7.36	<.001	-0.85	0.55	9.89	<.001	.40	.11
Som. Valid	0.90	0.13	20.20	<.001	-0.19	0.41	2.98	.01	.79	.14
Som. Invalid	0.84	0.16	13.34	<.001	-0.50	0.47	6.73	<.001	.27	.11

DISCUSSION

The main aim of this study was to investigate the effects of focusing attention to one sensory modality on both perceptual sensitivity and response bias using a signal detection task with weak (individually calibrated) somatosensory and auditory stimuli. The results showed that cueing attention to a specific sensory modality resulted in a higher perceptual sensitivity for validly cued targets as compared to invalidly cued targets, as well as in a more liberal response criterion for reporting stimuli in the valid modality than in the invalid modality.

These findings indicate that focusing attention on a specific sensory modality increases the chance that weak stimuli in that modality are more often detected than weak stimuli in other sensory modalities. Indeed, perceptual sensitivity for both somatosensory and auditory stimuli was significantly larger in validly cued trials as compared to invalidly cued trials. The self-report measures showed that our manipulation in terms of validly and invalidly predicting the modality of a target worked as participants reported to believe in the predictive value of the cues. This is in line with other studies investigating the effects of modality cueing on the processing of information using reaction time data (Soto-Faraco et al., 2005; Spence, Nicholls et al., 2001; Spence, Shore et al., 2001; Van Damme et al., 2002). Several studies have shown that attention not only has an effect on a behavioural level, but also on a neurological level (see for example the

theory of biased competition, Desimone & Duncan, 1995). Relevant in this context are findings showing that, when attention is directed to tactile or auditory stimulation, increases of neural processing can be observed in respectively the somatosensory and the auditory cortex (Burton et al., 1999; Calvert, Spence, & Stein, 2004). Future studies might consider including both behavioural and neurological measures to study effects of attention.The present finding provides further support for the idea that sensory input that is related to an individual's goal is prioritized by attention. Directing attention to a specific sensory modality might activate modality-specific features in working memory, and as such result in better detection of modality-congruent relative to modality-incongruent stimuli (Corbetta & Schulman, 2002; Legrain et al., 2009). Whether this prioritization of a sensory modality is reflected by facilitation of congruent information, inhibition of irrelevant information, or both (see, Forster & Eimer, 2005; Sinclair, Kuo, & Burton, 2000) cannot be determined from the present study, as the design did not contain uncued trials.

Of further interest, cueing a modality also affected response bias, indicating that participants used a less stringent criterion to report stimuli from the validly cued modality than to report stimuli from the invalidly cued modality, both in the presence and absence of actual sensory input. Apparently, cues not only affected perceptual sensitivity, but also altered decision criteria (Hawkins et al., 1990). This extends the findings from other studies that have already shown that the propensity to report the presence of single weak tactile stimuli in a somatosensory signal detection task is affected by attention (Lloyd, Mason, Brown, & Poliakoff, 2008; Mirams et al., 2012). Note that in those studies, only somatosensory signals had to be detected, as a result of which no conclusions can be drawn with regard to prioritization of one modality at the cost of other modalities.

A somewhat unexpected finding was the higher perceptual sensitivity and response bias for somatosensory compared to auditory stimuli. Such effect could be expected to occur rather in populations for whom the detection of bodily sensations is relevant for their current concerns or who are preoccupied with bodily cues because they perceive them as signalling potential physical harm, such as in patients with chronic pain (Crombez et al., 2005), than in healthy volunteers. However, there may be several ways to explain this finding. First of all, the thermode for admistering the somatosensory stimuli was moved between

blocks of trials in order to reduce habituation or sensitization effects. This procedure could have made somatosensory stimulation more salient than auditory stimulation. Indeed, after the experiment, the participants reported that they perceived the somatosensory stimuli as being more intense as compared to the auditory stimuli. Second, although participants did not report to attend more to thermal stimuli than to auditory stimuli, their belief in the predictive value of the somatosensory cue was stronger than in the predictive value of the auditory cue. Thirdly, it has been reported that, in modality cueing tasks, healthy persons have more difficulty shifting attention away from the somatosensory modality than from other modalities (Spence, Nicholls et al., 2001; Spence, Shore et al., 2001), which might also explain our findings. Interestingly, Anema, de Haan, Gebuis, and Dijkerman (2012), investigating the effect of tactile and auditory imagery on tactile and auditory information processing, also observed that the processing of tactile as compared to auditory stimuli was facilitated. The authors explained this effect by the spatial and somatotopic proximity of the location of the tactile targets (i.e., the fingers) as opposed to the auditory targets (i.e., the ears) and the body part by which participants needed to respond (i.e., the thumb). However, as in our study the somatosensory target was administered on the left arm and participants made a (non-speeded) response with their right hand, this is not likely to explain our findings. Fourth, the fact that participants' arms were placed upon the table, and as such visible, might have contributed to the facilitated processing of the somatosensory information as compared to the auditory information. Providing visual information has namely been shown to improve the processing of tactile information (Gillmeister & Forster, 2010; Press, Taylor-Clarke, Kennett, & Haggard, 2004). A final explanation for this effect can be found in the high percentage of female participants taking part in this study. There is some evidence that women report bodily symptoms more frequent than men (Barsky, Peekna, & Borus, 2001; Kroenke & Spitzer, 1998). This might limit the generalizability of the findings.

Three further issues should be mentioned. First, the negative values of the response bias measure (see also Brown, Brunt, Poliakoff, & Lloyd, 2010, Lloyd et al., 2008) suggest that participants overall had a stringent response strategy, i.e., they were rather conservative in reporting the presence of a stimulus. This might be due to the fact that the intensity of the stimuli was very weak, and participants

were instructed to be as accurate as possible. Second, because the auditory and the somatosensory stimuli were administered at different locations in space (thermal stimuli on left arm vs. auditory stimuli through headphones), our cueing procedure may have prioritized attention not only to the valid modality, but also to the spatial location associated with this modality (Spence & Driver, 1997; Spence, Nicholls et al., 2001). Although a similar overlap in mechanisms may occur in a typically naturalistic environment, like a patient with chronic low back pain who is preoccupied with somatosensory cues especially in the region of the back, future research might attempt to disentangle modality-related and location-related attentional prioritization (e.g., Turatto, Galfano, Bridgeman, & Umiltà, 2004). Third, a more sophisticated up/down staircase (Cornsweet, 1962; Levitt, 1971) may be a more suitable method to accurately determine perceptual threshold. However, it is likely that individual differences in sensitivity are nevertheless ruled out to a certain degree by means of the currently used staircase procedure. The results of the current study demonstrate that the paradigm used here is suitable for measuring differences in attentional focus. As such, this paradigm might be a promising tool to study the effects of preoccupation with bodily sensations on both perceptual and response biases in various non-clinical and clinical samples such as chronic pain patients (Crombez et al., 2005; Peters et al., 2000), patients with panic disorder (Schmidt, Lerew, & Trakowski, 1997), heart disease (Karsdorp, Kindt, Everaerd, & Mulder, 2007), or chronic itch (Van Laarhoven et al., 2010). For example, it can be expected that a strong attentional focus for bodily sensations might be reflected in a higher perceptual bias for somatosensory stimuli than for auditory stimuli in these clinical groups as compared to a control group without this condition. Moreover, as many clinical populations are characterized by psychomotor slowing and accordingly to slower RTs and increased RT variability (e.g., Veldhuijzen et al., 2012), this signal detection approach might be more reliable than traditional reaction time paradigms (Van Damme et al., 2008).

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3

SPATIAL ATTENTION MODULATES TACTILE CHANGE DETECTION[1]

ABSTRACT

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

[1]Van Hulle, L., Van Damme, S., Spence, C., Crombez, G., & Gallace, A. (2013). Spatial attention modulates tactile change detection. *Experimental Brain Research, 224*, 295-302.

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, Alisharan, Hu, & Gross, 2002). A remarkable observation is that even when tactile information is changing (thus becoming potentially relevant) we can still be unaware of it (Gallace & Spence, 2008). Empirical support for this notion mainly comes from research using a tactile change detection paradigm (Gallace, Auvray, Tan, & Spence, 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 & Levin, 1997; Triesch, Ballard, Hayhoe, & Sullivan, 2003) and auditory (e.g., Demany, Semal, & Pressnitzer, 2011) modality, has been referred to as “tactile change blindness” (Gallace et al., 2006a; Gallace, Tan, & Spence, 2007; Pritchett, Gallace, & Spence, 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, Crawley, Mikulis, and Davis (2000), brain regions responsive to stimulus change included unimodal areas such as the visual, auditory, and somatosensory cortices, as well as multimodally-responsive areas, comprising a right-lateralized network consisting of the temporoparietal junction, inferior frontal gyrus, insula, and the supplementary motor areas.

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

The main aim of the present study was to investigate whether focusing attention on one particular bodily location improves tactile change detection at that location in healthy volunteers. There are two reasons why one might expect that attention would affect performance in a tactile change detection task. First, in a typical tactile change detection task, attention needs to be divided between multiple locations. It is likely that in the limited time period that the tactile patterns are activated (typically for not longer than 200ms), not all of the stimulated locations can enter the focus of a participant's attention (see Gallace, Tan, & Spence, 2006c; Johansen-Berg & Lloyd, 2000; Lakatos & Shepard, 1997), thus making it difficult for participants to judge whether or not the two tactile patterns differed. Indeed, tactile information is likely to be processed serially, as research has shown that subitizing (i.e., an enumeration process in which a small number of items are processed rapidly, accurately, and pre-attentively; Mandler & Shebo, 1982) does not occur in the tactile modality (Gallace, Tan, & Spence, 2006b; but see Riggs et al., 2006). Second, research has demonstrated that focusing attention on a specific body location results in enhanced processing of tactile stimuli presented at that location as compared to an unattended location (Spence & Gallace, 2007; Spence & Parise, 2010; Yates & Nicholls, 2009, 2011). Tactile attention is thought to affect processing in the somatosensory cortex through

amplification of responses to relevant stimulus features and suppression of responses to irrelevant features (Burton et al., 1999; Forster & Eimer, 2005; Johansen-Berg & Lloyd, 2000; Jones, Pritchett, Stufflebeam, Hämäläinen, & Moore, 2007; Sambo & Forster, 2011).

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

METHODS

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.

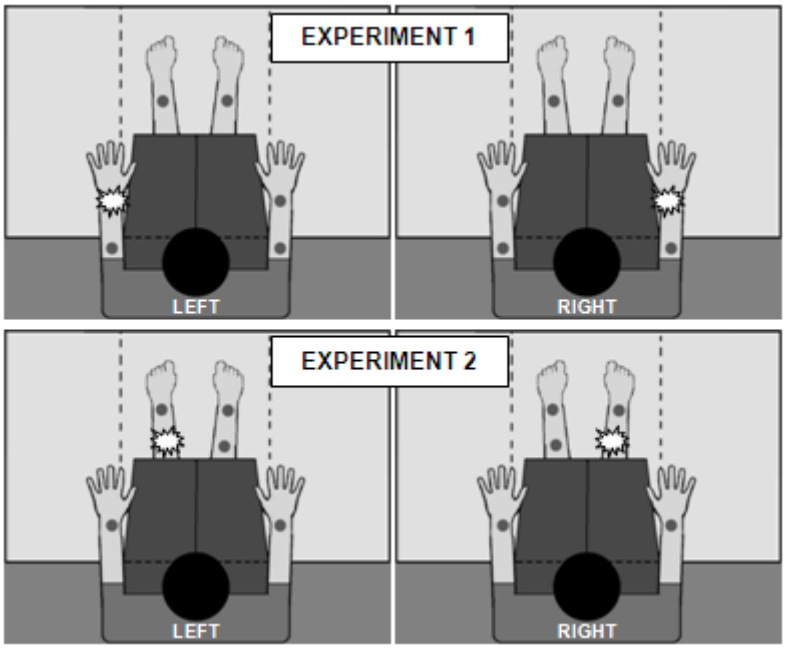

Figure 1. An illustration of the different tactor locations used in Experiments 1 and 2. During the experiment, these illustrations acted as cues representing the location at which a change was most likely to occur.

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 tactor 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.

Table 1

Means, standard deviations, and ranges of stimulus intensities (power, in watts) of the tactors positioned on different body sites. Stimulus intensities were mathematically derived from the self-developed software program to control the tactors.

	Experiment 1			
	Left		Right	
	M (*SD*)	Range	*M* (*SD*)	Range
Forearm	0.05 (0.04)	0.01-0.11	0.06 (0.05)	0.01-0.15
Upper arm	0.10 (0.06)	0.01-0.27	0.08 (0.04)	0.01-0.15
Above ankle	0.10 (0.03)	0.04-015	0.12 (0.03)	0.07-0.15
	Experiment 2			
	Left		Right	
	M (*SD*)	Range	*M* (*SD*)	Range
Forearm	0.04 (0.01)	0.02-0.07	0.04 (0.01)	0.02-0.07
Above ankle	0.11 (0.04)	0.04-0.21	0.11 (0.04)	0.05-0.21
Below knee	0.11 (0.04)	0.07-0.23	0.11 (0.04)	0.07-0.23

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 500 ms. Next, the first stimulus pattern was presented for 200 ms, followed by an empty stimulus interval of 110 ms, after which the second stimulus pattern was presented for 200 ms. 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 tactors that were active during the first pattern was inactive during the second pattern, and a tactor 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 2500 ms response time, and it was stressed that accuracy, rather than speed, was of importance.

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 ‘change’ trials, and 12 invalid ‘change’ trials).

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, Hedges, Higgins, & Rothstein, 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).

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).

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

directing attention to a specific location improves the detection of changes at that location.

Another interesting question following on from this concerns what might happen if attention is directed towards one side of the body instead of towards a specific location. One could argue that this particular side of the body might become an active feature in the attentional set, resulting in better performance for detecting pattern changes that involve this body side. Alternatively, if there are multiple possible stimulus locations within this body side, this might again result in competition between different spatial locations (Johansen-Berg & Lloyd, 2000), which might then lead to a decreased performance when trying to detect pattern changes involving this body side as compared to a situation in which there is no attentional competition. Moreover, as there are indications that in some clinical populations the altered processing of tactile information is not linked to the specific body part itself but rather to the location of this body part (Moseley, Gallace, & Spence, 2009, Moseley, Gallace, & Spence, 2012), it might be especially interesting to investigate whether heightened sensitivity for detecting changes in tactile information might be best understood within a somatotopic or rather a spatial frame of reference. Future research will help to provide a better insight into this topic.

A number of issues with regard to this study deserve further discussion. First, one could raise the issue that the attention manipulation used in our experiment might have resulted in participants using a strategy of only attending to the presence or absence of a stimulus at the indicated location, making this a signal detection task rather than a change detection task. Other studies have already suggested that the propensity to report the presence of single weak tactile stimuli in a somatic signal detection task is affected by attention (Lloyd, Mason, Brown, & Poliakoff, 2008; Mirams, Poliakoff, Brown, & Lloyd, 2012). However, the participants in the present study were clearly instructed to detect changes between the two tactile patterns. Our results confirmed that they indeed followed these instructions properly as even in the invalid trials, participants were still able to correctly respond on 61% of these trials. We can therefore conclude that the task is not simply a signal detection task in which the presence versus absence of a tactile stimulus at the cued location has to be detected in a situation with simultaneous distractors. Second, the current experiment consisted of valid trials,

in which attention was directed to the location of change, and invalid trials, in which attention was directed away from the location of change. There were, however, no 'neutral' trials (e.g., a block type in which no information was provided concerning the location of the pattern changes) in which attention was equally divided between all body locations. As such, the current study cannot clarify whether the difference between valid and invalid trials is due to a benefit from correctly directing spatial attention to the indicated location, or to a cost from incorrectly directing spatial attention to the indicated location. Using both RTs and event-related potentials, Forster and Eimer (2005) investigated the mechanisms underlying tactile spatial attention. They showed that costs were found to be larger than benefits. Based upon these findings, one might rather expect a cost for detecting invalid changes more than a benefit for detecting valid changes. Further research will, however, be needed in order to clarify this matter. Third, it is worth pointing out that the typical tactile change detection task only allows one to measure sensitivity for the detection of changes in pattern locations. Future research may consider using alternative approaches in which sensitivity for changes in the nature of a tactile stimulus (such as its intensity or frequency) could be assessed.

The current study is the first to demonstrate that focusing attention on a specific region of the body improves tactile change detection in that region. This experimental paradigm may be useful for investigating excessive attentional focus or hypervigilance to particular regions of the body in various clinical populations. One particular benefit of the current paradigm involves the focus on accuracy rather than RTs. It has been demonstrated that certain clinical populations such as chronic pain patients are characterized by cognitive dysfunction and psychomotor slowing (e.g., Dick, Eccleston, & Crombez, 2002; Glass, 2009; Veldhuijzen, Sondaal, & Oosterman, 2012). Because this may lead to slower RTs and increased RT variability, paradigms relying on response speed may prove less reliable in these populations (Van Damme, Crombez, & Notebaert, 2008). There are some studies (e.g., Brown, Brunt, Poliakoff, & Lloyd, 2010) that have used tactile paradigms in order to investigate illusory touch experiences in persons with somatoform symptoms, showing that these persons have a tendency to erroneously report tactile signals. Our approach, on the other hand, was specifically developed to investigate the intriguing – but largely unexplored idea –

of an excessive attentional focus or hypervigilance to particular regions of the body in various clinical populations such as patients with lower back pain (Crombez et al., 2005; Moseley, Gallace et al., 2012) or chronic itch (Van Laarhoven, Kraaimaat, Wilder-Smith, & Evers, 2010). Specific hypotheses can be tested when using this paradigm in clinical populations. Change detection performance on one body location that is relevant (or threatening) to the condition of a patient can be compared to change detection performance on irrelevant body locations, with increased attentional processing being reflected in a higher detection performance for changes involving the relevant location. When applying the change detection paradigm to a group of patients with lower back pain, for example, one might expect them to be more accurate in detecting pattern changes that involve the back location as compared to pattern changes that involve other bodily locations - if they are indeed more attentive to the back region (Crombez, Vervaet, Lysens, Baeyens, & Eelen,1998; but, see Moseley, Gallagher, & Gallace, 2012).

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4

ATTENTION MODULATES SENSORY SUPPRESSION DURING BACK MOVEMENTS[1]

ABSTRACT

Tactile perception is often impaired during movement. The present study investigated whether such sensory suppression also occurs during back movements, and whether this would be modulated by attention. In two tactile detection experiments, participants simultaneously engaged in a movement task, in which they executed a back-bending movement, and a perceptual task, consisting of the detection of subtle tactile stimuli administered to their upper or lower back. The focus of participants' attention was manipulated by raising the probability that one of the back locations would be stimulated. The results revealed that tactile detection was suppressed during the execution of the back movements. Furthermore, the results of Experiment 2 revealed that when the stimulus was always presented to the attended location, tactile suppression was substantially reduced, suggesting that sensory suppression can be modulated by top-down attentional processes. The potential of this paradigm for studying tactile information processing in clinical populations is discussed.

[1] Van Hulle, L., Juravle, G., Spence, C., Crombez, G., & Van Damme, S. (2013). Attention modulates sensory suppression during back movements. *Consciousness and Cognition, 22*, 420-429.

INTRODUCTION

Bending over to lift your shopping or reaching forward in order to grasp the television remote control are but two examples highlighting the fact that back movements are part of everyday life and are involved in many functional behaviours. In order to make sure that these movements are adequately accomplished and are not constantly interrupted by stimuli that we may become aware of, the mass of sensory information (e.g., tactile, proprioceptive) that is associated with the execution of such movements has to be selectively filtered (Bays & Wolpert, 2007; Gallace, Zeeden, Röder, & Spence, 2010). Relevant here is the finding that the detection of subtle, near-threshold tactile stimuli is impaired during the execution of movement, a phenomenon that has been referred to as sensory suppression (Chapman & Beauchamp, 2006; Juravle, Deubel, & Spence, 2011; Juravle, Deubel, Tan, & Spence, 2010; Juravle & Spence, 2011; Voss, Ingram, Wolpert, & Haggard, 2008; Wasaka, Hoshiyama, Nakata, Nishihira, & Kakigi, 2003; Williams, Shenesa, & Chapman, 1998). The suppression of tactile information seems to be related to the movement of the specific body part where the stimulation happens to be delivered. Previous studies have shown that the effect of sensory suppression decreases as the distance between the site of stimulation and the site of movement increases (Williams et al., 1998; Post, Zompa, & Chapman, 1994). The phenomenon of sensory suppression can be explained both by feed-forward motor signals that predict and modulate the activity evoked by incoming sensory signals, and by re-afferent sensations resulting from body movements, leading to backward masking (for a detailed discussion, see Chapman & Beauchamp, 2006; Voss et al., 2008).

Even though sensory suppression appears to serve the goal of efficient movement execution (Bays & Wolpert, 2007; Gallace et al., 2010), it remains important that this sensory suppression is not absolute, and that the movement can be interrupted by more important demands or goals. Interruption may occur as a result of the bottom-up selection of salient information, such as highly intense or unexpected stimuli (Chapman & Beauchamp, 2006; Coulter, 1976; Williams et al., 1998), but also in a more top-down fashion as, for example, when a stimulus is considered as relevant or informative for a current goal or concern. Stimulus features that are related to an individual's objectives are assumed to receive more

attention (Corbetta & Shulman, 2002; Folk, Remington, & Johnston, 1992; Yantis, 1998).

In a recent study reported by Juravle et al. (2011), the participants had to move one arm in order to grasp an object, while keeping their other arm still. During this movement, the participants received a tactile stimulus to either their moving or stationary hand and were instructed to detect its presence. As expected, tactile reaction times (RTs) were slower for stimuli delivered to the moving hand as compared to those stimuli delivered to the stationary hand. Interestingly, though, when the probability that stimulation would be administered to either the moving or stationary hand was raised, tactile RTs were correspondingly shorter, thus suggesting that attention can modulate tactile perception.

Thus far, studies on sensory suppression have mostly been documented in the context of the movement of the fingers (e.g., Chapman & Beauchamp, 2006; Wasaka et al., 2003; Williams et al., 1998; Williams & Chapman, 2000, 2002) or the arms (e.g., Chapman & Beauchamp, 2006; Gallace et al., 2010; Juravle et al., 2010, 2011; Juravle & Spence, 2011). The present study was designed to address the question of whether sensory suppression also occurs during movements involving the back, and further to investigate whether this can be modulated in a top-down manner by attention. Indeed, although one might well expect similar findings as in previous work (see Juravle et al., 2011), it has to be noted that there might be differences between the processing of sensory information in the region of the back as compared to the front of the body. For example, there is usually no visual information available in the region around our back and, as such, vision typically does not provide additional information about the location from which tactile stimuli have been presented. Indeed, providing visual information has, on occasion, been shown to improve the processing of tactile information (Gillmeister & Forster, 2010; Kóbor, Füredi, Kovács, Spence, & Vidnyánzky, 2006; Press, Taylor-Clarke, Kennett, & Haggard, 2004). Moreover, Tipper et al. (2001) reported that the additive effect of vision was larger when viewing more familiar body parts (e.g., the face) as compared to viewing less familiar (e.g., the neck or back) non-directly visible body sites. One might therefore expect that participants would be less sensitive in terms of detecting stimuli presented to the back, as they are not so familiar with being stimulated in this region. On the other hand, a study reported

by Weinstein (1968), measuring tactile sensitivity for different body parts by means of point localization, two-point discrimination, and pressure sensitivity, suggested that the back is clearly less sensitive than regions such as the head and the fingers, but more or less equally sensitive as compared to other body regions (e.g., the limbs). It is well-known that the cortical representation of the back is smaller as compared to more innervated regions like the fingers or the face (Banich, 2004). With regard to attentional processing in the space around the back, one study (Gillmeister & Forster, 2012) suggested that attentional processes may affect tactile information processing not only in the front but also in the back space of the body. It should, however, be noted that in this study, the tactile stimuli were applied to the hands, which were held behind the back, and not to the back itself.

We are especially interested in sensory suppression during back movements due to its potential clinical relevance. It is well-known that low back pain patients are typically concerned about pain and injury during activities that involve back strain, and report being over-attentive to pain and even non-painful sensations in their back (Crombez, Vervaet, Lysens, Baeyens, & Eelen, 1998). This fearful anticipation might be expected to lead to a stronger focusing of their attention (i.e., hypervigilance) to the region of the back, especially during back movements, in order to rapidly detect signals of potential harm (Crombez, Van Damme, & Eccleston, 2005; Legrain et al., 2009; Van Damme, Legrain, Vogt, & Crombez, 2010; Vlaeyen & Linton, 2000). Accordingly, low intensity somatosensory input presented to the back may be processed more thoroughly as compared to individuals without this condition. As yet, however, this has not been investigated by means of a valid experimental paradigm (Van Damme et al., 2010). We consider our study as a first step in developing such a paradigm.

Two tactile detection experiments are presented in which the perception of tactile information at rest and while performing back-bending movements are investigated. Tactile stimuli could be delivered to either the lower or upper back, as such creating a situation in which attention had to be divided between multiple stimulus locations. The focus of participants' attention was manipulated by means of raising the probability that either the upper or the lower back would be stimulated. First, in line with previous research, tactile perception was hypothesized to be suppressed during the execution of back movements. Second,

it was also hypothesized that the suppression of tactile stimulation during movement would be reduced when a participant's attention was manipulated toward the stimulated location.

EXPERIMENT 1

Methods

Participants

Twelve participants (10 females, 2 males; mean age = 24 years, age range 18-35 years), both students and PhD students from the Psychology Department who had no previous knowledge about the experiment, received a £5 voucher in return for taking part in the experiment. The study was conducted in accordance with the Declaration of Helsinki. All participants gave informed consent and were free to terminate the experiment at any time. They all reported normal tactile perception (absence of nerve damage or injuries) at those locations where the tactile stimuli would be delivered, and reported no history of back pain problems. All data were considered appropriate for further statistical analyses.

Apparatus and materials

Two computer mice (the *start* mice) were affixed to the surface of the table in front of the participant, at a distance of 50 cm from two other mice (the *goal* mice) that were placed on the other side of the table (see Figure 1). The participants were seated so that their arms were stretched when holding the start mice. This meant that the participants always had to make a back-bending movement whenever they reached for the goal mice. Tactors (VBW32 skin stimulators, 1.6 x 2.4cm vibrating surface, Audiological Engineering Corp., Somerville, MA, USA) were attached with tape to both the lower (lumbar curve, ± L4) and the upper back (upper thoracic curve, ± T2) of the participant. The participants wore a pair of headphones for the duration of the experiment in order to reduce the possibility that they would hear the operation of the tactors (Beyer Dynamic DT 531). The tactors were controlled by means of a custom-built tactor box connected to the main computer (Dell Technologies) and interfaced through Matlab (Psychophysics Toolbox 3; Brainard, 1997; Pelli, 1997) on Windows XP.

Auditory stimuli (start signal, 100 ms, 800 Hz; stop signal, 50 ms, 400 Hz) were delivered by means of two loudspeakers, placed on both sides of the table, and could be clearly perceived by the participants despite wearing headphones. Participants responded by means of two foot pedals connected to the computer.

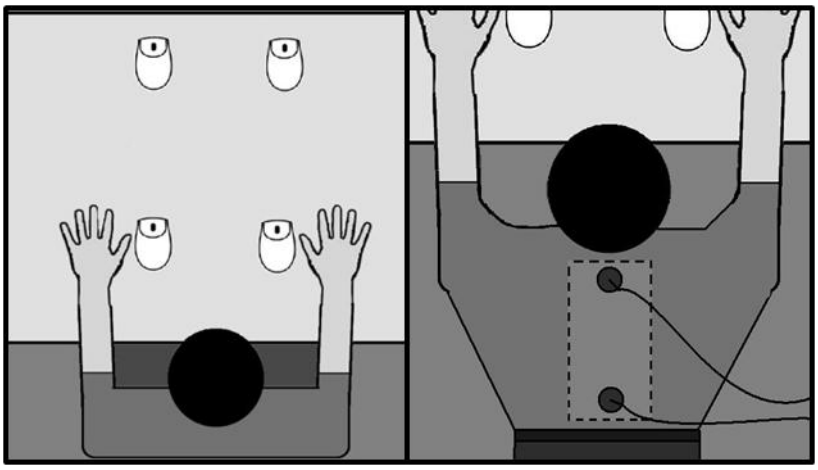

Figure 1. Representation of experimental set-up and stimulus locations used in Experiment 1. The participant is depicted with both hands next to the starting mice.

Task

In this dual-task paradigm, the participants simultaneously engaged in a movement task and a perceptual task. The *movement* task consisted of moving both hands from the start mice toward the goal mice (see Figure 1). More specifically, a trial started when the participant pressed the fingers of both hands on the buttons of the start mice. Immediately thereafter, a start signal indicated that the reach-to-grasp movement had to be initiated. When grasping the goal mice, the participants also needed to press them with both hands. Successful accomplishment of the task was indicated by a stop signal. In the rest condition, in which no back movement was required, the participants kept their hands at rest on top of the start mice. Each trial started with a start signal, which was followed, 600-900 ms later, by the stop signal. The *perceptual* task consisted of an unspeeded detection of subtle tactile stimuli administered on either the upper or lower back. In half of the trials, a tactile stimulus (11 dB, 250 Hz, 2 ms) was presented (*signal trials*), whereas, in the remainder of the trials, no stimulus was presented (*noise*

trials). The intensity of the tactile stimulus was tested prior to the experiment. For this purpose, two collaborators performed a number of trials of the movement/perceptual task with different stimulus intensities. A stimulus intensity was chosen that could be perceived not only during rest but also during movement. The participants were instructed to indicate whether they felt a stimulus by pressing their left (right) foot down on a foot pedal when the signal was present (absent). Response assignments were counterbalanced across participants. The stimuli could be presented either during the preparation phase of the movement (10 – 100 ms following the start signal) or during its' execution phase (300 – 600 ms after the start signal). In order to reduce expectancy effects, stimuli were randomly delivered within these time windows and could be delivered with equal probability either during the preparation or execution stage of the movement (e.g., a stimulus could presented at 10, 11, …, 100 ms during the preparation phase or at 300, 301, …, 600 ms during the execution phase). In the rest condition, tactile stimuli were delivered at the same points in time.

Design

The experimental design was blocked with six experimental conditions[2] each consisting of 64 trials: Movement (rest, movement) x Attention (divided, focused-up, focused-low). The order of the blocks was counterbalanced across participants. In half of the blocks, the participants only had to perform the perceptual task (*rest*). In the other half of the blocks, the participants executed both the perceptual and movement tasks (*movement*). In order to manipulate attention to a specific body site, there were three different block types. In one block type (*divided*), the stimuli were in 50% of the signal trials delivered to the upper/lower back. In the second block type (*focused-up*), the stimuli were in 75% of the signal trials presented to the upper back and in 25% delivered to the lower back. In a third block type (*focused-low*), the stimuli were presented to the lower back in 75% of the signal trials and in 25% of trials to the upper back. The

[2] For the purpose of this study, the location of the stimulation (upper or lower back) and the timing of the stimulation (preparation or execution phase) were not analyzed as separate experimental conditions. However, other studies have demonstrated that movement execution causes sensory suppression during both movement preparation and execution phases (Juravle et al., 2011; Williams et al., 1998).

participants were informed about the proportion of stimuli that would be presented to the lower or upper back within each block. The experimental session took between 60 and 75 minutes to complete.

Data analysis

Signal detection theory was used in order to calculate the hit and false alarm rates; which further allowed differentiation between perceptual sensitivity and response bias (Macmillan & Creelman, 2005; Stanislaw & Todorov, 1999; Wickens, 2002). A signal trial was defined as a trial in which a tactile stimulus was delivered, whereas a noise trial was defined as a trial in which no tactile stimulus was delivered. The hit rates (*H*) and false alarm rates (*F*) were computed for each experimental condition (for an overview of the calculations, see Appendix). As a measure of perceptual sensitivity, *A'* was calculated for each experimental condition, by using the following equation:

$$A' = 0.5 + [sign(H-F)(H-F)^2+|H-F|] / [4max(H,F)-4HF] \quad (1)$$

Values of *A'* range between zero and one, with values of 0.5 or above indicating that perceptual sensitivity exceeds chance level, thus showing that participants were able to distinguish signals from noise. As a measure of response bias, *c* was calculated for each experimental condition, by using the following equation:

$$c = -(\Phi^{-1}(H)+ \Phi^{-1}(F))/2 \quad [3] \quad (2)$$

In this study, the sign of *c* was reversed in order to simplify its interpretation. Therefore, a value of zero here indicates no response bias, a positive value indicates a bias toward 'yes'-responses (i.e., a bias to respond that a signal was present), and a negative value a bias toward 'no'-responses (i.e., a bias to

[3] *Φ* represents the 'phi' score used to convert *z* scores into probabilities.

respond that no signal had been presented)[4]. For ease of comparison with the divided attention condition, the data of the focus-up and focus-low condition were merged (*focused*).

The data were analyzed using repeated measures Analyses of Variance (ANOVAs). 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) formula (as cited in Borenstein, Hedges, Higgins, & Rothstein, 2009). 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).

Results

Perceptual sensitivity

Overall, perceptual sensitivity measures differed significantly from chance level, indicating that the participants were able to distinguish the signal from the noise. The means and standard deviations, and one-sample *t*-tests are presented in Table 1. A separate comparison of the focused-up or focused-low condition with the divided condition cannot be interpreted, as no distinction could be made for stimuli delivered at the upper vs. lower back in the divided attention condition. A repeated measures ANOVA was performed with Attention (divided, focused) and Movement (rest, movement) as independent variables, and perceptual sensitivity as the dependent variable. There was a main effect of Movement (($F(1,11) = 22.58$, $p = .001$); $d = 0.98$, 95% CI [0.48, 1.47]), revealing a decreased perceptual sensitivity for detecting tactile stimulation in the movement condition ($M = 0.84$, $SD = 0.11$), as compared to the rest condition ($M = 0.97$, $SD = 0.02$). There was no main effect of Attention ($F(1,11) < 1$, *ns*; $d = 0.00$, 95% CI [-0.28, 0.28]), indicating

[4] No sensitivity and response bias measures can be calculated for the location (or the timing of the stimulation) separately. More specifically, when a stimulus is present, a distinction can be made between stimuli delivered to the upper or the lower back (or during the preparation or execution phase) and a hit rate can be calculated. However, when no stimulus is present, no such distinction can be made regarding the upper and lower back (or the preparation or execution phase) in order to calculate separate false alarm rates.

that perceptual sensitivity did not differ significantly when attention was divided between the two body locations (*M* = 0.91, *SD* = 0.06) as compared to when attention was focused on the location where the stimulation was most likely to be delivered (*M* = 0.91, *SD* = 0.07). The Attention x Movement interaction also failed to reach statistical significance (*F*(1,11) = 1.00, *p* = .34). See Figure 2 for a graphical representation of the data.

Table 1

Hit (H) and false alarm (F) rates for each condition together with means and standard deviations for perceptual sensitivity (A') and response bias (c) in Experiment 1. One sample t-tests were used to assess whether perceptual sensitivity exceeded chance level (A > 0.50) and whether there was any indication of response bias (c ≠ 0).

	A'				*c*				*H*	*FA*
	M	*SD*	*t*(11)	*p*	*M*	*SD*	*t*(11)	*p*		
Rest Divided	0.96	0.04	37.82	.00	-0.23	0.33	2.43	.03	.90	.02
Movement Divided	0.85	0.10	12.25	.00	-0.77	0.57	4.68	.001	.60	.05
Rest Focused	0.98	0.01	118.74	.00	-0.15	0.24	2.19	.05	.95	.02
Movement Focused	0.83	0.14	8.38	.00	-0.75	0.70	3.90	.002	.58	.07

Response bias

One sample *t*-tests revealed that all but one of the measures of response bias was significantly different from zero. The negative values indicated that overall participants were conservative in reporting the presence of a stimulus. The means and standard deviations, and one-sample *t*-tests are presented in Table 1. A repeated measures ANOVA was performed with Attention (divided, focused) and Movement (rest, movement) as independent variables and response bias (*c*) as the dependent variable. There was a main effect of Movement (*F*(1,11) = 18.84, *p* = .001; *d* = 1.12, 95% CI [0.48, 1.75]), indicating that participants were more inclined to report the presence of a stimulus in the rest condition (*M* = -0.19, *SD* = 0.26) than in the movement condition (*M* = -0.76, *SD* = 0.56). There was no main effect of Attention (*F*(1,11) < 1, *ns*; *d* = 0.03, 95% CI [-0.35, 0.40]), indicating that

participants were no more inclined to report the presence of a stimulus in the focused attention condition (*M* = -0.45, *SD* = 0.42) than in the divided attention condition (*M* = -0.44, *SD* = 0.34), nor was there a significant Attention x Movement interaction effect ($F(1,11) < 1$).

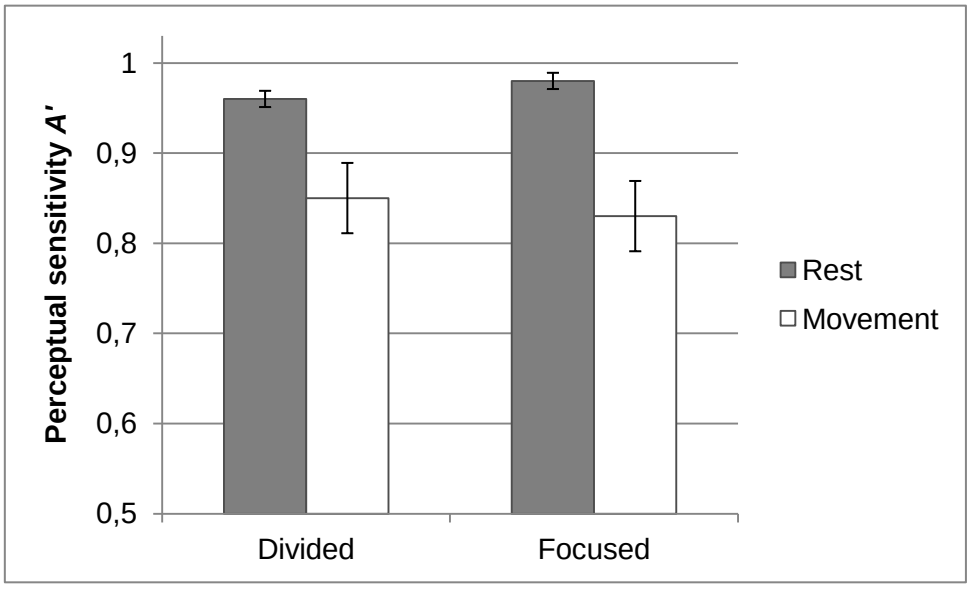

Figure 2. Perceptual sensitivity measures (*A'*) depending on Movement and Attention in Experiment 1. Vertical error bars represent the standard errors of the mean.

Interim Discussion

The present results clearly demonstrate that the detection of tactile information is suppressed while participants perform a back movement as compared to rest. These results therefore extend the findings from previous research that has investigated the processing of tactile information during hand or arm movements (e.g., Gallace et al., 2010; Juravle et al., 2010, 2011; Wasaka et al., 2003; Williams et al., 1998; Williams & Chapman, 2000, 2002). There was, however, no effect of the attention manipulation. With their attention divided between the two locations, participants performed equally well as compared to when they were instructed to focus their attention on a specific location. This result might be explained by the fact that in the focused attention condition, there was also a 25% chance of receiving a stimulus at the other location. This might have

led the participants to divide their attention between both locations in the 'focused attention' condition as well. Therefore, in Experiment 2, a stronger attentional manipulation was used. In the focused attention condition, all (i.e., 100%) of the stimuli were delivered to one location, i.e., either the upper or the lower back. In a control condition (divided attention), the probability of receiving tactile stimulation to the lower versus upper back was equalized.

It should be noted that the perceptual sensitivity of the participants was near ceiling in the rest condition. This might be the result of the particular stimulus intensity that was chosen. In order to examine the influence of attention on detection performance, participants would ideally need to show a 'medium' level of performance in the absence of any attentional manipulation. However, prior testing revealed that when a stimulus intensity was chosen that gave rise to an intermediate level of performance at rest, performance dropped to zero during movement. On the other hand, when a stimulus intensity was chosen that gave rise to an intermediate level of performance during movement, performance approached ceiling under conditions of rest. As we were especially interested in the influence of attention on stimulus detection during movement, the second option was preferred. In the pre-experimental phase of Experiment 2, we used a standard psychophysical procedure in order to improve the determination of the stimulus intensity for the experimental phase.

As in the first experiment, the participants were expected to have a higher perceptual sensitivity while at rest as compared to while performing a movement. In addition, it was expected that the participants would show better performance during movement when their attention was focused on one body location as compared to when their attention was divided equally between the upper and the lower back.

EXPERIMENT 2

Methods

Participants

Fourteen participants (13 females, 1 male; mean age = 26 years, age range 19-31 years), all students and PhD students from the Psychology Department who had no previous knowledge of the experiment, received a £5 voucher for taking

part in the study. The study was conducted in accordance with the Declaration of Helsinki. All of the participants gave their informed consent and were free to terminate the experiment at any time. The participants reported normal tactile perception (and the absence of nerve damage or injuries) at the locations where the tactile stimuli would be delivered, and reported no history of back pain problems. One participant was excluded from further analysis because of technical problems (no tactile stimuli were delivered during the experimental blocks).

Task and procedure

In a *pre-experimental phase*, the intensity of the tactile stimulation was determined at rest by means of an adaptive procedure comprising two different interleaved staircases for each of the two stimulation locations (upper or lower back). Each of the two staircases consisted of a one-up four-down adaptive procedure designed to keep performance at a level of 90% correct (Levitt, 1971). For the first trial, each of the two staircases started with an above threshold stimulation intensity (6 dB). The presentation of trials from each of the staircases was randomized throughout this pre-experimental phase. The participants were instructed to respond whenever they felt the presence of a stimulus. The staircase changed direction after one incorrect response (i.e., increasing the corresponding location stimulation by one step – 'UP') or a sequence of four correct responses (i.e., decreasing the corresponding location stimulation by one step – 'DOWN'). Changes in the direction of the staircase are referred to as 'reversals'. The pre-experimental phase required the participants to complete a maximum of 240 trials. After the completion of every 60 trials, the participants were informed by three consecutive beeps that the block had finished and that they could take a break if they so desired. During the breaks, the experimenter could monitor a progress bar presented on the screen behind their chair. This provided an estimate of the number of trials remaining, calculated on the basis of the total number of possible reversals (34). The experimenter pressed a key on the keyboard in order to continue on to the next block. The staircase for each stimulation location terminated once the total number of reversals (17) or the total number of trials (120) had been reached. The first five reversals were excluded from the final threshold calculations, which consisted of the average value of upward and

downward reversals. The average intensity was found to be the same for each location and for each individual (14 dB, 250 Hz). This intensity was then used for the experimental trials described next.

Both the perceptual and the movement task were similar to those used in Experiment 1. Only the attention manipulation differed slightly. The experimental design was blocked with six experimental conditions each consisting of 64 trials: Movement (movement vs. rest) x Attention (focused vs. divided). The order of the blocks was counterbalanced across participants. In half of the blocks, the participants executed both the perceptual and the movement tasks (*movement*). In the other half of the blocks, the participants only had to perform the perceptual task (*rest*). In order to manipulate attention to a specific body location, there were three different block types. In one block type, all (i.e., 100%) of the stimuli were presented to the participant's upper back (*focused-up*); in the second block type, all of the stimuli were presented to the participant's lower back (*focused-low*); and in a third block type, 50% of the stimuli were presented to the upper back and 50% to the lower back (*divided*). The participants were informed about the proportion of stimuli presented at the lower or the upper back within each block. Signal detection measures of perceptual sensitivity and response bias were computed (see, Section *2.1.5.*; for an overview of the calculations, see Appendix).

Results

Perceptual sensitivity

Overall, measures of perceptual sensitivity differed significantly from chance level, indicating that the participants were able to distinguish the signal from the noise. See Table 2 for means, standard deviations, and one-sample *t*-tests. A repeated measures ANOVA was performed with Attention (divided, focused) and Movement (rest, movement) as independent variables and perceptual sensitivity (*A'*) as the dependent variable. The analysis revealed a significant main effect of Movement ($F(1,12) = 36.80$, $p < .001$; $d = 2.24$, 95% CI [0.91, 3.57]), indicating that participants exhibited a lower perceptual sensitivity in the movement condition ($M = 0.70$, $SD = 0.12$) than in the rest condition ($M = 0.93$, $SD = 0.08$) than in the movement condition. There was also a significant main effect of Attention ($F(1,12) = 6.26$, $p = .03$; $d = 0.47$, 95% CI [0.04, 0.99]), with higher perceptual sensitivity

being observed when participants' attention was focused on the location of stimulation (*M* = 0.84, *SD* = 0.09) as compared to when it was divided between the two locations (*M* = 0.80, *SD* = 0.08). Of particular interest, the analysis revealed a significant Attention x Movement interaction ($F(1,12) = 6.03$, $p = .03$). To further explore this interaction, contrast analyses were carried out. These analyses revealed that, in the rest condition, perceptual sensitivity did not differ significantly when participants' attention was focused on the location where the stimuli would be administered as compared to when participants' attention was divided between the two body locations ($F(1,12) = 0.12$, $p = .74$; $d = 0.11$, 95% CI [-0.25, 0.49]). However, in the movement condition, perceptual sensitivity was significantly higher when participants' attention was focused on the location where the stimuli would be administered as compared to when their attention during movement was divided between the two body locations ($F(1,12) = 8.08$, $p = .02$; $d = 0.68$, 95% CI [0.21, 1.15]). See Figure 3 for a graphical representation of the data.

Table 2

Hit (H) and false alarm (F) rates for each condition together with means and standard deviations for perceptual sensitivity (A') and response bias (c) in Experiment 2. One sample t-tests were used to assess whether perceptual sensitivity exceeded chance level (A' > 0.50) and whether there was any indication of response bias (c ≠ 0).

	A'				*c*				*H*	*FA*
	M	*SD*	*t*(12)	*p*	*M*	*SD*	*t*(12)	*p*		
Rest Divided	0.93	0.08	18.56	<.001	-0.26	0.35	2.69	.02	.85	.06
Movement Divided	0.66	0.12	4.82	<.001	-0.94	0.60	5.68	<.001	.34	.13
Rest Focused	0.94	0.09	17.39	<.001	-0.23	0.33	2.49	.03	.86	.05
Movement Focused	0.75	0.14	6.23	<.001	-1.23	0.28	16.10	<.001	.33	.04

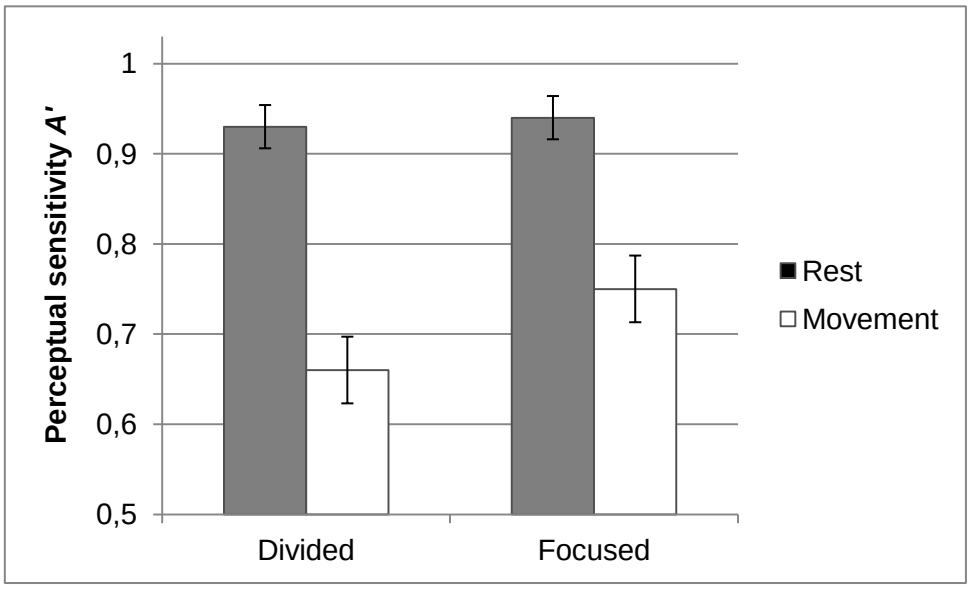

Figure 3. Perceptual sensitivity (*A'*) measures depending on Movement and Attention in Experiment 2. Vertical error bars represent the standard errors of the mean.

Response bias

One sample *t*-tests revealed that all response bias measures were significantly different from zero. The negative values indicated that, overall, participants were conservative in reporting the presence of a stimulus. See Table 2 for means, standard deviations, and the results of one-sample *t*-tests. A repeated measures ANOVA was performed with Attention (divided, focused) and Movement (rest, movement) as independent variables and response bias (*c*) as the dependent variable. There was a significant main effect of Movement ($F(1,12) = 55.17$, $p < .001$; $d = 2.61$, 95% CI [1.18, 4.04]), indicating that participants were more inclined to report the presence of a stimulus in the rest condition ($M = -0.24$, $SD = 0.27$) than in the movement condition ($M = -1.09$, $SD = 0.37$). There was no significant main effect of attention ($F(1,12) = 2.26$, $p = .16$; $d = 0.42$, 95% CI [-0.16, 1.01]), indicating that participants were no more inclined to report the presence of a stimulus when their attention was divided between two body locations ($M = -0.60$, $SD = 0.35$), as compared to when it was focused on one body site ($M = -.73$, $SD = 0.24$). The Attention x Movement interaction was not significant ($F(1,12) = 2.50$, $p = .14$).

GENERAL DISCUSSION

The aim of the present study was to investigate: (1) whether the performance of a back movement, i.e., bending over in order to grasp an object, leads to the sensory suppression of tactile perception on the back; and (2) whether attention modulates the processing of tactile information during the execution of a back movement. Two experiments were conducted in which participants were instructed to detect the presence of subtle tactile stimuli delivered to either their lower or upper back, while either performing a back-bending movement or while at rest. The focus of participants' attention was manipulated by informing them that the probability of stimulation of either the lower or the upper back would be raised during the upcoming experimental block.

First of all, it was expected that participants' perceptual sensitivity for the detection of tactile stimuli would be lower while they were simultaneously performing a back-bending movement as compared to rest. This hypothesis was confirmed by the results of both experiments. The findings clearly demonstrate a sensory suppression effect during the execution of the back movement. Our results extend the findings of previous research that has investigated the processing of tactile information during the movement of the hand or arm (e.g., Gallace et al., 2010; Juravle et al., 2010, 2011; Wasaka et al., 2003; Williams et al., 1998; Williams & Chapman, 2000, 2002), as sensory suppression also seems to play a role when performing a back-movement. Although there might be reasons to assume that the processing of sensory information in front and rear space may not be identical because, for example, no visual information is available for the region of the back (Gillmeister & Forster, 2010; Kóbor et al., 2006; Press et al., 2004; Tipper et al., 2001; but see Weinstein, 1968), it appears that the effect of sensory suppression was quite similar.

Furthermore, it was hypothesized that the suppression effect would be reduced when participants' attention was focused toward the stimulated location. This effect was not observed in Experiment 1, where the results revealed that participants performed equally well no matter whether their attention was divided between the two body locations or focused on a specific location. In Experiment 2, in which a stronger attentional manipulation was used, the results clearly demonstrated that participants were better able to detect the stimuli when their attention was focused on one body location as compared to when it was divided

equally between two body locations, but only when they were executing the movement. Thus, the suppression seemed to be counteracted by the effects of attention, presumably because attention increased perceptual sensitivity. Gillmeister and Forster (2012) already suggested that attentional processes may affect both the space in front as well as behind the body. Intriguingly, our findings suggest that the suppression mechanism described above might not only be regulated by bottom-up (or stimulus-driven), but also by top-down (or goal-driven) attentional processes. From an evolutionary perspective, it makes sense that it is not only highly intense or novel stimulation that captures our attention. It is widely accepted that the processing of sensory information results from an interaction between stimulus features and personal, or task, goals (Corbetta & Shulman, 2002; Folk et al., 1992; Legrain et al., 2009; Santangelo & Spence, 2008). It has been proposed that individuals adopt 'attentional control settings' including certain stimulus features or characteristics that are relevant for their goals and that will receive more attention if they are present in the environment (Yantis, 1998). In Experiment 2, the information that the tactile stimuli would only be delivered to the upper back might have activated the features 'tactile' and 'upper back' in the participants' attentional set, resulting in higher attention for that specific location. However, when participants were informed that the tactile stimuli could be delivered both at the upper and lower back, the location feature in their attentional set was defined less precisely and participants therefore needed to divide their attention between the two locations on their back. This may also explain why the attention manipulation used in Experiment 1, in which the location feature was also defined less precisely, did not result in higher perceptual sensitivity.

The results of both experiments revealed that the execution of a movement also affected response bias. When they did not have to perform any movement, participants were more inclined to report the presence of a tactile stimulus as compared to when they were executing the back movement. One explanation that has been proposed for the response bias is that the suppression phenomenon might involve a decision-based component (Juravle & Spence, 2011). Besides this, the fact that movement execution is accompanied by more noise (as compared to rest) might have led to an altered decision criterion (i.e., a conservative response strategy) because of a high level of uncertainty during the task. This was the case particularly because the importance of accuracy rather

than response speed was stressed before the experiment. The fact that the perceptual task was more difficult during movement might have resulted in participants having different expectations about the task during movement versus at rest. It has been suggested before that expectations might affect the response criterion used by participants (Summerfield & Egner, 2009).

It should be noted that there are some limitations with regard to the interpretation of the results of the present study. First, Juravle et al.'s study (2011), by utilizing the speed of response as a dependent variable, illustrated an additional effect of attention on the detection of tactile stimuli that were delivered to participants' stationary hand. In contrast, neither of the experiments described here demonstrate that attention increased participants' perceptual sensitivity while they were at rest. However, these results should be interpreted with caution. Participants' performance in the rest condition was very good, suggesting the presence of a ceiling effect. The interaction between the attention manipulation and the movement conditions in Experiment 2 might thus have resulted from the fact that the performance in the rest condition was too high to show any gains in the focused attention condition. Seemingly, the standard psychophysical procedure used in the pre-experimental phase of Experiment 2 did not get round the problem of ceiling effects. A more time-consuming procedure that might, however, avoid ceiling effects and, as such, make all potential effects of attention visible would be to determine stimulus intensities separately during movement and rest (see Juravle et al., 2010; Williams & Chapman, 2000) in a pre-experimental phase.

Second, it has been suggested previously that the simultaneous execution of two tasks may explain the deterioration in stimulus detection in sensory suppression experiments. Indeed, a rest-condition in which participants are given a dual task that doesn't require movement would make it possible to rule out this possibility. Available studies, however, have shown that decrements in detection performance during movement can only partly be explained by dual-task effects (Gallace et al., 2010; Williams & Chapman, 2000, 2002; Williams et al., 1998). Gallace and his colleagues (2010), for example, investigated tactile change detection performance in three conditions: a dual-task condition in which a verbal response was required, a dual-task condition in which a motor-response was required, and a single-task. The results revealed that a secondary task did indeed

diminish participants' sensitivity for the detection of change. However, the execution of a motor response resulted in a much larger drop in participants' change detection performance as compared to the verbal response condition. Future research might well be advised to try and avoid these two limitations by including, besides a movement condition, a rest condition in which participants have to make a movement that is irrelevant to the stimulus locations (e.g., eye movements). That way, both conditions would constitute dual task conditions, which makes it easy to interpret the results in terms of movement-related suppression. Furthermore, such a condition might eventually result in a lower detection performance in the rest condition and thus avoid ceiling effects.

Third, although one might suspect that the current study suffers from limited statistical power due to the relatively low number of participants tested, a closer look at the data of Experiment 2 for each participant separately revealed that for most participants, perceptual sensitivity during movement was higher when their attention was focused at the location of stimulation (9 out of 13 participants). Furthermore, this effect has a large effect size according to Cohen's (1988) norms. This underlines the robustness of the findings reported here.

In conclusion, the results of the two experiments reported here expand our understanding concerning the processing of tactile information during movement execution. More research is certainly needed before any firm conclusions can be drawn, but sensory suppression seems to be present in the execution of many body movements. Nevertheless, our results extend previous findings by showing that, in the back region just as elsewhere on the body surface, this mechanism is flexible as it allows modulation by top-down attentional processes. Furthermore, future research on sensory suppression could be expected to advance our knowledge on the processing of bodily sensations in certain clinical populations, such as those individuals suffering from chronic lower back pain. One particular benefit of this paradigm involves the focus on accuracy rather than RTs. As it been demonstrated that certain clinical populations such as chronic pain patients are characterized by cognitive dysfunction and psychomotor slowing (e.g., Dick, Eccleston, & Crombez, 2002; Glass, 2009; Veldhuijzen, Sondaal, & Oosterman, 2012), paradigms relying on response speed may prove less reliable in these populations (Van Damme, Crombez, & Notebaert, 2008). Multiple hypotheses can be specified when applying this paradigm in persons with chronic low back pain.

The hypervigilance hypothesis assumes that individuals with chronic low back pain spontaneously focus their attention on the region of the back, especially in situations that evoke bodily threat, such as the execution of a movement involving the back (Crombez et al., 2005; Vlaeyen & Linton, 2000). It is known that the presence of threat leads to the facilitated processing of threat-related information (Van Damme et al., 2010). When applying this paradigm – without an experimental manipulation of attention – to chronic low back pain patients, it might be expected that they will spontaneously focus attention to the back because back-related movements are threatening for them. As such, a better detection of tactile information during movement as compared to a control group without back pain could be expected. The paradigm is thus primarily intended to investigate the presence of hypervigilance, rather than reductions in pain experience during movement or physical activity as a result of distraction. Of course, other hypotheses can be specified. For example, it has been hypothesized that individuals with chronic low back pain might suffer from tactile dysfunction (e.g., Moseley, Gallagher, & Gallace, 2012), which might result in an overall decreased detection performance in this group as compared to a control group.

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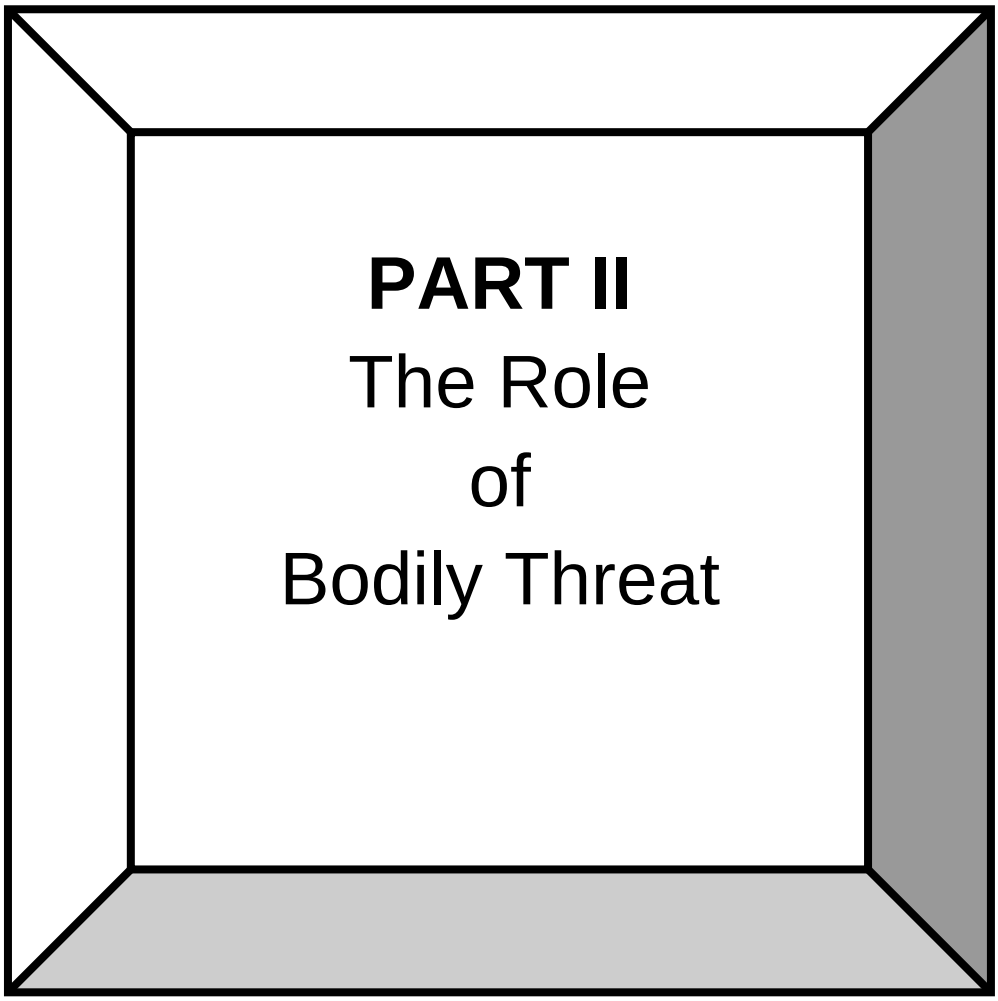
Appendix

Calculation of the hit (H) and false alarm (F) rates for each condition in both experiments. Where the hit rate was perfect (H = 1), or where there were no false alarms (F = 0), the proportions 1 and 0 were adjusted by 1/2N and 1/(1-2N) respectively (Juravle & Spence, 2011).

		H	*F*
Rest	Focused-up	# Correctly reported up-signals / # Up-signals	# Incorrectly reported signals / # Noise trials
	Focused-low	# Correctly reported low-signals / # Low-signals	# Incorrectly reported signals / # Noise trials
Movement	Divided	# Correctly reported signals / # Signals	# Incorrectly reported signals / # Noise trials


PART II
The Role
of
Bodily Threat

5

TACTILE CHANGE DETECTION IN A BODY REGION WHERE PAIN IS EXPECTED[1]

ABSTRACT

We investigated whether the threat of experimental pain on a specific body location facilitated the detection of tactile changes on that particular body location. Healthy participants (*N* = 47) engaged in a tactile change detection task in which they had to detect changes between two consecutively presented spatial patterns of tactile stimuli administered at different locations on the arms and legs. In half of the trials, the stimulated body sites in the two patterns were identical. In the other half of the trials, one of the stimulus locations differed between the two patterns. A painful stimulus was occasionally administered to one of the stimulus locations in order to experimentally induce pain anticipation at that location. We hypothesized that this would result in an attentional focus to the threatened body location, and consequently would lead to a better detection of tactile changes occurring at that location. The results showed that changes were detected better if they involved the threat location as compared to locations at other body parts, but not as compared to another location at the same body part. Tactile changes occurring not involving the threat location, but involving another location at the same body part, were also detected better than tactile changes at other body parts. The findings suggest that pain anticipation resulted in a higher awareness of tactile changes not only at the threatened location, but by extension at the whole body part on which pain was expected. Future research will need to validate these results and further investigate the scope of the attentional processing of tactile information under conditions of bodily threat.

[1] Van Hulle, L., Van Damme, S., Durnez, W., & Crombez, G. (submitted). Tactile change detection in a body region where pain is expected.

INTRODUCTION

Accurate detection and localization of pain and bodily threats is an evolutionarily adaptive ability, allowing protection of the body against actual or potential damage by triggering defensive behaviors (Dowman & ben-Avraham, 2008; Eccleston & Crombez, 1999; Haggard, Iannetti, & Longo, 2013). Attention is believed to support this ability by amplifying behavioral and physiological responses to relevant information and attenuating responses to irrelevant information (Legrain et al., 2009; Van Damme, Legrain, Vogt, & Crombez, 2010). More specific, it has been proposed that the brain possesses a multisensory salience detection system that orients and monitors attention to stimuli potentially threatening the integrity of the body (Legrain, Iannetti, Plaghki, & Moureaux, 2011; Moseley, Gallace, & Spence, 2012a). In line with this are cognitive-behavioral pain models stating that fearful appraisal and anticipation of pain enhances attention towards cues signaling potential pain or bodily harm (Crombez, Van Damme, & Eccleston, 2005; Vlaeyen & Linton, 2000). One can easily call to mind the situation of an individual with low back pain, who is worried about a potential injury, and continuously scans his back in order to detect signals of potential harm. It is likely that, as a result of such strong focus of attention on the back, this person will notice even subtle somatosensory changes in that body region.

Surprisingly, no direct empirical evidence for this intriguing idea is available. Although it has been shown that the threat of pain enhances attention to visual signals nearby the body location where pain is anticipated (Van Damme & Legrain, 2012; Van Damme, Crombez, & Lorenz, 2007), no studies have examined if the anticipation of pain facilitates the detection of (non-painful) somatosensory stimulation at the threatened location. Yet, somatosensory stimuli are prototypical signals for bodily threat, as the somatosensory system directly conveys information concerning changes in the representation of the body. Moreover, there is substantial overlap between the cortical representation of pain and touch, and there are indications for strong interactions between pain and touch in the primary somatosensory cortex (S1) (Haggard et al., 2013). For example, Mouraux, Diukova, Lee, Wise, and Iannetti (2011), presenting a random sequence of brief nociceptive somatosensory, non-nociceptive somatosensory, auditory and visual stimuli on or nearby the same body location, found that nociceptive and non-

nociceptive somatosensory stimuli elicited spatially indistinguishable responses in S1.

Some studies have examined the effects of pain on touch. A typical finding is that tactile thresholds on the hand are elevated by co-occurring, ipsilateral, tonic pain stimulation (e.g., Bolanowski, Maxfield, Gescheider, & Apkarian, 2000). This phenomenon of “touch gating” has been shown to be a purely sensory rather than a cognitive effect (e.g., Harper & Hollins, 2012). In contrast, another study has found that short (phasic) pain stimulation on the hand facilitates processing in the somatosensory cortices of tactile stimuli applied 500 ms later (Ploner, Pollok, & Schnitzler, 2004). The fact that the facilitation was found for both ipsilateral and contralateral trials, suggests this to be a generalized alerting or attention effect. Missing, however, are studies investigating if and how tactile processing is affected by anticipated rather than actual pain. The aim of the present study, therefore, was to investigate whether the threat of impending pain on a specific location of the body leads to the prioritized processing of tactile stimuli on that particular body location.

To address this research question, a tactile change detection task (Gallace, Tan, & Spence, 2006) was used in a sample of undergraduate students. In this task, participants were instructed to detect changes between two consecutively presented spatial patterns of tactile stimuli that were administered at different locations of the arms and legs. In half of the trials, the stimulated body sites in the two patterns were identical. In the other half of the trials, one of the stimulated body locations differed between the two patterns. We have recently shown that the ability to detect such tactile changes is modulated by spatial attention (Van Hulle, Van Damme, Spence, Crombez, & Gallace, 2013). More specific, focusing attention to a specific location of the body improved the detection of tactile changes at that location. In the present study, a painful electrocutaneous stimulus was occasionally administered to one of the tactile stimulus locations, in order to experimentally induce pain anticipation at that location. It was hypothesized that the anticipation of pain would result in an attentional focus to the threatened body location, consequently leading to a better detection of tactile changes occurring at that location.

METHODS

Participants

Forty-seven undergraduate psychology students (37 females, 10 males; mean age = 19.2 years, range 17-28 years) took part in the experiment in order to fulfil course requirements. 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, and that painful (but harmless) electrocutaneous stimuli (ES) would be administered during this task. All participants provided informed consent and were free to terminate the experiment at any time should they so desire. All participants reported normal tactile perception at all tactor locations and normal or corrected to normal visual perception. Nine participants were excluded because technical problems led to a faulty administration of the ES.

Apparatus and Materials

The vibrotactile stimuli (200 ms) were presented by means of eight resonant-type tactors (C-2 TACTOR, Engineering Acoustics, Inc., Florida) 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 tactile stimulus characteristics (amplitude and frequency) were controlled by means of a self-developed software program. The stimuli were administered to the dorsal aspects of eight different body locations (see Figure 1). These locations included the left and right forearms, the left and right upper arms, the area just above the left and right ankles, and the area just below the left and right knees. 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 perceived stimulus intensities at each tactor location 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

(as in Van Hulle et al., 2013). First, a tactile stimulus (reference stimulus, *Power* = 0.04 watts) was presented at the left forearm. Next, tactile stimuli were presented separately at each relevant location, and participants had to verbally report whether the intensity was lower than, higher than, 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.

The painful ES (bipolar; 3 mA; 50Hz; 200 ms; instantaneous rise and fall time) were delivered by means of a Constant Current Stimulator (DS5, Digitimer Ltd, Hertfordshire, UK) with two lubricated Medcat surface electrodes (1cm diameter). There was an acquaintance phase in which participants received a series of three stimuli of increasing intensities (respectively 1 mA, 2 mA and 3 mA). The intensity of the last stimulus was effectively used in the experiment.

The Tactile Change Detection Task

The tactile change detection task (see also Van Hulle et al., 2013) 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 500 ms. Next, the first tactile pattern was presented for 200 ms, followed by an empty stimulus interval of 110 ms, after which the second tactile pattern was presented for 200 ms. Tactile patterns always consisted of three simultaneously-presented tactile stimuli. The different possible 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 tactors that were active during the first pattern was inactive during the second pattern, and a tactor 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.

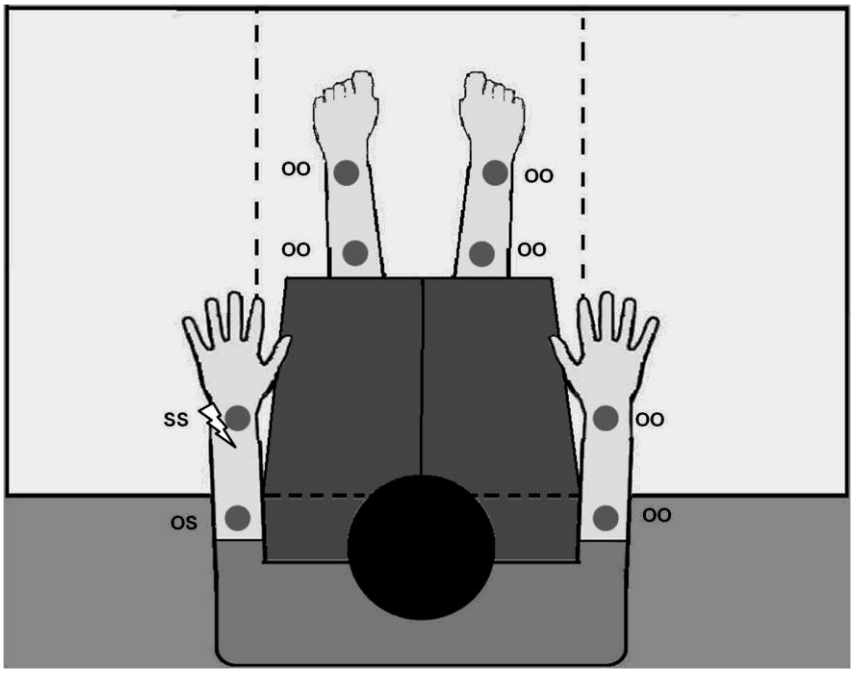


Figure 1. An illustration of the different tactor locations used in the experiment. For the administration of the ES (depicted as a lightning), two electrodes were attached just below the tactor on the non-dominant forearm. The different types of change trials, based upon the position on the body where the change occurred relative to the threat location, are indicated: same position-same body part changes (SS), other position-same body part changes (OS), and other position-other body part changes (OO).

Procedure and Threat Manipulation

In the acquaintance phase, a series of three ES of increasing intensity was administered. Participants were asked to rate the painfulness and unpleasantness of the last ES on an 11-point Likert scale ranging from 0 (“not at all”) to 10 (“very much”).

Before engaging in the tactile change detection task, the participants were informed that each trial consisted of the presentation of two tactile patterns that could either be identical or not. They were instructed to indicate whether the patterns were the same or not. As a manipulation of bodily threat, one of the stimulus locations was made treathening by informing the participants that during the change detection task, a painful ES could be administered to their non-dominant lower arm (i.e., adjacent to the tactor at that location). In 14.3% of the trials, a painful ES was actually administered to the threatened location.

Several types of trials are distinguished. In *ES trials*, an ES was presented instead of either the first or the second tactile pattern. This temporal unpredictability was installed to avoid that the participants would interpret the administration of the first tactile pattern as a 'safety signal'. Participants were instructed not to respond to ES trials. In *same trials*, the first and the second tactile pattern were identical. Of particular relevance for the hypothesis were the *change trials*, which were divided into three categories, reflecting the relative position of the tactile change with regard to the threat location (for a schematic representation, see Figure 1):

(1) SAME POSITION-SAME BODY PART changes (SS). In these trials, the difference between the first and the second pattern involved the exact threat location (i.e., the lower part of the non-dominant arm). This means that after the first tactile pattern, a tactile stimulus was either added to the threat location, or omitted from that location. However, no actual ES was administered in these trials.

(2) OTHER POSITION-SAME BODY PART changes (OS). In these trials, the difference between the first and the second pattern did not involve the threat location, but the other location on the same body part (i.e., the upper part of the non-dominant arm). These trials were included as a check that potential threat effects were specific for the threatened location, and not the result of focusing on the whole body part.

(3) OTHER POSITION-OTHER BODY PART changes (OO). In these trials, the difference between the first and the second pattern involved one of the (not-threatened) locations on the other body parts (dominant arm, both legs).

The threat location could be included in both patterns, but a change could never occur on the threatened location.

All tactor locations, including the threatened location, were stimulated an equal amount of times, namely in 37.50% of the same trials, change trials and ES trials. In the change trials, all tactor locations, including the threatened location, were involved in an equal amount (12.50%) of the changes. A re-location of one tactile stimulus to another body location could occur from all body locations. The 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 448 trials, divided into four blocks of 112 trials (16 ES trials, 48 same trials, 48 change trials). The ES trials were not analyzed, as in these trials one of the tactile patterns was replaced by an ES.

After the experiment, participants were asked to complete a number of self-reports assessing the experienced painfulness and unpleasantness of the ES that was administered during the experiment, to what extent they expected that a painful ES would be administered during the experiment, fear for the painful ES, anxiety during the experiment, and to what extent they attended to the threatened body location. Participants were asked to rate these items on an 11-point Likert scale ranging from 0 (“not at all”) to 10 (“very much”).

Statistical Analysis

The data were analyzed using repeated measures Analyses of Variance (ANOVAs), with Location (SS, OS, OO) as a within-subject factor. Only the change trials were included in the analyses in order to test our hypothesis. To obtain an objective and standardized measure of the magnitude of the observed effects, namely, a standardized difference between two means, an effect size (Cohen’s *d*) for independent samples was calculated using Morris and DeShon’s (2002) formula (as cited in Borenstein, Hedges, Higgins, & Rothstein, 2009). 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).

RESULTS

Analyses were performed on the data of 38 participants. Trials in which participants failed to give a response (0.3% of the trials) were not included in any of the data analyses. The participants correctly responded to same trials in 93.01 (*SD* = 7.01) % of these trials. On average, the participants correctly detected tactile changes in 68.66 (*SD* = 16.40) % of the change trials.

Tactile Change Detection

A repeated measures ANOVA was performed on the proportion accurately detected change trials as the dependent variable and location (SS, OS, OO) as the within subjects factor in order to test the hypothesis that tactile changes would be better detected when the threat location was involved.

The results revealed that the main effect of location was significant ($F(2,36) = 5.86$, $p < .01$). Paired-samples *t*-tests revealed that the proportion of accurately detected tactile changes were significantly larger in SS trials (M=0.71, SD=0.20) as compared to OO trials (M = 0.66, SD = 0.17; $t(1,37) = 2.18$, $p < .05$; d = 0.26, 95% CI [0.03, 0.50]), but – in contrast to the hypothesis – not as compared to OS trials (M = 0.73, SD = 0.18), ($t(1,37) = 1.05$, *n.s.*; d = -0.10, 95% CI [-0.36, 0.15]). In addition, the proportion of accurately detected changes was also significantly larger in OS trials than in OO trials ($t(1,37) = 3.32$, $p < .01$; d = 0.40, 95% CI [0.13, 0.67]. Figure 2 provides an illustration of these effects.

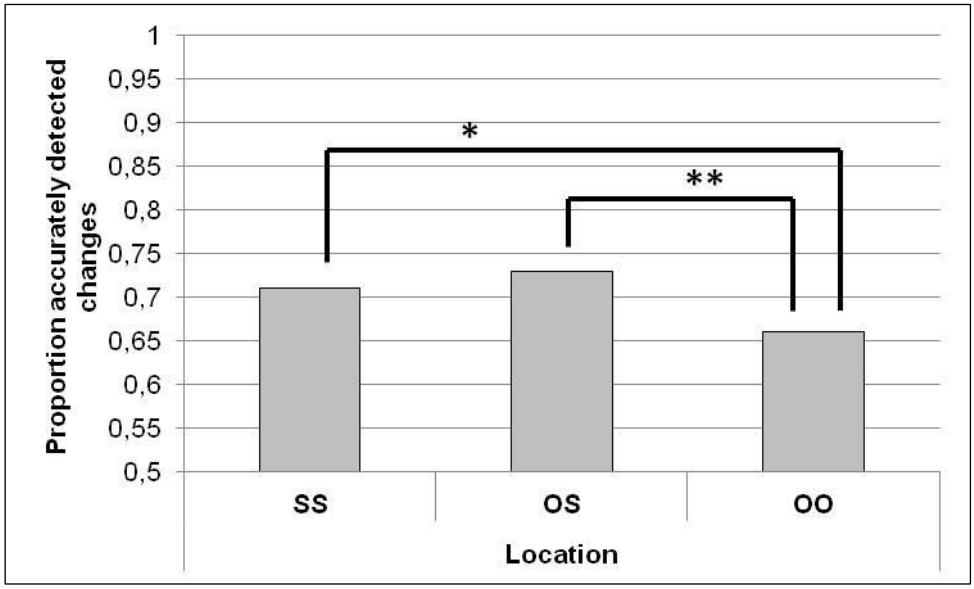


Figure 2. The mean proportion of correctly detected changes as a function of Location: same position-same body part (SS), other position-same body part (OS), other position-other body part (OO). [Note: *$p < .05$. **$p < .01$.]

Self-report Data

The means, standard deviations and ranges of the self-report items that were administered before and after the experimental phase can be found in Table 1. Overall, participants reported that they experienced the ES as painful and unpleasant, and that they fearfully anticipated the administration of the ES.

Table 1

Means, standard deviations and ranges of the self-report items that were administered before (pre) and after (post) the experimental phase

	M	*SD*	*Range*
Painfulness ES - pre	5.72	1.49	3-9
Unpleasantness ES - pre	6.58	1.57	4-9
Painfulness ES - post	6.29	1.58	3-9
Unpleasantness ES - post	7.42	1.52	3-10
Expectation ES – post	5.81	1.98	1-10
Fear for ES - post	5.61	2.44	0-9

DISCUSSION

The present study investigated by means of a tactile change detection task (Gallace et al., 2006; Van Hulle et al., 2013) whether the threat of impending pain on a specific location of the body increases the chance that somatosensory changes on that particular body location are detected. Participants were instructed to detect changes between two consecutively presented patterns of tactile stimulation presented at different locations of the body. Pain anticipation was experimentally induced by occasionally administering a painful stimulus at one of the tactor locations. It was expected that this would lead to a spontaneous attentional focus to the threatened body location, resulting in a better detection of tactile changes involving that location.

The data only partially supported our hypothesis. Tactile changes were indeed detected better when they occurred on the threatened location than on locations at other body parts. However, in contrast to what was expected, tactile changes involving the threatened location were not detected better than tactile changes not involving the threatened location but occurring on the same body part. In addition, tactile changes not involving the threatened location but occurring on the same body part, were also detected better than tactile changes on other body parts. These results suggest that the expectation of pain at a certain body location may have made participants more aware of tactile changes involving the whole body part on which pain was expected, rather than the exact threatened location.

This study extends previous research on the effects of pain on tactile perception. Several studies have found evidence for the phenomenon of “touch gating”, meaning that during experimental pain stimulation, tactile thresholds in the painful region are elevated (Apkarian, Stea, & Bolanowski, 1994; Bolanowski et al., 2000; Harper & Hollins, 2012). While such pain-touch interactions are believed to occur at a purely sensory level, we rather focus on the question how the anticipation of pain affects the processing of tactile stimuli at a cognitive level. Neurocognitive theories have proposed that the brain possesses a multisensory salience detection system that orients and monitors attention to stimuli potentially threatening the integrity of the body (Haggard et al., 2013; Legrain et al., 2011; Moseley et al., 2012a; Van Damme et al., 2010). Given the close correspondence between pain and touch, it may be assumed that tactile changes in a body region

where pain is expected are particularly salient and will therefore receive processing priority. The present study suggests that such attentional prioritization may not be limited to the exact pain location. It is plausible that also tactile changes in adjacent body regions, for instance in the whole body part on which pain is expected, become more salient, and as such are more easily detected. However, more research specifically testing the spatial boundaries of the attentional prioritization effect of pain anticipation on tactile perception is clearly needed.

The present work may also have relevance for clinical pain models and research. Cognitive-behavioral pain models have proposed that fearful appraisal and anticipation of pain enhances attention towards cues signaling potential pain or bodily harm, and that such "hypervigilance" may be particularly prominent in patients with chronic pain (Crombez et al., 2005; Vlaeyen & Linton, 2000). Surprisingly, research investigating this idea is mainly limited to studies comparing the deployment of attention to pain-related and neutral words (e.g., Asmundson, Wright, & Hadjistavropoulos, 2005; Haggman, Sharpe, Nicholas, & Refshauge, 2010; Liossi, Schoth, Bradley, & Mogg, 2009). However, evidence that attentional bias to pain-related words is specifically enhanced in chronic pain patients is mixed, and a recent meta-analysis by Crombez, Van Ryckeghem, Eccleston, and Van Damme (2013) indicates that such bias is a subtle phenomenon. It has been argued that the visual stimulus material used in these studies might not be sufficient to activate 'schemata' of bodily threat, as these are only semantic representations of pain, and it has been recommended to use somatosensory attention paradigms in future studies (Crombez et al., 2013). Tactile detection paradigms, such as the one used in the present study, may provide valuable tools to investigate the idea of hypervigilance in clinical populations. Individuals with chronic low back pain or persistent orofacial pain, for example, may then be hypothesized to exhibit prioritized tactile attention at the specific region of the body where their pain problem is situated. Such research would complement previous studies investigating somatosensory sensitivity in patients with chronic pain (Geisser et al., 2003; Hollins et al., 2009; Peters, Vlaeyen, & van Drunen, 2000). Note that it is not clear in those studies whether increased somatosensory sensitivity was due to sensory abnormalities, attentional mechanisms, or a combination of both, and that sensitivity was measured on arbitrary body locations.

One benefit of the current procedure is the fact that we controlled for potential confounds due to individual differences in tactile sensitivity. There is evidence that within an individual, sensitivity differs depending on the body part that is stimulated (Weinstein, 1968). In the current paradigm, the different stimulus intensities were matched prior to the experiment, as result of which the results cannot be attributed to sensory differences.

The finding that pain anticipation facilitates the processing of somatosensory information in the corresponding body region may also be weighted up against research showing that in certain clinical samples, such as complex regional pain syndrome and chronic low back pain, there are indications that tactile perception in the affected region of the body is reduced (Moseley, 2008; Moseley, Gallagher, & Gallace, 2012b), suggesting a neglect-like phenomenon. Although these findings are, at first sight, in contrast with the idea of attentional prioritization of tactile stimuli at a threatened body part, it cannot be excluded that the mechanisms underlying tactile processing in the context of clinical and experimental pain are fundamentally different. One challenge for future research is to investigate how these apparently opposing mechanisms are integrated in patients with chronic pain and if there are subtypes of patients that either prioritize or neglect tactile information at the affected body part.

In sum, the present study suggests that the threat of impending pain on a specific location of the body does not lead to heightened attention to innocuous tactile information presented on that specific body location, but rather to the broader region or body part involving this threatened location. However, future research is definitely needed to validate the current results and further investigate the scope of the attentional processing of tactile information under conditions of bodily threat. An interesting avenue for further research considers the study of attentional processing of somatosensory information in patients with chronic pain.

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6

SENSORY SUPPRESSION DURING THE EXECUTION OF A PAIN-RELATED MOVEMENT[1]

ABSTRACT

The current study examined whether the expectation of pain during movement execution leads to a reduced sensory suppression of tactile information on the body part where pain is expected. Forty undergraduate students engaged in a movement-detection task in which they were instructed to (1) move both arms either to the left or to the right, or keep them at rest, and (2), at the same time, detect the presence or absence of a tactile stimulus on the left or the right forearm. One movement was made threatening by occasionally associating it with the administration of a painful stimulus on either the left or the right forearm. The results showed that the overall detection of tactile stimuli was worse during movement than during rest, as such demonstrating sensory suppression. As hypothesized, during the execution of a threatening movement, tactile stimuli on the threatened body part were detected better than tactile stimuli on the neutral body part, indicating reduced sensory suppression as a result of pain anticipation. In contrast to the hypothesis, tactile stimuli on the threatened body part were not detected better during the execution of a threatening as compared to a neutral movement. Instead, tactile stimuli at the neutral location were detected worse during the threatening than during the neutral movement. Implications for the theory of somatosensory hypervigilance are discussed, as well as the potential use of the sensory suppression paradigm to assess somatosensory hypervigilance in chronic pain patients.

[1] Van Hulle, L., Van Damme, S., & Crombez, G. (in preparation). Sensory suppression during the execution of a pain-related movement.

INTRODUCTION

It is well documented that during the execution of a movement, the perception of somatosensory information on the moving body part is reduced, a phenomenon that is often referred to as 'sensory suppression' (Chapman & Beauchamp, 2006; Gallace, Zeeden, Röder, & Spence, 2010; Juravle, Deubel, & Spence, 2011; Juravle, Deubel, Tan, & Spence, 2010; Kemppainen, Leppänen, Waltimo, & Pertovaara, 1993; Van Hulle, Juravle, Spence, Crombez, & Van Damme, 2013; Williams & Chapman, 2000, 2002; Williams, Shenasa, & Chapman, 1998). Some authors have suggested this to be a functional mechanism, preventing movement execution from being constantly hampered by irrelevant information (Bays & Wolpert, 2007; Gallace et al., 2010). From an evolutionary perspective, however, it is clearly important that salient or relevant somatosensory information can still be perceived and processed during movements, particularly when it signals potential bodily threat (Chapman & Beauchamp, 2006; Dowman & ben-Avraham, 2008; Eccleston & Crombez, 1999; Williams et al.,1998).

Recently, it has been suggested that there exists a salience detection system in the brain by which attention is oriented and monitored to stimuli that are potentially threatening the integrity of the body (Haggard, Iannetti, & Longo, 2013; Legrain, Iannetti, Plaghki, & Mouraux, 2011; Moseley, Gallace, & Spence, 2012). Indeed, somatosensory stimuli have been shown to capture attention particularly when they are intense, novel, or unpredictable (Crombez, Eccleston, Baeyens, & Eelen, 1996; Dowman, 2011; Legrain, Bruyer, Guérit, & Plaghki, 2005). In addition, it has been argued that somatosensory stimuli may also be prioritized by the attentional system because of their affective-motivational relevance (Legrain et al., 2009; Van Damme, Legrain, Vogt, & Crombez, 2010). For instance, recent studies have indicated that the threat of pain at a certain body part enhances the processing of tactile stimuli at that body part (Vanden Bulcke, Van Damme, Durnez, & Crombez, submitted; Van Hulle, Van Damme, Durnez, & Crombez, submitted).

A certain movement may acquire a threat value when it is repeatedly followed by pain (Meulders, Vansteenwegen, & Vlaeyen, 2011; Moseley & Hodges, 2005), and this kind of associative learning has been suggested to underlie avoidance behaviour in patients with chronic pain (Meulders & Vlaeyen, 2013). When one anticipates pain during the execution of a movement,

somatosensory information becomes particularly relevant because it is closely related to pain, and may therefore be considered as a prototypical signal for potential bodily damage (Haggard et al., 2013). One could therefore argue that during a threatening movement, somatosensory stimuli on the moving body part are likely to be prioritized by the attentional system, as a result of which sensory suppression would be reduced. Note that it has already been demonstrated that sensory suppression of tactile stimuli is less pronounced when attention is voluntarily focused to the stimulated location (Juravle et al., 2011; Van Hulle et al., 2013). One might expect that the execution of a pain-evoking movement will spontaneously induce an attentional focus at the threatened body part, and consequently will reduce sensory suppression of tactile stimuli at that body part. However, to our knowledge, no studies have investigated sensory suppression during pain-related movements.

The aim of the current study was to examine whether the expectation of pain during a specific movement leads to reduced sensory suppression of tactile stimuli on the body part where pain is anticipated. In order to test this hypothesis, a sample of undergraduate students engaged in a movement-detection task in which they were instructed to simultaneously (1) move both arms either to the left or to the right, or keep them at rest, and (2) detect the presence or absence of a tactile stimulus on the left or the right forearm. One movement (threat movement; left or right; counterbalanced across participants) was occasionally associated with the administration of a painful stimulus on one location (threat location; left or right forearm; counterbalanced across participants). It was hypothesized that (1) the overall detection of tactile stimuli would be worse during movement than during rest, reflecting sensory suppression, (2) during the execution of the threatening movement, sensory suppression on the threat location would be reduced. If the latter hypothesis is correct, tactile stimuli during the threatening movement should be better detected on the threat location than on the neutral location, and tactile stimuli on the threat location should be better detected during the execution of the threatening movement as compared to the neutral movement.

METHODS

Participants

Forty healthy undergraduate psychology students (31 females, 9 males; mean age = 21 years, age range 18-32 years) were paid to take part in the experiment. The study was conducted in accordance with the Declaration of Helsinki. All participants gave informed consent and were free to terminate the experiment at any time. They all reported normal tactile perception (absence of nerve damage or injuries) at those locations where the tactile stimuli would be delivered.

Apparatus and Materials

The tactile stimuli (200 ms) were presented by means of two resonant-type tactors (C-2 TACTOR, Engineering Acoustics, Inc., Florida) 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 left and the right forearm. 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 of each tactor were determined individually, as there is evidence for variation in sensitivity depending on the body site stimulated (e.g., Weinstein, 1968). In order to do so, the intensity of the tactile stimulation was determined at rest for each participant by means of an adaptive double random staircase procedure designed to keep performance at a level of 50% (Levitt, 1971). Both staircases started with a randomly chosen stimulation intensity between 0.00017 watts and 0.01377 watts (Power). As such, each staircase started with a different stimulation intensity. The presentation of trials from each of the staircases was randomized throughout this pre-experimental phase. The participants were instructed to respond whether or not they felt the presence of a stimulus by pressing on the corresponding keys (respectively ‘f’ and ‘j’ on an AZERTY keyboard). A staircase changed direction after one negative response (i.e.,

increasing the corresponding location stimulation by one step – 'UP') or one positive response (i.e., decreasing the corresponding location stimulation by one step – 'DOWN'). Changes in the direction of the staircase are referred to as 'reversals'. A run consists of a sequence of changes in stimulus level in one direction only, thus starting with a reversal. The staircase terminated once the total number of trials (30) had been reached. The first run was excluded from the final threshold calculations which consisted of the average of the mean values of each even run. The participants went through this procedure separately for the left and the right forearm. The order was randomly assigned across participants. As a stimulus with a 50% detection threshold intensity determined at rest can impossibly be perceived during movement execution, the intensity obtained by our procedure needed to be multiplied by a certain factor in order to make sure that participants would actually be able to detect the stimuli during movement. Pilot testing revealed that the obtained value needed to be increased in order to obtain a substantial level of performance during movement. In the present study, we used two different intensities for the tactile stimuli: detection threshold was multiplied by two in half of the trials (*low intensity*) and by three in the other half of the trials (*high intensity*).

The painful stimuli were electrocutaneous stimuli (ES) delivered by constant current stimulators (Digitimer DS5 2000, Hertfordshire, UK). The ES consisted of trains of 20 ms sinusoid pulses with a frequency of 50 Hz, and were delivered via two lubricated Fukuda standard Ag/AgCl electrodes (1 cm diameter) for 200 ms. Although electrodes were attached on both the left and the right forearm, just below the location of the tactors, participants could only receive a painful stimuli on either the left or the right forearm. This way, we controlled for possible effects of the mere presence of electrodes on the skin. Prior to the experiment, this painful location was randomly assigned to each participant. A double random staircase procedure was used to select a pain intensity for the experiment that elicited an average self-report rating of '7' on a 11-point Likert scale (0 = "not painful at all"; 10 = "worst imaginable pain"). A first staircase started with an intensity between 0.5 mA and 0.9 mA, while a second staircase started with an intensity between 1mA and 1.4 mA. In total, sixteen ES were presented to the participants' left or right forearm, and self-reports were collected after each ES.

The set-up of the experiment is depicted in Figure 1. A movement consisted of the relocation of both hands from the start positions to the goal mice either at a left or right angle with the start positions. Two warning signals (auditory stimuli; 150 ms, 8399 Hz) and a starting signal (an auditory stimulus; 200 ms, 9491 Hz), with an inter-stimulus interval (ISI) of 550ms, indicated when a movement needed to be executed.

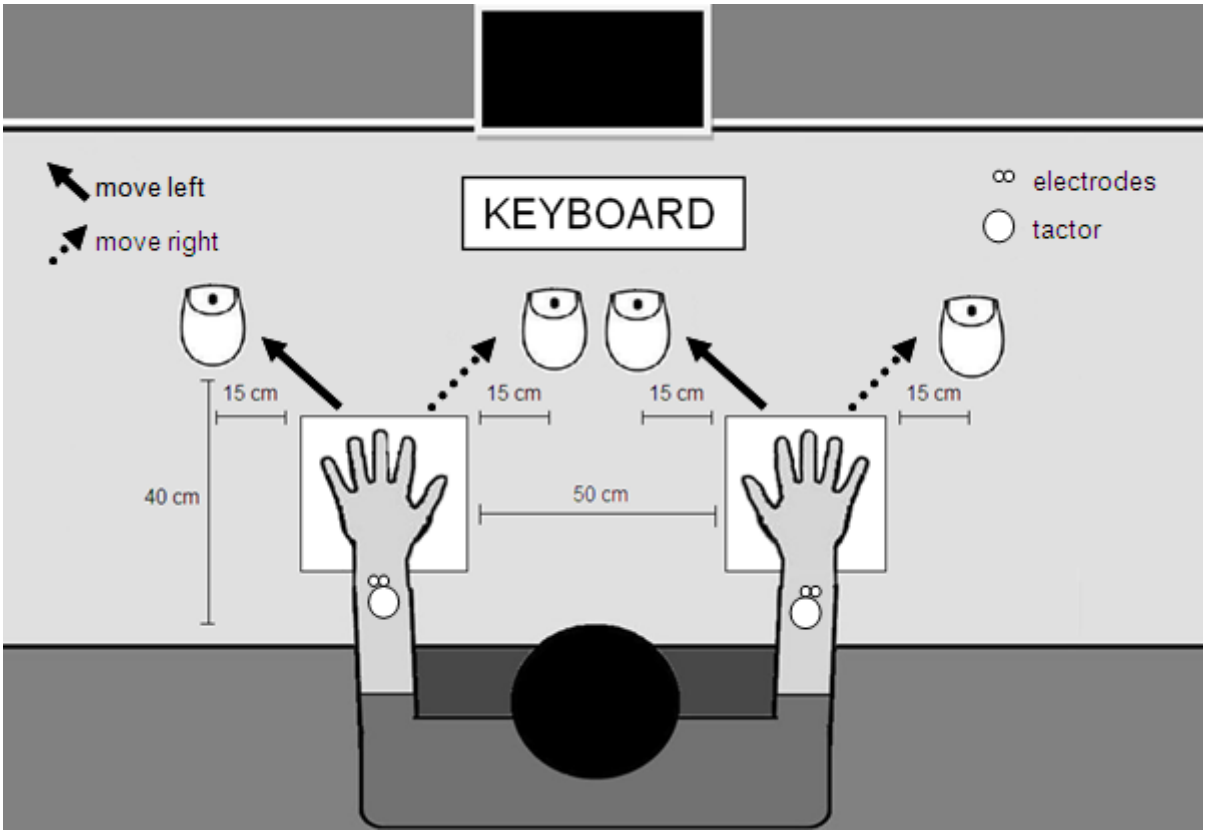

Figure 1. An illustration of the set-up of the experiment. At each forearm, tactors and electrodes were attached. The white squares indicate the start positions, and the arrows indicate which movements had to be performed by the participants.

Movement-detection Task

The paradigm was programmed and controlled by Inquisit Millisecond software (Inquisit 3.0) on a PC laptop (HP Compaq nc6120) with a keyboard. In this dual-task paradigm, the participants simultaneously engaged in a movement task and a perceptual task. The *movement* task consisted of moving both hands

from the start positions either toward the left goal mice, or toward the right goal mice (see Figure 1). A trial started with a picture (1500 ms) indicating whether participants needed to move their hands to the left or to the right, or needed to hold their hands still. 100 ms later, participants heard three auditory signals (200 ms), with an ISI of 550 ms: two warning signals which indicated that they needed to prepare for movement execution, and a start signal, which indicated that they needed to execute the required movement immediately. The participants were instructed to press all buttons of the goal mice at arrival. When no movement needed to be executed, the trial ended 2000 ms after the start signal. The *perceptual* task consisted of an unspeeded detection of tactile stimuli that could be administered on either the left or the right forearm during the movement execution or rest trials. It was also possible that no stimulus was delivered during these trials (*catch trials*). The stimuli were presented at two different timings (400 or 600 ms after the start signal) during the execution phase of the movement in order to reduce expectancy effects. In rest trials, tactile stimuli were delivered at the same points in time. Two different tactile stimulus intensities, selected in the pre-experimental phase, were used. An equal amount of stimuli with a low or high intensity were randomly administered within each block. In *ES trials*, an ES was presented instead of a tactile stimulus, either 400 or 600 ms after the start signal.

After clicking the goal mice, or after the end of a rest trial, the participants could respond whether they felt a tactile stimulus on the left forearm, on the right forearm, or not at all, by pressing the corresponding response keys (respectively, ‘1’, ‘2’ or ‘3’ on an AZERTY keyboard) with the index finger of their right hand. It was stressed that accuracy, rather than speed, was of importance. Hereafter, participants were instructed (on screen) to bring the hands back to the start positions, and the next trial was started.

Procedure and Threat Manipulation

Before engaging in the movement-detection task, the participants were informed that one movement (either the left or the right) was associated with the occasional administration of a painful ES on (either the left or the right) forearm. As such, there were four possible threat manipulations, which were randomly distributed across the participants, namely (1) a condition in which an ES could be

delivered on the left forearm during the movement to the left (*MovL-PainL*), (2) a condition in which an ES could be delivered on the left forearm during the movement to the right (*MovR-PainL*), (3) a condition in which an ES could be delivered on the right forearm during the movement to the left (*MovL-PainR*), and (4) a condition in which an ES could be delivered on the right forearm during the movement to the right (*MovR-PainL*). Table 1 provides an overview of the different manipulation conditions.

Table 1.

An overview of the different between-subjects manipulation conditions.

		Body location associated with pain	
		Left	**Right**
Movement direction	**Left**	MovL-PainL	MovL-PainR
associated with pain	**Right**	MovR-PainL	MovR-PainR

In a first practice phase, the participants first performed six trials in which they got acquainted with the task. No ES's were administered during this phase. In a second practice phase, the participants performed a total of 18 trials, including 6 ES trials. The first trial always consisted of an ES trial, to make sure that the participants associated the correct movement and location with the ES administration. Participants were also explicitly informed during which movement and at which location a painful stimulus could be administered.

The experimental phase consisted of twelve within-subject conditions: Movement (rest, neutral, threat) x Stimulus Location (left forearm, right forearm) x Intensity (low, high). An overview of the number of trials in each condition is provided in Table 2. The participants performed two blocks of 132 trials. They were informed that they could take a short break between these two blocks, if they so desired.

Table 2

An overview of the number of trials in each within-subject condition. The ES trials and the catch trials were removed for further analyses. In half of these trials, the tactile stimuli had a low intensity (50% detection threshold multiplied by two). In the other half of the trials, the tactile stimuli had a higher intensity (50% detection threshold multiplied by three).

		Stimulus administration			
		Neutral location	Threat location	No stimulus	ES
Movement	Rest	32	32	32	/
	Neutral	32	32	32	/
	Threat	24	24	24	24

Self-report Measures

After each block, the participants were asked to complete a number of self-reports assessing to what extent they had expected that a painful ES would be administered during the threat and the neutral movement, and to what extent they had been fearful for the painful ES during the threat and the neutral movement. Participants were asked to rate these items on a 11-point Likert scale ranging from 0 (“not at all”) to 10 (“very much”).

Data-analysis

Trials in which an ES was delivered, as well as catch trials, were removed for further analyses. The data were analyzed using repeated measures Analyses of Variance (ANOVAs) with Intensity (low, high), Movement (rest, neutral, threat), and Location (neutral, threat) as within-subject factors, Threat Manipulation (MovL-PainL, MovR-PainL, MovL-PainR, MovR-PainR) as between-subjects factor, and the proportion accurately detected stimuli as the dependent variable. Paired samples *t*-tests and independent samples *t*-tests were used to explore differences within and between groups. 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) formula (as cited in Borenstein, Hedges, Higgins, & Rothstein, 2009). 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).

RESULTS

Self-report Measures

The data of the self-report measures were averaged across blocks. Paired samples *t*-tests indicated that participants anticipated the presence of a painful stimulus significantly more during the execution of the threat movement (M = 5.36, SD = 2.37) as compared to the neutral movement (M = 0.44, SD = 1.05; $t(39) = 11.24$, $p < .001$; d = 2.74, 95% CI [1.70, 3.79]). Moreover, participants reported more fear for the ES during the execution of the threat movement (M = 4.43, SD = 2.95) as compared to the neutral movement (M = 0.44, SD = 1.36; $t(39) = 7.19$, $p < .001$; d = 1.78, 95% CI [1.00, 2.55]).

Movement-detection Task

The mean latency of the movement was 1424 ms (SD = 210). Overall, participants accurately detected 75.13% of the stimuli. A repeated-measures ANOVA was performed with Intensity (low, high), Movement (rest, neutral, threat), and Location (neutral, threat) as within-subject factors, Threat Manipulation (MovL-PainL, MovR-PainL, MovL-PainR, MovR-PainR) as between-subjects factor, and the proportion accurately detected tactile stimuli as the dependent variable.

Main effects. The analyses revealed a significant main effect of Intensity ($F(1,36) = 51.22$, $p < .001$), indicating that stimuli were detected significantly better when the stimulus intensity was high (M = 0.79, SD = 0.14) as compared to when stimulus intensity was low (M = 0.72, SD = 0.16). There was also a significant main effect of Movement ($F(2,36) = 104.99$, $p < .001$). This effect was further explored by means of paired samples *t*-tests. These revealed that stimuli were

detected significantly worse during the threat movement (*M* = 0.59, *SD* = 0.24) and the neutral movement (*M* = 0.64, *SD* = 0.22) trials, as compared to the rest trials (*M* = 0.99, *SD* = 0.02; resp. *t*(39) = 10.78, *p* < .001; *d* = 2.19, 95% CI [1.44, 2.93] and *t*(39) = 9.98, *p* < .001; *d* = 2.08, 95% CI [1.37, 2.81]). Tactile stimuli were detected significantly worse during the threat movement trials as compared to the neutral movement trials (*t*(39) = 3.28, *p* = .002; *d* = 0.21, 95% CI [0.08, 0.35]). There were no other significant main effects.

Two-way interaction effects. The interaction Intensity x Movement was significant (*F*(2,35) = 26.07, *p* < .001). Paired samples *t*-tests indicated that on neutral movement trials, the participants were significantly better in detecting tactile stimuli of a high (*M* = 0.70, *SD* = 0.22) as compared to a low intensity (*M* = 0.57, *SD* = 0.24; *t*(39) = 6.79, *p* < .001; *d* = 0.56, 95% CI [0.39, 0.72]). Also, on threat movement trials, the participants were significantly better in detecting tactile stimuli of a high (*M* = 0.66, *SD* = 0.25) as compared to a low intensity (*M* = 0.52, *SD* = 0.24; *t*(39) = 5.98, *p* < .001; *d* = 0.57, 95% CI [0.37, 0.77]). On rest trials, there was no difference between the proportion accurately detected stimuli of a high (*M* = 0.99, *SD* = 0.03) or a low intensity (*M* = 0.99, *SD* = 0.02; *t*(39) = 0.74, *p* = .463; *d* = 0.00, 95% CI [-0.46, 0.46]).

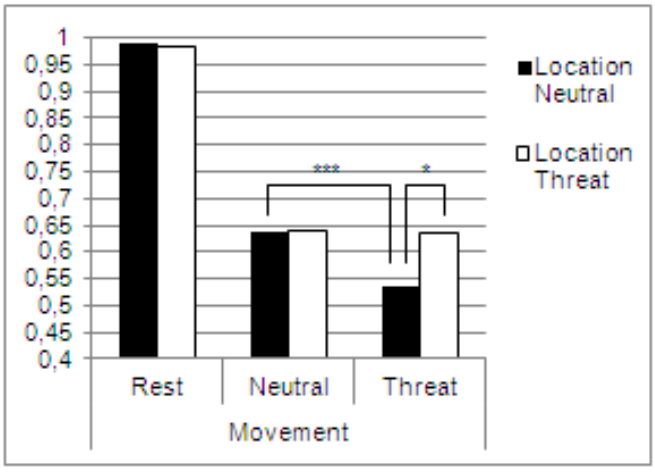

Figure 2. The mean proportion of accurately detected stimuli as a function of Movement (rest, neutral, threat) and Location (neutral, threat). Note: *p < .10. **p < .05. ***p < .001.

The interaction Movement x Location was borderline significant ($F(2,35) = 3.24$, $p = .053$). As our *a priori* hypothesis related to this interaction, it was further explored by means of paired samples *t*-tests (see Figure 2). A borderline significant effect ($t(39) = 2.01$, $p = .052$; $d = 0.35$, 95% CI [0.00, 0.69]) indicated that during a threat movement, as hypothesized, stimuli were detected better on the threat ($M = 0.64$, $SD = 0.24$) than on the neutral location ($M = 0.54$, $SD = 0.32$). However, opposed to our hypothesis, the proportion accurately detected stimuli on the threat location did not significantly differ between the threat movement and the neutral movement ($t(39) = 0.12$, $p = .908$; $d = 0.00$, 95% CI [-0.23, 0.23]). The analyses further showed that stimuli on the neutral location were detected significantly worse during the threat movement as compared to the neutral movement ($t(39) = 4.20$, $p < .001$; $d = 0.32$, 95% CI [0.17, 0.47]). During the neutral movement, the proportion accurately detected stimuli did not significantly differ between the threat location ($M = 0.64$, $SD = 0.26$) and the neutral location ($M = 0.64$, $SD = 0.30$; $t(39) = 0.07$, $p = .941$; $d = 0.00$, 95% CI [-0.37, 0.37]). The proportion accurately detected stimuli during rest did not differ between the neutral location ($M = 0.99$, $SD = 0.02$) and the threat location ($M = 0.98$, $SD = 0.02$; $t(39) = 1.86$, $p = .070$; $d = 0.50$, 95% CI [0.05, 0.95]).

Other two-way interaction terms were not significant.

Three- and four-way interaction effects. Only the Movement x Location x Threat Manipulation interaction reached significance ($F(6,70) = 3.16$, $p = .013$), indicating that the hypothesized Movement X Location interaction was dependent upon which threat manipulation was used. Therefore, the paired samples t-tests were repeated for each treat manipulation condition separately (see Figure 3).

First, although in all four threat manipulation conditions, detection of tactile stimuli during the threat movement was apparently better on the threat location than on the neutral location, none of these effects reached statistical significance (MovL-PainL: $t(8) = 1.12$, $p = .296$; MovR-PainR: $t(9) = 0.90$, $p = .391$; MovL-PainR: $t(11) = 1.08$, $p = .302$; MovR-PainL: $t(8) = 0.76$, $p = .468$).

Second, stimuli on the threat location appeared to be better detected during the threat movement than during the neutral movement in two of the threat manipulation conditions, although this was only significant in one condition (MovR-PainL: $t(9) = 3.65$, $p = .005$; MovL-PainR: $t(11) = 0.86$, $p = .410$). In the other

threat manipulation conditions the opposite effect was found, though this was only significant in one condition (MovR-PainR: $t(8) = 2.95$, $p = .019$; MovL-PainL; $t(8) = 1.69$, $p = .130$).

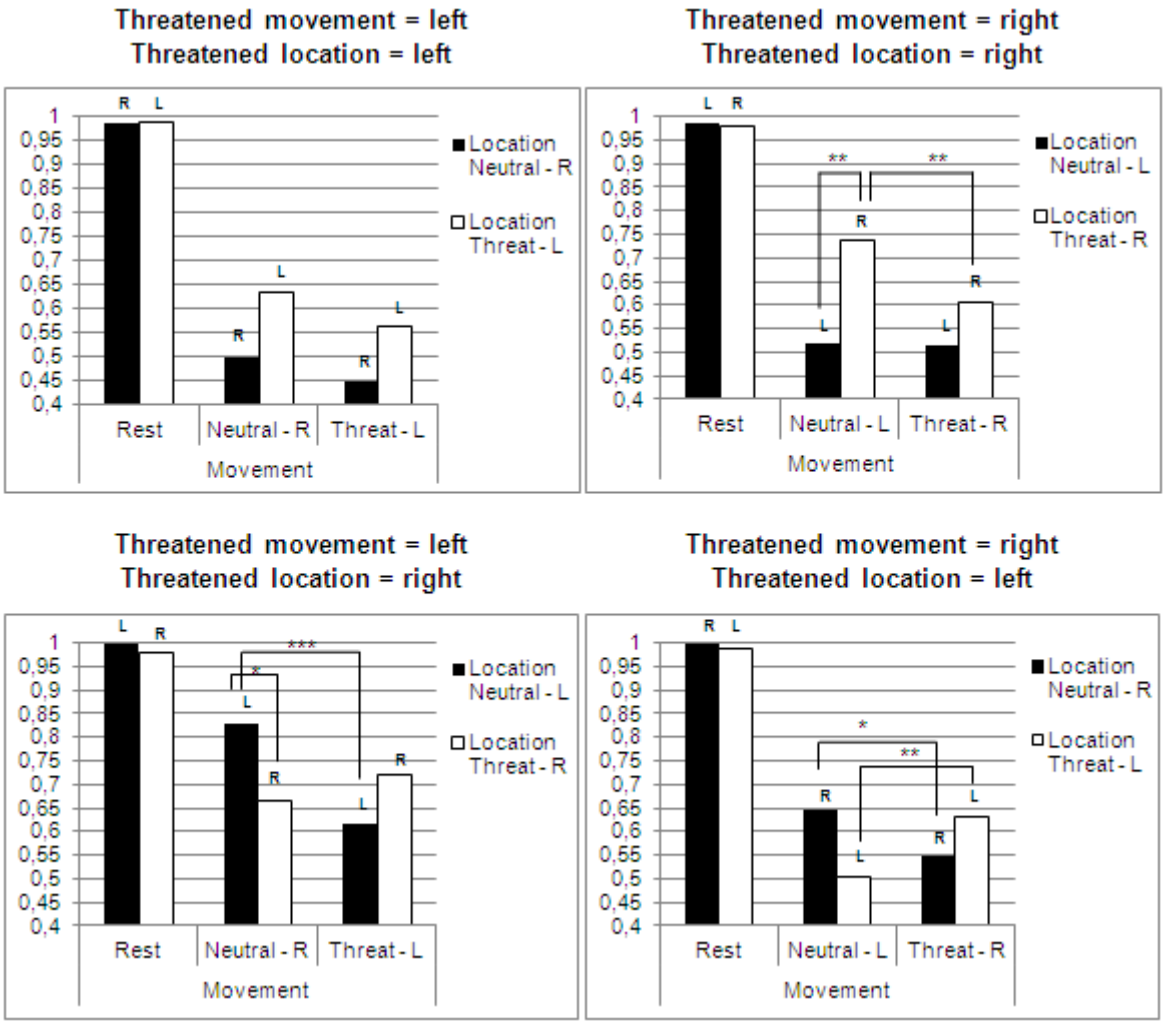

Figure 3. The mean proportion of accurately detected stimuli as a function of Movement (rest, neutral, threat), Location (neutral, threat), and Threat Manipulation (MovL-PainL, MovR-PainL, MovL-PainR, MovR-PainR). [Note: *p<.10 **p<.05 ***p<.001]

Third, detection of tactile stimuli on the neutral location was worse during the threat movement than during the neutral movement in all threat manipulation conditions, but this was not significant in two condition (MovL-PainL: $t(8) = 1.07$, p

= .318; MovR-PainR condition: $t(9) = 0.22$, $p = .832$; MovL-PainR: $t(11) = 5.01$, $p < .001$; MovR-PainL: $t(8) = 2.29$, $p = .051$).

Fourth, during neutral movements, detection of stimuli was better on the threat location than on the neutral location in two of the threat manipulation conditions, though only significantly in one condition (MovR-PainR: $t(9) = 2.92$, $p = .017$; MovL-PainL: $t(8) = 1.09$, $p = .309$). The opposite pattern was found in the other two threat manipulation conditions, although this was not significant in one condition (MovL-PainR: $t(11) = 1.91$, $p = .082$; MovR-PainL: $t(8) = 1.56$, $p = .157$).

DISCUSSION

The present study investigated whether the anticipation of pain during the execution of a movement leads to reduced sensory suppression on the body part where pain is expected. In order to test this hypothesis, the participants engaged in a movement-detection task in which they were instructed to simultaneously (1) move both arms either to the left or to the right, or keep them at rest, and (2) detect the presence or absence of a tactile stimulus on the left or the right forearm. One movement was made threatening by occasionally associating it with the administration of a painful stimulus on one body location. It was hypothesized that (1) tactile stimuli would be detected less during movement as compared to rest (sensory suppression), and (2) that during the execution of a threatening movement, sensory suppression on the threat location would be reduced.

Our results demonstrated a clear overall sensory suppression effect, supporting the first hypothesis and confirming the results of several other studies (Chapman & Beauchamp, 2006; Gallace et al., 2010; Juravle et al., 2010, 2011; Kemppainen et al., 1993; Kemppainen, Vaalamo, Leppällä, & Pertovaara, 2001; Van Hulle et al., 2013; Williams & Chapman, 2000, 2002; Williams et al., 1998). Moreover, sensory suppression was less pronounced when the intensity of the tactile stimulus was higher, as has been reported previously (Van Hulle, Van Damme, Danneels, & Crombez, in preparation; Williams & Chapman, 2000).

The findings only partially supported the hypothesis that during a threatening movement, sensory suppression on the threat location would be reduced. During the execution of a threatening movement, tactile stimuli on the threat location were detected better than on the neutral location. However, tactile

stimuli on the threat location were not detected better during the threat movement than during the neutral movement. Furthermore, the results revealed that the two-way interaction Movement x Location, which was explored because of a priori reasons, was qualified by a three-way interaction with the type of threat manipulation. In what follows, we will further elaborate on this. As it is known that lower-order effects cannot readily be interpreted in the presence of higher-order interaction effects, the results should however be interpreted with caution.

First, although visual inspection of the data indicates that in all four threat manipulation conditions the detection of tactile stimuli during the threatening movement was better on the threatened body location than on the neutral body location, this effect was not significant for any of the four conditions separately. However, given the low number of participants in each condition, it is likely that the tests that were used to explore the three-way interaction effect lacked statistical power. Second, the results revealed that in some threat manipulation conditions, tactile stimuli were detected better during the execution of a threatening as compared to a neutral movement, while in other conditions, tactile stimuli seemed to be detected better during the execution of a neutral as compared to a threatening movement. It is unclear how these differences can be explained. However, it was observed that during neutral movements, participants were always better in detecting stimuli on the left arm when they were instructed to move both arms to the right, and better in detecting stimuli on the right arm when they were instructed to move both arms to the left. This may have interfered with the hypothesized threat effects. Two explanations may be proposed for this observation. First, during movement execution, there was always one arm that needed to be stretched, and one arm that needed to be flexed in order to reach the goal mice. More specifically, when moving to the right (left), the left (right) arm was flexed and the right (left) arm was stretched. Although we are not aware of studies that have investigated the amount of sensory suppression during these different arm movements, we may speculate that a stretching movement may have evoked more sensory suppression as compared to a flexing movement. Perhaps an arm stretch elicits stronger re-afferent sensations than a flexion of the arm, as such resulting in an increased backward masking (for a detailed discussion of the mechanisms underlying sensory suppression, see Chapman & Beauchamp, 2006; Voss, Ingram, Wolpert, & Haggard, 2008). Second, when a participant made a

movement to the right (left), this implied that the right (left) arm moved further away from the body midline, while the left (right) arm moved toward the body midline. It may be speculated that a limb that is approaching the body midline is considered to be more salient than a limb moving away from the own body, as a result of which tactile stimuli on the 'approaching' arm may be detected better. However, future research is definitely needed to explore these speculative ideas.

Taken together, these findings suggest that pain anticipation during movement execution may affect the processing of tactile information. It may be assumed that in the context of a pain-related movement, attention is oriented to the body region where pain is expected in order to detect stimuli that are potentially threatening the integrity of the body (Haggard et al., 2013; Legrain et al., 2011; Moseley et al., 2012; Van Damme et al., 2010). Our results also extend the findings of other studies indicating that the threat of impending pain on a specific body location affects the processing of tactile stimuli at that body part (Vanden Bulcke et al., submitted; Van Hulle et al., submitted), by showing that this may be particularly the case in the context of pain-related movements. However, while our hypothesis presumed that the anticipation of pain during a certain movement would result in a benefit in the attentional processing of relevant, potentially threatening information, the current results also point into the direction of a cost in the attentional processing of irrelevant (neutral) information. Indeed, an unexpected finding was that tactile stimuli on the neutral location were detected worse during the threatening movement than during the neutral movement. This is in line with a previous study of Van Damme, Crombez, and Notebaert (2008), whose results demonstrated that a bias toward (visual) threat-related information reflected a decrease in accuracy for neutral information, but no increase in accuracy for threatening information. This is also in keeping with a number of other studies using reaction times as a measure of attention (Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004; Van Damme, Crombez, & Eccleston, 2004; but see Poliakoff, Miles, Xinying, & Blanchette, 2007).

The present results are particularly intriguing with regard to the hypothesis of increased attentional processing of somatosensory information in individuals with chronic pain (Crombez, Van Damme, & Eccleston, 2005; Vlaeyen & Linton, 2000). It has been argued that these attentional processes should be studied in more ecologically valid situations (e.g., Crombez, Van Ryckeghem, Eccleston, &

Van Damme, 2013), such as in the context of pain-evoking movements (Van Hulle et al., 2013). Both chronic low back pain patients and patients with persistent orofacial muscle pain have been assumed to be fearful for movements that are related to the painful region (Visscher, Orbach, van Wijk, Wilkosz, & Naeije, 2010; Vlaeyen, Kole-Snijders, Boeren, & van Eek, 1995). It has been suggested that movements may acquire a threat value as a result of associative learning processes (Meulders et al., 2011). As studies with healthy volunteers have already demonstrated the presence of sensory suppression in the context of back movements (Van Hulle et al., 2013) and jaw movements (Andreatta & Barlow, 2003; Kemppainen et al., 1993, 2001), an interesting avenue for future research would be to investigate in individuals with chronic pain whether the execution of a movement that is expected to induce pain in the affected body part leads to a reduced sensory suppression on that part of the body.

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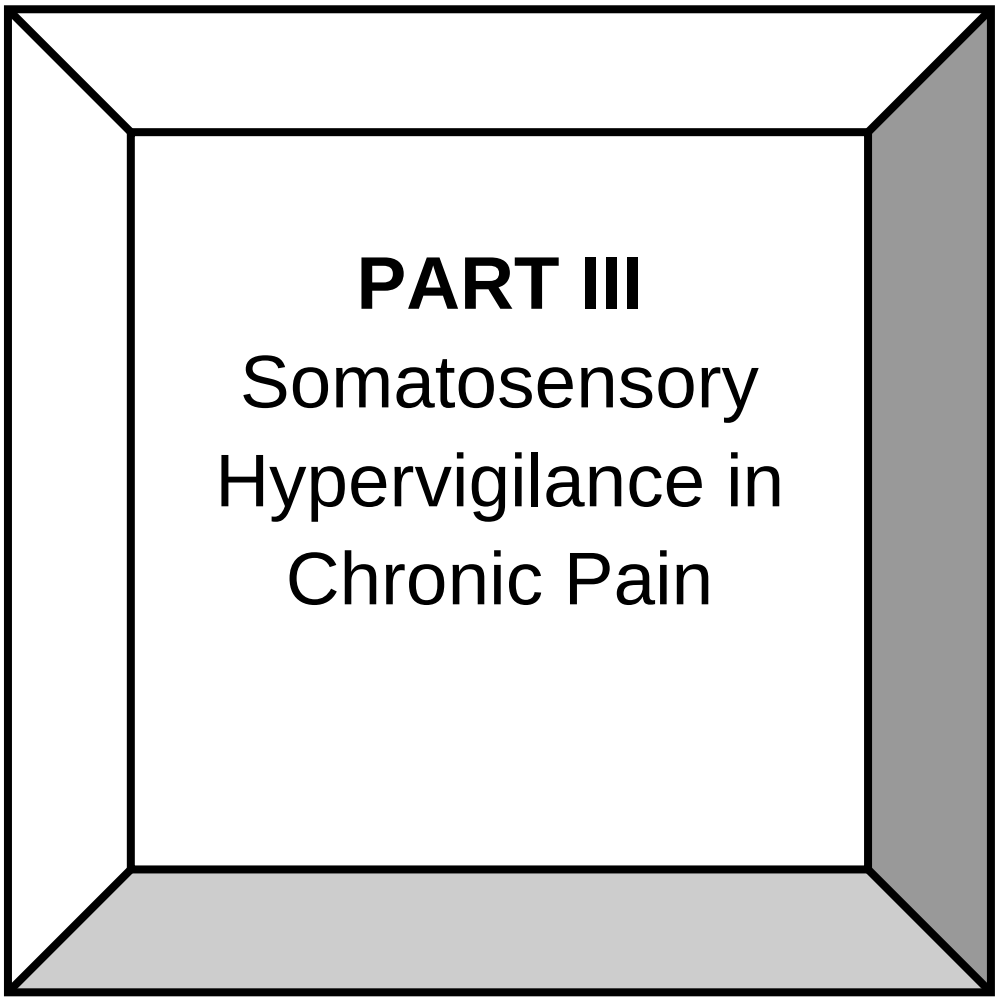
PART III
Somatosensory
Hypervigilance in
Chronic Pain

7

SOMATOSENSORY HYPERVIGILANCE IN PATIENTS WITH FIBROMYALGIA: AN EXPERIMENTAL INVESTIGATION[1]

ABSTRACT

Hypervigilance is often assumed to play an exacerbating role in pain and disability in persons with fibromyalgia (FM). Compelling evidence for the idea that these persons have a stronger attentional focus on pain-related information is however lacking. The present study examined somatosensory hypervigilance in a sample of individuals with FM and a matched control group by means of both self-report and behavioral measures. The behavioral measure consisted of a tactile change detection task in which participants had to detect changes between two consecutively presented patterns of tactile stimuli at various body locations. The task was performed under two conditions. In the divided attention condition, tactile changes occurred equally often at all possible body locations. In the focused attention condition, participants were informed about which body location would be most likely to be involved in tactile changes. The results did not support the thesis that persons with FM exhibit somatosensory hypervigilance. Although questionnaire scores suggested that participants with FM are more attentive to pain and other bodily sensations as compared to the control group, this was not confirmed by the results on the behavioral measure. In neither condition participants with FM were better than the control participants in detecting tactile changes. Possible explanations for these findings, as well as implications for hypervigilance theory and assessment, are discussed.

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INTRODUCTION

Hypervigilance is a central concept in several theoretical models attempting to explain amplified pain perception, disability, and distress in chronic pain sufferers (Chapman, 1986; Crombez, Van Damme, & Eccleston, 2005; Rollman, 2009; Sullivan, Rodgers, & Kirsch, 2001; Vlaeyen & Linton, 2000). The idea that patients display an excessive attentional focus (i.e., hypervigilance) toward pain and pain-related information is particularly popular in the context of fibromyalgia (FM), a chronic pain condition characterized by widespread, medically unexplained, muscle pain and other physical symptoms. Patients with FM typically show higher scores on self-report measures of hypervigilance, such as the Pain Vigilance and Awareness Questionnaire (PVAQ; McCracken, 1997), than healthy controls (Crombez, Eccleston, Van den Broeck, Goubert, & Van Houdenhove, 2004; Peters, Vlaeyen, & van Drunen, 2000; Roelofs, Peters, McCracken, & Vlaeyen, 2003; Tiemann et al., 2012). However, it has been argued that these elevated scores may be confounded by report bias and the mere presence of multiple somatic complaints in FM patients (Crombez et al., 2004).

The presence of hypervigilance in FM patients is also often derived indirectly from studies showing an increased sensitivity to both painful and non-painful somatosensory information. For instance, several studies have demonstrated lowered pain threshold and tolerance in patients with FM as compared to healthy controls (Kosek, Ekholm, & Hansson, 1996; Lautenbacher, Rollman, & McCain, 1994; McDermid, Rollman, & McCain, 1996). Furthermore, there are indications that FM patients perceive non-painful somatosensory stimuli as more intense than healthy controls (Geisser et al., 2003; Hollins et al., 2009), although a study by Peters et al. (2000) failed to demonstrate faster detection of slowly increasing innocuous electrical stimuli at different body locations in FM patients as compared with healthy controls. However, it should be noted that hypervigilance is not the same as hypersensitivity (Van Damme et al., 2009). Crucial to infer the presence of hypervigilance is the demonstration that pain-related features are prioritized by the attention system at the expense of other information (Crombez et al., 2005; Van Damme, Legrain, Vogt, & Crombez, 2010). Essential, therefore, are behavioral paradigms that are capable of assessing the selection of pain-related information in an environment with multiple demands.

Although there are indications that FM patients' attention is biased towards pain-related words (González et al., 2010; Vago & Nakamura, 2011), the suitability of visual selective attention paradigms to assess somatosensory hypervigilance can be questioned. A recent meta-analysis showed that the effect size of the attentional bias towards pain-related words in chronic pain patients was only small, and even not significantly different from that observed in healthy controls (Crombez et al., 2013). It has been argued that the use of linguistic stimuli is unfortunate, as there are doubts about their capability to activate schemata of bodily threat, and the development of somatosensory versions of attentional bias paradigms has been recommended as a potential way to overcome this problem (Crombez, Van Ryckeghem, Eccleston, & Van Damme, 2013; Van Damme et al., 2010). One can easily argue that somatosensory stimuli, being administered directly to the participants' skin, might be both personally relevant and ecologically valid. Nonetheless, studies investigating somatosensory hypervigilance in FM patients are rare. In one study, however, Tiemann et al. (2012) applied individually calibrated laser pain stimuli during a visual reaction time task in 50% of the trials, and found no difference in reaction time degradation during pain between FM patients and healthy controls. This suggests that when the intensity of pain stimuli is matched between FM patients and healthy controls, pain is not prioritized more by the attentional system in FM patients than in healthy controls. Possibly, however, hypervigilance in FM patients may only emerge in the processing of non-painful somatosensory information, as pain has an intrinsic attention-demanding character in everyone (Eccleston & Crombez, 1999). Studies investigating this idea are lacking.

The aim of the present study was to examine somatosensory hypervigilance in a sample of patients with FM and in a matched control group by means of a multi-method approach using both self-report questionnaires and a behavioral measure of somatosensory hypervigilance. The behavioral measure consisted of a tactile change detection task (Gallace, Tan, & Spence, 2006), in which two consecutive patterns of innocuous tactile stimuli were presented at various body locations. In half of the trials, the stimulated body sites in the two patterns were identical. In the other half of the trials, one of the stimulated body sites differed between the two patterns. Participants had to report whether the patterns were the same or not. As it has been demonstrated previously that focusing attention to a

certain body location improves the detection of tactile changes on that location (Van Hulle, Van Damme, Spence, Crombez, & Gallace, 2013), somatosensory hypervigilance should be reflected by a more accurate detection of tactile changes. The tactile change detection task was performed under two conditions. In the divided attention condition, tactile changes occurred equally often at all possible body locations. In the focused attention condition, participants were informed about which body location would be most likely to be involved in tactile changes. The following hypotheses were tested: (1) self-reported hypervigilance is higher in individuals with FM than in matched controls; (2) tactile change detection performance in the divided attention condition is better in individuals with FM than in matched controls; (3) in the focused attention condition, FM patients are better than matched controls in detecting tactile changes at unattended locations. That is, we expected that the habit to scan the body for signals of potential threat in individuals with FM would interfere with the task instruction to attend to one particular location of the body.

METHODS

Participants

Forty-one individuals with FM (N = 41; 37 females, 4 males) between 19 and 63 years (M = 45.34, SD = 10.15) were paid to take part in the study. The participants were recruited through the Multidisciplinary Pain Clinic of Ghent University Hospital. They were informed about the opportunity to participate in a study by means of a poster in the waiting room of the clinic, information given by their physician, and information letters. Individuals who granted permission for contact were contacted by the researcher in order to provide more information, check their eligibility, and to make an appointment, if they so desired. The participants were screened for eligibility using the following criteria: a diagnosis of FM according to the criteria of Wolfe et al. (1990), the absence of neurological conditions, age between 18 and 65 years, and sufficient knowledge of Dutch language. The control group consisted of forty-two individuals (N = 42; 38 females, 4 males) between 21 and 65 years (M = 42.69, SD = 10.81) who fulfilled the following criteria: the absence of chronic pain problems and neurological conditions, age between 18 and 65 years, and sufficient knowledge of Dutch

language. The control group was recruited by means of advertisement in local papers. Individuals who granted permission for contact were contacted by the researcher in order to provide more information, check the eligibility criteria, and to make an appointment, if they so desired.

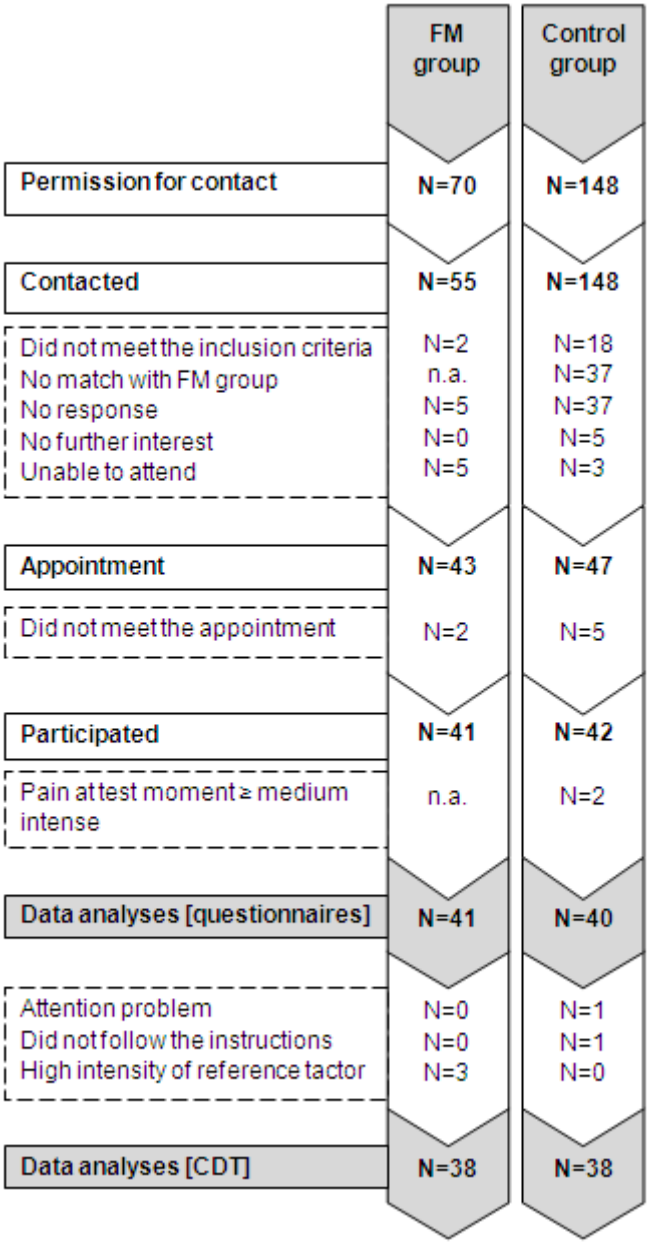

Figure 1. Flow chart visualizing participants' drop out from initial recruitment till suitability for analyses with regard to the questionnaires and the tactile change detection task (CDT).

Figure 1 provides a flow chart of the study. The FM and the control group were matched for age, sex, and education level on a group level. The study was approved by the Medical Ethical Committee of the Ghent University Hospital. All participants gave informed consent and were free to terminate the experiment at any time.

Apparatus and Materials

Tactile stimuli (200 ms) were presented by means of eight resonant-type tactors (C-2 TACTOR, Engineering Acoustics, Inc.) consisting of a housing of 3.05 cm diameter and 0.79 cm high, with a skin contactor of 0.76 cm diameter. The stimuli were administered on eight different body locations (see Figure 2). These locations included the forearm (left and right), the upper arm (left and right), the area just above the ankle (left and right), and the area just below the knee (left and right). Tactors were attached directly to the skin 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 environment noise. Prior to the start of the experiment, the stimulus intensities of each tactor were individually matched, as there is evidence for variation in sensitivity depending on the stimulated body site (Weinstein, 1968). In order to accomplish this matching procedure a tactile stimulus (reference stimulus, P = 0.04 watt) was presented at the right wrist. When participants were not able to perceive this stimulus, the intensity was slightly raised (+0.03 watt or +0.06 watt). Next, tactile stimuli were presented separately at each relevant location, and participants were asked whether the intensity was lower, higher, or equal to the intensity of the reference stimulus. The reference stimulus was repeatedly administered before moving to another tactor location, in order to make sure that they remembered the intensity of the reference stimulus correctly. The intensity of each tactor was varied until it was perceived as being equal to the intensity of the reference stimulus. As such, tactile stimulation at each location was perceived as equally intense (i.e., matched) by the participant (Van Hulle et al., 2013).

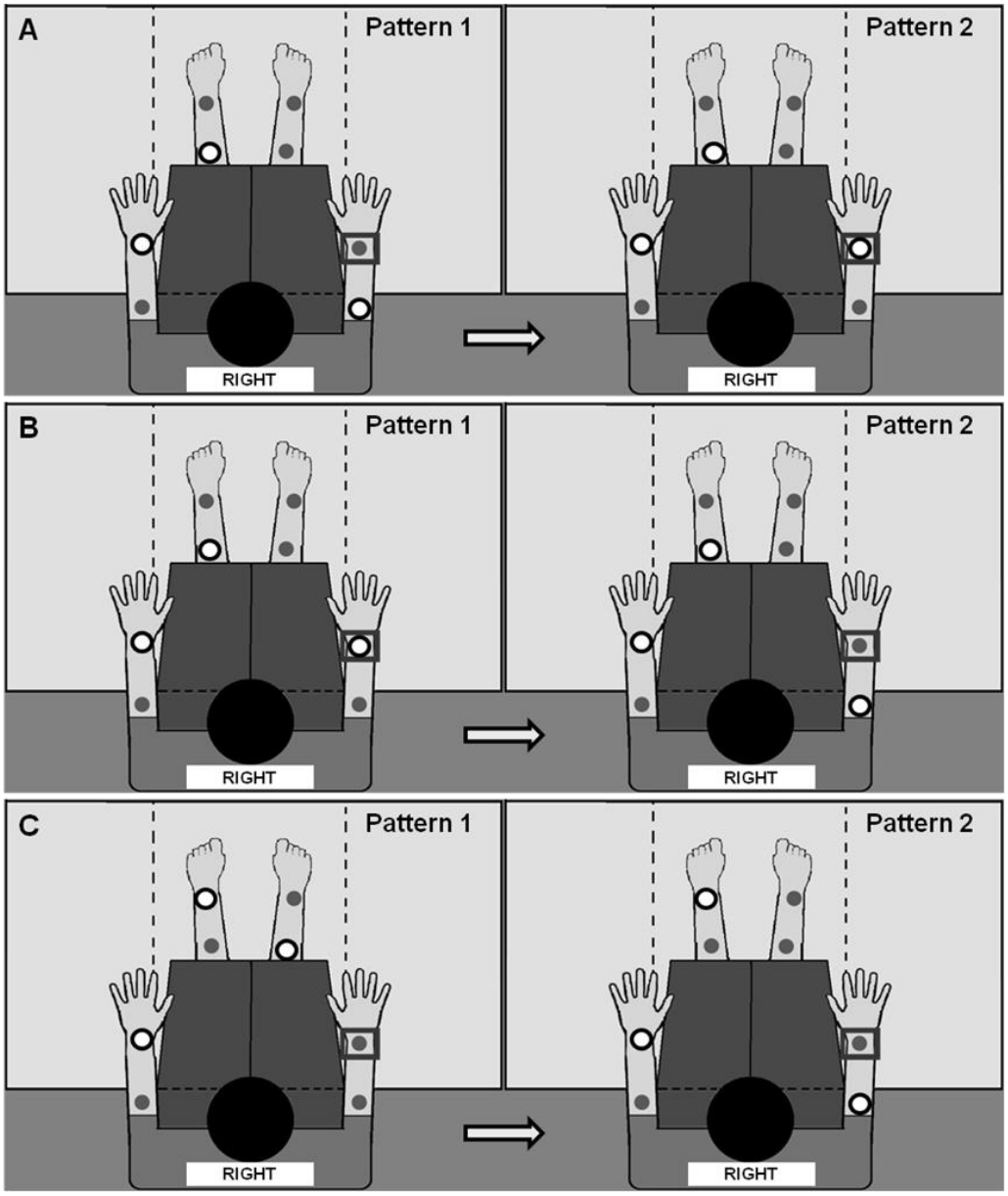

Figure 2. The three panels illustrate the different trial types in the focused attention condition. The grey dots represent the tactor locations that were used in the experiment. The white dots represent active tactor locations. The squares indicate the body location to which participants' attention was manipulated, in this example the right forearm. Panel A provides an example of a valid change trial in which a tactor location of the first pattern becomes inactive in the second pattern, and the tactor location on the valid location becomes active instead. Panel B provides an example of a valid change trial in which the tactor location on the valid location becomes inactive in the second pattern, and another tactor location becomes active instead. Panel C provides an example of an invalid change trial, in which the tactile does not involve the manipulated body location.

The Tactile Change Detection Task

The paradigm was programmed and controlled by Inquisit Millisecond software (Inquisit 3.0) on a PC laptop (HP Compaq nc6120) with a keyboard. The participants were instructed to keep their eyes on the black-colored screen for the duration of the experiment. Each trial started with a white fixation cross that appeared in the centre of the screen for 500 ms. Next, the first stimulus pattern was presented for 200 ms, followed by an empty stimulus interval of 110 ms, after which the second stimulus pattern was presented for 200 ms. 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 towards another location in the second tactile pattern. So, one of the three tactors that were active during the first pattern was inactive during the second pattern, and a tactor positioned at another body location became active instead (see Figure 2 for an illustration). 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 3500 ms response time, and it was stressed that accuracy, rather than speed, was of importance.

Procedure and Attention Manipulation

Before engaging in the tactile change detection task, the participants were instructed that each trial consisted of the presentation of two consecutive tactile patterns that could either be identical or not. The tactile change detection task was performed under two conditions. In the *divided attention* condition, participants were instructed that changes in tactile locations could occur with an equal probability from/toward all body locations. In the *focused attention condition,* participants’ focus of attention was manipulated toward one specific body location (left or right forearm; counterbalanced across blocks; see Figure 2 for an illustration). Before each block, a picture was shown that indicated on which arm a change was most likely to occur. The location on which the change could occur

was validly indicated in 2/3rd of the trials (valid trials), and invalidly on the remaining 1/3rd of the trials (invalid trials). As such two types of change trials were distinguished. In *valid* change trials, a pattern change implied a relocation of one tactile stimulus from one body location toward the manipulated location or from the manipulated location toward another body location. There was an equal proportion of trials in which a change implied a relocation from the left or right arm or leg to the manipulated body location, and vice versa. In *invalid* change trials, a pattern change involved a relocation of one tactile stimulus to another location of the body, but never the manipulated location. A relocation of one tactile stimulus to another body location could occur from all body locations. The different trials 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 28 trials. In the experimental phase, the participants completed a total of 528 trials, which were divided into six experimental blocks. There were two divided attention blocks, consisting of 2 x 88 trials (44 'same' trials, 44 'different' trials), two focused attention blocks in which attention was directed to the right forearm, consisting of 2 x 88 trials (44 'same' trials, 28 valid 'different' trials, and 16 invalid 'different' trials), and two focused attention blocks in which attention was directed to the right forearm, consisting of 2 x 88 trials (44 'same' trials, 28 valid 'different' trials, and 16 invalid 'different' trials). The order of the blocks was counterbalanced across participants. The participants were informed that they could take a break between these blocks, if they so desired.

Self-report Measures

The Dutch version of the PainDetect (Freynhagen, Baron, Gockel, & Tölle, 2006; Timmerman et al., 2013), provided a measure of pain intensity at the moment of testing, average pain intensity during the last four weeks, and most intense pain during the last four weeks. Participants had to rate this items on an 11-point numerical rating scale from 0 ("none") to 10 ("maximal").

The Pain Disability Index (PDI; Pollard, 1984) is a 7-tem inventory designed to measure the degree to which pain interferes with functioning across a range of activities (e.g., social, work, or daily activities) on an 11-point rating scale ranging from 0 ("no disability") to 10 ("total disability"). The total PDI score thus ranges

frome 0 to 70. This questionnaire has been shown to be reliable (Cronbachs' α = .86) and valid (Tait, Chibnall, & Krause, 1990). Cronbachs' α in the current study was 0.96.

The Dutch version of the *Pain Vigilance and Awareness Questionnaire* (PVAQ; McCracken, 1997; Roelofs, Peters, Muris, & Vlaeyen, 2002) contains 16 items rated on a 6-point scale measuring self-reported vigilance for pain sensations (e.g., *I focus on sensations of pain* [1 = "never", 5 = "always"]). The PVAQ has been shown to be valid and reliable in both healthy populations and chronic pain patients (Roelofs et al., 2002, 2003). Cronbach's α of the PVAQ in this study was 0.83.

The *Body Vigilance Scale* (BVS; Schmidt, Lerew, & Trakowski, 1997) is a four-item questionnaire measuring vigilance for bodily symptoms on a 11-point numerical rating scale (e.g., *On average, how much time do you spend each day 'scanning' your body for sensations* [0 = "no time", 10 = "all of the time"]). The last item is an average of the awareness scores of 15 non-specific body symptoms (e.g., *Rate how much attention you pay to each of the following … heart palpitations, dizziness, nausea, … sensations* [0 = "none", 10 = "extreme"]). Cronbach's α of the BVS in this study was 0.92.

Data Reduction and Data Analysis

A number of participants were excluded for further analyses because of the following reasons (see Figure 1): (1) the presence of a medium to high pain intensity at the moment of testing in the control group, (2) one person reported an attention problem as a result of which he/she could not stay focused on the task, (3) one participant reported not to follow task instructions, (4) for three participants the initial intensity of the reference tactor needed to be doubled (or more) in order to perceive this stimulus.

The data were analyzed using repeated measures Analyses of Variance (ANOVAs), independent samples *t*-tests, and Pearson correlations. In the divided attention condition, analyses were performed on the proportion of accurately detected changes, and on the proportion of false alarms. The proportion of false alarms is the proportion of inaccurately (falsely) detected changes on same trials. In the focused attention condition, analyses were performed on the proportion

accurately detected changes on valid and invalid trials. Furthermore, a validity index was calculated by subtracting the proportion accurately detected changes on invalid trials from the proportion accurately detected changes on valid trials. Note that the proportion of false alarms could not be calculated for the valid and invalid location separately. More specifically, when a change was present, a distinction could be made whether this change occured at a valid or invalid location. However, during same trials, when no change occured, it was not possible to determine whether a false alarm corresponded with valid or invalid trials.

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) formula (as cited in Borenstein, Hedges, Higgins, & Rothstein, 2009). 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).

RESULTS

Sample Characteristics

An independent samples *t*-test showed that there was no significant difference in age between the FM (M = 45.34, SD = 10.15) and the control group (M = 42.37, SD = 10.37; $t(79) = 1.30$, $p = .197$). Chi-square tests showed that both sex ($X^2(1, N = 81)) = 0.13$, $p = .718$) and education level ($X^2(4, N = 81)) = 7.09$, p=.131) were equally distributed among the fibromyalgia and the control group.

All the participants (100%) of the FM group (N = 41) and 67.50% of the participants of the control group (N = 40) reported to have experienced pain in the last four weeks. Independent samples *t*-tests revealed that average pain during the last four weeks was significantly higher in the FM group (M = 6.61, SD = 1.22) as compared to the control group (M = 1.43, SD = 1.63; $t(79) = 16.22$, $p < .001$; d = 3.60, 95% CI [2.90, 4.31]). Furthermore, most intense pain during the last four weeks was higher in the FM group (M = 8.49, SD = 1.19) than in the control group (M = 2.45, SD = 2.62; $t(79) = 13.41$, $p < .001$; d = 2.98, 95% CI [2.35, 3.61]). All participants (100%) of the FM group reported pain at the moment of testing, in

contrast to 30% of the control group. Pain intensity at the moment of testing was significantly higher in the FM group (M = 6.32, SD = 1.51) than in the control group (M = 0.50, SD = 0.85; $t(79) = 21.34$, $p < .001$; d = 4.73, 95% CI [3.89, 5.58]). Moreover, PDI-scores revealed that participants with FM were significantly more disabled (M = 46.61, SD = 7.08) than healthy controls (M = 7.95, SD = 11.96; $t(79) = 17.97$, $p < .001$; d = 3.95, 95% CI [3.20, 4.69]).

Self-report Measures

Independent samples t-tests revealed that the FM group (M = 43.20, SD = 8.74) had significantly higher scores on the PVAQ as compared to the control group (M = 32.55, SD = 10.54; $t(79) = 4.96$, $p < .001$; d = 1.10, 95% CI [0.63, 1.57]). The FM group (M = 17.94, SD = 6.45) also had higher scores on the BVS than the control group (M = 15.50, SD = 5.76), although this effect was only detected at trend level ($t(79) = 1.80$, $p = .076$; d = 0.40, 95% CI [-0.04, 0.84]).

The tactile change detection task

Task performance in the divided attention condition. Independent samples t-tests revealed that there was no significant difference in the proportion of accurately detected tactile changes between the FM (M = 0.60, SD = 0.18) and the control group (M = 0.58, SD = 0.17; $t(74) = 0.51$, $p = .612$; d = 0.11, 95% CI [-0.34, 0.56]). There was also no significant difference in the proportion inaccurate responses on same trials (false alarms) between the FM (M = 0.16, SD = 0.15) and the control group (M = 0.14, SD = 0.12; $t(74) = 0.59$, $p = .559$; d = 0.15, 95% CI [-0.30, 0.60]).

Task performance in the focused attention condition. A repeated measures ANOVA was performed with location (valid, invalid) as within-subjects variable, group (FM, control) as between-subjects variable, and the proportion accurately detected changes as the dependent variable. This analysis revealed that there was no main effect of location ($F(1,74) = 1.19$, $p = .279$; d = 0.15, 95% CI [-0.08, 0.37]), indicating that there was no difference in the proportion of

accurately detected tactile changes in valid trials (*M* = 0.61, *SD* = 0.20) as compared to invalid trials (*M* = 0.63, *SD* = 0.19). There was also no main effect of condition (*F*(1,74) = 0.13, *p* =.721; *d* = 0.11, 95% CI [-0.34, 0.56]), indicating that there was no difference in the proportion of accurately detected tactile changes between the FM (*M* = 0.61, *SD* = 0.20) and the control group (*M* = 0.63, *SD* = 0.16). The interaction effect between location and condition also proved to be not significant (*F*(1,74) = 0.36, *p* = .551), providing no support for the hypothesis that FM patients would be better than matched controls particularly in the detection of tactile changes at the unattended locations.

Table 1

Correlations between self-report measures of vigilance and awareness for pain and vigilance for bodily sensations on the one hand, and the proportion of accurately detected tactile changes in the divided attention condition, the proportion false alarms in the divided attention condition, and the validity index in the focused attention condition on the other hand.

	Fibromyalgia group		Control group	
	PVAQ	BVS	PVAQ	BVS
Proportion accurate responses on change trials	-.03	.32*	.35*	.21
Proportion inaccurate responses on same trials	.04	.12	-.09	.13
Validity index	-.07	.11	.06	.16
PVAQ	-	.46**	-	.62**
BVS		-		-

* p<.05. ** p<.01.

Pearson Correlations

Pearson correlations were calculated between self-report measures of hypervigilance and the proportion of accurately detected tactile changes in the divided attention condition, the proportion false alarms in the divided attention

condition, and the validity index in the focused attention condition. An overview of all these correlations is provided in Table 1.

The results showed that participants' scores on the BVS were positively correlated with the proportion accurately detected changes in the divided attention condition, although this was only significant in the FM group. Furthermore, the results demonstrated a positive correlation between the scores on the PVAQ and the proportion accurate responses on change trials in the control group, but not in the FM group. In both the FM and the control group, participants' scores on the PVAQ were significantly positively correlated with their scores on the BVS. None of the other correlations proved to be significant.

DISCUSSION

The present study examined somatosensory hypervigilance in a sample of individuals with FM and a matched control group by means of both self-report and behavioral measures. The behavioral paradigm consisted of a tactile change detection task in which the participants needed to detect changes between two consecutively presented tactile patterns. The tactile stimuli were calibrated to be perceived as equally intense across the different body locations. The task was performed under two experimental conditions: in the divided attention condition, tactile changes occurred equally often at all possible body locations; in the focused attention condition, participants were informed that most tactile changes would occur at one specific body location. It was tested whether (1) self-reported hypervigilance was higher in individuals with FM than in matched controls; (2) tactile change detection performance in the divided attention condition was better in the FM group than in the matched control group; (3) in the focused attention condition, FM patients were better than matched controls in detecting tactile changes at unattended locations.

The results demonstrated that the mean level of self-reported hypervigilance for pain (PVAQ; McCracken, 1997) was higher for individuals with FM as compared to control participants, thereby replicating the results of several other studies (Crombez et al., 2004; Peters et al., 2000; Roelofs et al., 2003; Tiemann et al., 2012). Participants with FM also reported more vigilance for non-painful bodily sensations, as measured with the BVS (Schmidt et al., 1997), than

matched control subjects, but this effect was only found at trend level. Yet, it should be borne in mind that the scores on these self-report measures in the FM group may be affected, at least to some extent, by the continuous presence of pain and other somatic symptoms, perhaps rather reflecting multiple somatic complaints than an excessive attentional focus (Crombez et al., 2004). Therefore, it is recommended to look also at behavioral measures that are less susceptible to such report bias.

Results of the behavioral measure did not support our hypotheses. In the divided attention condition participants with FM were not better than the control participants in detecting tactile changes. Also in the focused attention condition, no differences could be found between FM patients and healthy controls. That is, the detection of tactile changes was not better in FM patients than in healthy controls, neither at the attended location or at the unattended locations. This finding corroborates the results of Tiemann et al. (2012), who did not find differences between FM patients and healthy controls in the attentional processing of painful somatosensory information. The current study extends this finding by also not showing differences between these two groups in attention toward non-painful tactile stimuli. Altogether, the current findings are not supportive for the view that individuals with FM are hypervigilant toward innocuous somatosensory information. A number of issues require further elaboration. First, it could be raised that hypervigilance may only emerge in particular situations, as for example in the context of a movement execution that is expected to induce pain. Interestingly, it has already been suggested that movements may be able to acquire a threat value when they are repeatedly associated with pain (Meulders, Vansteenwegen, & Vlaeyen, 2011). Future research is definitely needed to test the idea of “situational hypervigilance”. Second, the task instructions that were given prior to the experiment may also have induced a state of elevated attention (i.e., ‘hypervigilance’) toward the body in the control group, making it more difficult to detect differences between FM patients and controls. Third, our results may seem at odds with studies that have demonstrated amplified perception of non-painful somatosensory stimuli in FM patients as compared to healthy controls (e.g., Hollins et al., 2009; McDermid et al., 1996; but see Peters et al., 2000). However, in the current study, somatosensory hypervigilance was operationalized as the prioritized selection of somatosensory information in an environment with

competing demands (Crombez et al., 2005). Such operationalization distinguishes the process of attention from the possible products resulting from elevated attention, such as lower pain threshold and tolerance levels. Hypervigilance is only one mechanism that may account for research findings demonstrating hypersensitivity in FM patients. Other processes, such as central sensitization (e.g., Arendt Nielsen & Henriksson, 2007; Staud, Robinson, & Price, 2007), have also been hypothesized to account for lowered pain threshold and tolerance levels in persons with FM. It is therefore recommended not to simply equate hypervigilance with hypersensitivity (Crombez et al., 2005; Van Damme et al., 2009)

Interestingly, correlation analyses showed that participants' scores on the BVS were positively associated with the proportion accurately detected changes in the divided attention condition of the change detection task. This may indicate that the BVS and the tactile change detection task measure, at least to some extent, similar processes, i.e., attention toward (non-painful) bodily sensations. It should be noted, however, that this correlation was only significant in the FM group. The results further showed that participants' scores on the PVAQ correlated with the proportion accurately detected changes in the control group, but not in the FM group. This differential effect may be the result of a smaller range and variability in PVAQ scores in the FM group as compared to the control group.

One limitation of the current study is that, in the focused attention condition, tactile change detection was not better in the valid trials than in the invalid trials, in neither the FM or the control group. This is in contrast to another change detection study that used a similar manipulation of attention (Van Hulle et al., 2013). In this study, healthy participants engaged in a tactile change detection task, and attention was manipulated toward one body location by instructing participants which new bodily location was most likely to be stimulated in the second pattern. It was found that changes at the attended location were detected more accurately than changes at bodily locations that were unattended. A number of differences between these studies may explain why the attentional manipulation did not work in the current study. First, in the study of Van Hulle et al. (2013), participants were informed that a change between the two tactile patterns would most likely imply an addition of a tactile stimulus on a specified body location. However, in the current study, participants' attention was manipulated to a specific location of the body by

informing them that a change would imply either an addition of a tactile stimulus on that location after the first pattern, or an omission from that location after the first pattern. However, this instruction may have complicated the task too much, possibly resulting in the failed attention manipulation. Second, while the participants in the study of Van Hulle et al. (2013) consisted of a student population familiar with performing behavioral tasks, the present study recruited an older participant sample from the general population. As a second limitation, it should be considered that the somatosensory stimuli used in the present study were very specific. Indeed, the stimuli in the present study were tactile, quite subtle, and had a duration of only 300ms. This limits the generalizability of the findings. Future research is needed to test whether different types of somatosensory information (e.g., in terms of modality, stimulus intensity and duration, …) can extend the present results.

In conclusion, although FM patients reported to be more attentive for painful and non-painful bodily sensations than matched controls, the data collected with a behavioral measure of somatosensory hypervigilance do not support the thesis that persons with FM exhibit somatosensory hypervigilance. This indicates that findings obtained with self-report measures of (hyper)vigilance should be interpreted with caution, as these measures are likely to be affected by other processes than attention. Before any firm conclusions can be drawn, however, future research may want to investigate the attentional processing of somatosensory information in more ecologically valid situations.

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8

DO BACK MOVEMENTS LEAD TO SOMATOSENSORY HYPERVIGILANCE IN PERSONS WITH CHRONIC LOW BACK PAIN?[1]

ABSTRACT

Although it is commonly assumed that fear of movement or (re)injury may lead to hypervigilance for (i.e., heightened attention to) pain-related information in individuals with chronic pain, studies have not yet investigated hypervigilance during ongoing pain-related movements. The aim of the current study was to examine whether individuals with chronic low back pain are hypervigilant for somatosensory information during the execution of a back movement. Both participants with chronic low back pain and matched control subjects engaged in a movement-detection task in which they were instructed to (1) perform a back movement, an arm movement, or no movement, and (2) at the same time, detect the presence or absence of a tactile stimulus on the back, chest, or arm. While movement is typically known to reduce the perception of tactile stimuli at the moving body part, a phenomenon called "sensory suppression", it may be assumed that such suppression is less pronounced when attention is strongly focused at the moving body part. It was hypothesised that during back movements, chronic low back pain patients would focus attention more strongly to the back than healthy controls, resulting in reduced sensory suppression of tactile stimuli at the back. Overall, tactile stimuli were detected worse during both movements in both groups, indeed reflecting sensory suppression. The hypothesis that participants with chronic low back pain, as compared to healthy controls, would show less sensory suppression on the back during back movements was not confirmed. However, the chronic low back pain group showed overall better tactile detection than the control group, irrespective of which movement condition

[1] Van Hulle, L., Van Damme, S., Danneels, L., & Crombez, G. (in preparation). Do back movements lead to somatosensory hypervigilance in persons with chronic low back pain?

and which body part was stimulated. Explanations for this finding are discussed, as well as directions for future research.

INTRODUCTION

Hypervigilance, or the prioritized attentional processing of pain-related information, is often assumed to maintain or exacerbate pain and disability (Crombez, Van Damme, & Eccleston, 2005; Vlaeyen & Linton, 2000). It is commonly assumed that hypervigilance is induced by fear of movement or (re)injury (Crombez, Eccleston, Baeyens, Van Houdenhove, & Van Den Broeck, 1999; Roelofs et al., 2007; Vlaeyen & Linton, 2000, 2013). There is evidence that certain movements may acquire a threat value through associative learning processes (Meulders, Vansteenwegen, & Vlaeyen, 2011; Moseley & Hodges, 2005), and it has been proposed that these processes may also underlie movement-related fear in patients with chronic low back pain (CLBP) (Meulders & Vlaeyen, 2013). As it has been theorized that attention is oriented and monitored toward potential bodily threats (Haggard, Iannetti, & Longo, 2013; Legrain, Iannetti, Plaghki, & Mouraux, 2011; Van Damme, Legrain, Vogt, & Crombez, 2010), it may be expected that, during a threatening movement, attention will be focused on the body part where pain is anticipated, leading to increased perception of somatosensory information in that body part. Imagine, for example, an individual with CLBP who is about to bend over to lift up a heavy bag. He or she may be fearful that this movement will cause (further) damage, or worsen the pain, and as a result carefully scan the back region in order to detect potential signals of damage.

To the best of our knowledge, no studies have investigated hypervigilance in the context of pain-related movements. The aim of the current study is therefore to examine whether individuals with CLBP exhibit heightened attention to somatosensory information during the execution of movements that are related to the painful body part. For this purpose, a group of individuals with chronic low back pain and a matched control group engaged in a movement-detection task in which they were instructed to (1) perform a back movement, an arm movement, or no movement, and (2), at the same time, detect the presence or absence of a subtle tactile stimulus on the back, chest, or arm. It is well-documented that the

perception of somatosensory information is reduced during movement execution (Chapman & Beauchamp, 2006; Juravle, Deubel, & Spence, 2011; Kemppainen, Vaalamo, Leppällä, & Pertovaara, 2001; Williams, Shenasa, & Chapman, 1998; Williams & Chapman, 2000, 2002; Van Hulle, Van Damme, & Crombez, in preparation; Voss, Ingram, Wolpert, & Haggard, 2008). This phenomenon, often referred to as 'sensory suppression', is thought to result from both feed-forward motor signals that predict and modulate the activity evoked by incoming sensory signals, and re-afferent sensations resulting from body movements, leading to backward masking (for a detailed discussion, see Chapman & Beauchamp, 2006; Voss et al., 2008). However, it has been shown that voluntarily focusing attention to the stimulated location reduces sensory suppression (Juravle et al., 2011; Van Hulle, Juravle, Spence, Crombez, & Van Damme, 2013). Moreover, the results of a recent study suggest that during the execution of a pain-related movement, attention is directed toward the body part where the pain is expected, leading to a reduced sensory suppression on that body part (Van Hulle et al., in preparation).

The following hypotheses were tested. First, it was expected that, in line with previous research on sensory suppression, the detection of tactile stimuli would be worse during movement than at rest. Second, if individuals with chronic low back pain are indeed over-attentive for the back region during the execution of the back movements, this should be reflected in reduced sensory suppression of tactile stimuli at the back, in comparison with the control group.

METHODS

Participants

Thirty-two individuals with CLBP (18 females, 14 males; mean age = 40 years, age range 21-60 years) were paid to take part in the experiment. The participants were screened for eligibility using the following criteria: the presence of non-specific chronic low back for six months or more, the absence of other primary pain complaints and neurological conditions, age between 18 and 65 years, and sufficient knowledge of Dutch language. The participants were recruited through advertisement in local papers. Individuals who granted permission for contact were contacted by the researcher in order to provide more information, check their eligibility, and to make an appointment, if they so desired.

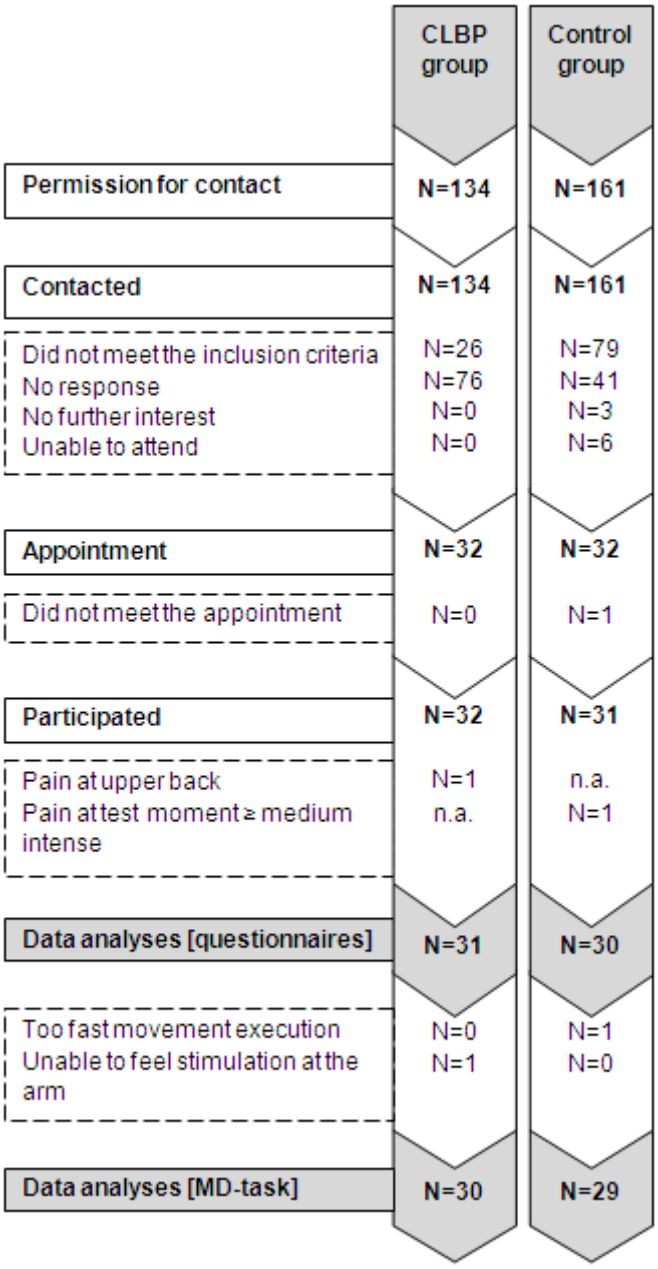

Figure 1. Flow chart visualizing participants' drop out from initial recruitment till suitability for analyses with regard to the questionnaires and the movement-detection task (MD-task).

The control group consisted of thirty-one individuals (16 females, 15 males; mean age = 39 years, age range 23-59 years) who fulfilled the following criteria: the absence of chronic pain problems and neurological conditions, age between 18 and 65 years, and sufficient knowledge of Dutch language. These participants

were partly recruited by means of advertisement in local papers, and partly from a group of randomly selected volunteers from a pre-existing database of the Health Psychology research group of Ghent University. All individuals who granted permission for contact were contacted by the researcher in order to provide more information, check the eligibility criteria, and to make an appointment, if they so desired.

Figure 1 provides a flow chart of the study. The CLBP and the control group were matched for age, sex, and education level on a group level. The study was approved by the Medical Ethical Committee of the Ghent University Hospital. All participants gave informed consent and were free to terminate the experiment at any time. They all reported normal tactile perception (absence of nerve damage or injuries) at those locations where the tactile stimuli would be delivered.

Apparatus and Materials

The tactile stimuli (200 ms) were presented by means of three resonant-type tactors (C-2 TACTOR, Engineering Acoustics, Inc., Florida) 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 tactors were applied to the lower back, the upper arm (M. Deltoïdus), and the chest. In the control group, the side of the body where the stimuli were applied was alternated between the subjects. In the clinical group, the tactors were applied to the body side where the participant reported to experience the most low back pain. 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 intensity of each tactor was determined individually, as there is evidence for variation in sensitivity depending on the body site stimulated (e.g., Weinstein, 1968). In order to do so, the intensity of the tactile stimulation was determined at rest for each participant by means of an adaptive double random staircase procedure designed to keep performance at a level of 50% (Levitt, 1971). Both staircases started with a randomly chosen

stimulation intensity between 0.00017 watts and 0.01377 watts (Power). As such, each staircase started with a different stimulation intensity. The presentation of trials from each of the staircases was randomized throughout this pre-experimental phase. The participants were instructed to respond whether or not they felt the presence of a stimulus by pressing on the corresponding keys (respectively ‘f’ and ‘j’ on an AZERTY keyboard). A staircase changed direction after one negative response (i.e., increasing the corresponding location stimulation by one step – ‘UP’) or one positive response (i.e., decreasing the corresponding location stimulation by one step – ‘DOWN’). Changes in the direction of the staircase are referred to as ‘reversals’. A run consists of a sequence of changes in stimulus level in one direction only, thus starting with a reversal. The staircase terminated once the total number of trials (30) had been reached. The first run was excluded from the final threshold calculations which consisted of the average of the mean values of each even run. The participants went through this procedure separately for the back, the arm, and the chest. As a stimulus with a 50% detection threshold intensity determined at rest can impossibly be perceived during movement execution, the intensity obtained by our procedure needed to be multiplied by a certain factor in order to make sure that participants would actually be able to detect the stimuli during movement. Pilot testing revealed that the obtained value needed to be multiplied by at least two in order to obtain a sufficient level of performance during movement. In the present study, we used three different intensities for the tactile stimuli: detection threshold was multiplied by two in one third of the trials (*low intensity*), by three in another third of the trials (*medium intensity*), and by four in the last one third of the trials (*high intensity*).

The set-up of the experiment is depicted in Figure 2. A movement consisted of the relocation of both hands from the start positions to the goal mice either horizontal or diagonal from the start positions. Two warning signals (auditory stimuli; 150 ms, 8399 Hz) and a starting signal (an auditory stimulus; 200 ms, 9491 Hz), with an inter-stimulus interval (ISI) of 550 ms, indicated when a movement needed to be executed.

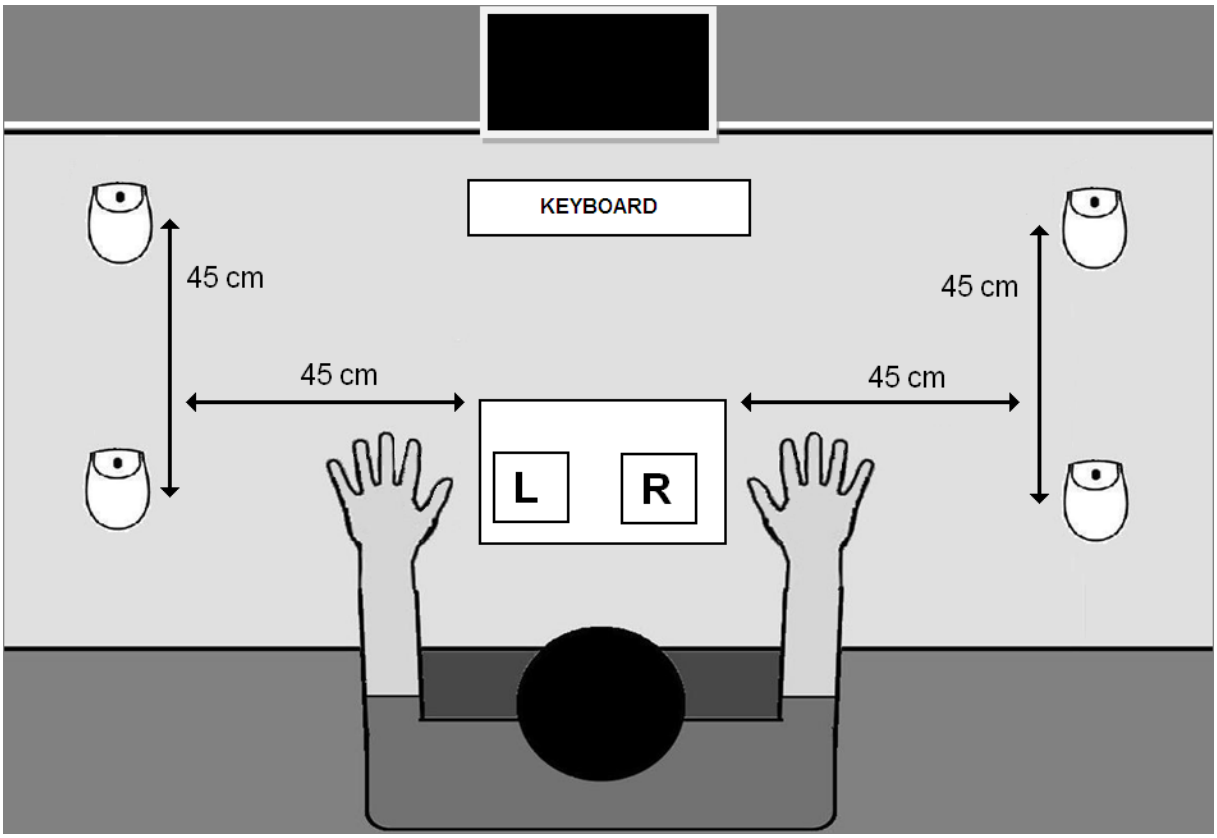

Figure 2. An illustration of the set-up of the experiment. At each forearm, tactors and electrodes were attached. Participants had to move both arms from the start positions to the goal mice either horizontal or diagonal from the start positions.

Movement-detection Task

In this dual-task paradigm, the participants simultaneously engaged in a movement task and a perceptual task. The *movement* task consisted of moving both hands from the start positions either toward the goal mice horizontal from the start position, which resulted in an arm movement, or toward the goal mice diagonal from the start position, which resulted in a back movement (see Figure 1). Before each block, a picture indicated whether participants needed to perform the arm movement or the back movement, or needed to keep their hands on the start position. The participants needed to press the space bar in order to start the first trial. Each trial, participants heard three auditory signals (200 ms), with an ISI of 550 ms: two warning signals which indicated that they needed to prepare for movement execution, and a start signal, which indicated that they needed to execute the required movement immediately. The participants were instructed to

press all buttons of the goal mice at arrival. When no movement needed to be executed, the trial ended 2900 ms after the start signal. The *perceptual* task consisted of an unspeeded detection of subtle tactile stimuli that could be administered on the back, the upper arm or the chest during the movement execution or rest blocks. It was also possible that no stimulus was delivered during these trials (*catch trials*). The stimuli were presented at two different timings (500 or 700 ms after the start signal) during the execution phase of the movement in order to reduce expectancy effects. In a rest block, tactile stimuli were delivered at the same points in time. Three different tactile stimulus intensities, selected in the pre-experimental phase, were used. An equal amount of stimuli with a low, medium, or high intensity were randomly administered within each block.

After clicking the goal mice, or after the end of a rest trial, the participants could respond whether they felt a tactile stimulus on the back, the upper arm, the chest, or not at all, by pressing the corresponding response keys (respectively, '1', '2', '3', or '0' on an AZERTY keyboard) with the index finger of their right hand. It was stressed that accuracy, rather than speed, was of importance. After each trial, the participants were instructed (on screen) to bring back their hand to the start position, and the next trial was started.

Self-report measures

Participants' pain prior to the experiment was assessed by means of the *Graded Chronic Pain Scale* (Von Korff, Ormel, Keefe, & Dworkin, 1992). This questionnaire consists of several items measuring pain intensity (*pain right now*, *worst* and *average pain during the past 6 months*) and disability (*interference with daily activities*, *social activities*, and *work activities*) that need to be rated on an 11-point numerical rating scale ranging from 0 to 10. Total intensity and disability scores vary from 0 to 100. The participants also register the total number of disability days during the past 6 months. The participants are classified in grades, ranging from 0 (pain free) to 4 (high disability-severely limiting). This questionnaire has shown to be valid and reliable for several pain problems (Von Korff et al., 1992).

The Dutch version of the *Pain Vigilance and Awareness Questionnaire* (PVAQ; McCracken, 1997; Roelofs, Peters, Muris, & Vlaeyen, 2002) contains 16

items rated on a 6-point scale measuring self-reported vigilance for pain sensations (e.g., *I focus on sensations of pain* [1 = “never”, 5 = “always”]). The PVAQ has been shown to be valid and reliable in both healthy populations and chronic pain patients (Roelofs et al., 2002, Roelofs, Peters, McCracken, & Vlaeyen, 2003). Cronbach’s α of the PVAQ in this study was .88.

The *Body Vigilance Scale* (BVS; Schmidt, Lerew, & Trakowski, 1997) is a four-item questionnaire measuring vigilance for bodily symptoms on an 11-point numerical rating scale (e.g., *On average, how much time do you spend each day ‘scanning’ your body for sensations* [0 = “no time”, 10 = “all of the time”]). The last item is an average of the awareness scores of 15 non-specific body symptoms (e.g., *Rate how much attention you pay to each of the following … heart palpitations, dizziness, nausea, … sensations* [0 = “none”, 10 = “extreme”]). Cronbach’s α of the BVS in this study was 0.91.

The Tampa Scale for Kinesiophobia (TSK; Kori, Miller, & Todd, 1990; Vlaeyen, Kole-Snijders, Boeren, & van Eek, 1995) measures fear of movement and (re)injury, and has been shown to be both valid and reliable (Vlaeyen et al., 1995). It consists of 17 items (e.g., *I’m afraid I might injure myself if I exercise*) that need to be rated on a 4-point numerical rating scale (0 = “strongly disagree” , 3 = “strongly agree”). Cronbachs’ α in the current study was 0.74.

Procedure

First, participants gave their informed consent and were asked to fill in the Graded Chronic Pain Scale (Von Korff et al., 1992) and general questionnaire, inquiring their age, sex, and education level.

Next, participants received the instructions for the movement-detection task. In a practice phase, the participants first performed six ‘movement task only’ and four ‘perception task only’ trials in which they got acquainted with the two tasks separately. Thereafter, the participants performed a total of 28 trials in which these two tasks were combined, as was the case in the experimental phase. Before the start of the experimental phase, the participants were asked to rate on an 11-point Likert scale (0 = “not at all”, 10 = “very much”) to what extent they feared that the back movement would evoke pain at the back; to what extent they feared that the

arm movement would evoke pain at the back; and to what extent they feared that they would experience pain at the back during rest.

The experimental condition consisted of total of 330 trials, divided between 15 experimental blocks: five arm movement blocks, five back movement blocks, and five rest blocks. Each block consisted of 22 trials. The order of the blocks was counterbalanced across the participants. As such, the experiment consisted of 27 within-subject conditions: Intensity (low, medium, high) x Movement (rest, arm, back) x Stimulus Location (chest, upper arm, back). An overview of the number of trials in each condition is provided in Table 1. The participants were informed that they could take a short break between the blocks, if they so desired. After each block, the participants were asked to complete a number of self-reports assessing to what extent they experienced pain at the back during the preceding block. The participants were asked to rate these items on a 11-point Likert scale ranging from (0 = “not at all”, 10 = “very much”). For each block type (rest, arm movement, and back movement), the mean pain ratings were calculated.

After the experiment, the participants were asked to complete the PVAQ (McCracken, 1997; Roelofs, 2002), the BVS (Schmidt, et al., 1997), and the TSK (Kori et al., 1990; Vlaeyen et al., 1995).

Table 1

An overview of the number of trials in each within-subject condition. The catch trials were removed for further analyses. In one third of these trials, the tactile stimuli had a low intensity (50% detection threshold multiplied by two), in one third of the trials, the tactile stimuli had a medium intensity (50% detection threshold multiplied by three), and in one third of the trials, the tactile stimuli had a high intensity (50% detection threshold multiplied by four).

		Stimulated body location			
		Chest	Arm	Back	No stimulus
Movement	Back	30	30	30	15
	Arm	30	30	30	15
	Rest	30	30	30	15

Data Reduction and Data analysis

A number of participants were excluded for further analyses because of the following reasons (see Figure 1): (1) the presence of pain at the upper back instead of low back pain in the CLBP group, (2) a medium to high pain intensity at the test moment in the control group, (3) too fast movement execution, i.e., faster than the administration of the tactile stimuli, (4) inability to feel tactile stimulation at the arm during the experimental phase – in contrast to the pre-experimental phase.

The data were analyzed using repeated measures Analyses of Variance (ANOVAs) with Intensity (low, medium, high), Movement (rest, arm, back), and Location (chest, arm, back) as within-subject factors, Group (control, CLBP) as a between-subjects factor, and the proportion accurately detected stimuli as the dependent variable. Paired samples *t*-tests and independent samples *t*-tests were used to test relevant effects. 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) formula (as cited in Borenstein, Hedges, Higgins, & Rothstein, 2009). 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).

RESULTS

Sample Characteristics

An independent samples *t*-test showed that there was no significant difference in age between the CLBP (M = 39.90, SD = 12.16) and the control group (M = 40.31, SD = 11.42; $t(57) = -0.13$, $p = .894$). Chi-square tests showed that both sex ($X^2(1, N = 59) = 0.15$, $p = .703$) and education level ($X^2(4, N = 59) = 1.67$, $p = .796$) were equally distributed among the CLBP and the control group.

All participants were classified in different grades of pain disability and intensity according to the Graded Chronic Pain Scale (Von Korff et al., 1992). A chi-squares test indicated that this classification was not equally distributed between the CLBP and the control group ($X^2(4, N = 59) = 33.94$, $p < .001$). More

specifically, from the participants in the CLBP group, 43.3% were classified in Grade 1 (low disability-low intensity), 36.7% in Grade 2 (low disability-high intensity), 13.3% in Grade 3 (high disability-moderately limiting), and 6.7% in Grade 4 (high disability-severely limiting). From the participants in the control group, 65.5 % was classified in Grade 0 (no pain), 24.1% in Grade 1 (low disability-low intensity), and 10.3% Grade 3 (high disability-moderately limiting). All participants of the CLBP group (100%), and 34.5% of the control group experienced pain during the last six months. Independent samples *t*-tests revealed that the reported "average pain" during the past six months was significantly higher in the CLBP group (M = 4.27, SD = 1.57) as compared to the control group (M = 0.86, SD = 1.53; $t(57) = 8.44$, $p < .001$; d = 2.20, 95% CI [1.55, 2.85]). The reported "most intense pain" during the past six months was higher in the CLBP group (M = 7.43, SD = 1.48) than in the control group (M = 1.97, SD = 3.17; $t(57) = 8.54$, $p < .001$; d = 5.14, 95% CI [4.08, 6.20]). Of CLBP participants, 93.3% reported pain at the moment of testing, in contrast to 17.20% of the control group. The reported pain intensity at the moment of testing was significantly higher in the CLBP group (M = 3.52, SD = 2.42) than in the control group (M = 0.41, SD = 1.02; $t(57) = 6.39$, $p < .001$; d = 1.66, 95% CI [1.07, 2.26]).

Questionnaires

Independent samples *t*-tests revealed that the CLBP group (M = 39.86, SD = 10.08) had higher scores on the PVAQ as compared to the control group (M = 27.66, SD = 12.39), as measured with the PVAQ ($t(59) = 4.23$, $p < .001$; d = 1.08, 95% CI [0.54, 1.62]). The CLBP group (M = 19.27, SD = 5.81) also had higher scores on the BVS in comparison with the control group (M = 15.91, SD = 7.22; $t(59) = 2.01$, $p = .049$; d = 0.51, 95% CI [0.00, 1.02]). Furthermore, the CLBP had higher TSK scores (M = 35.68, SD = 7.27) as compared to the control group (M = 31.30, SD = 5.44; $t(59) = 2.65$, $p = .010$; d = 0.68, 95% CI [0.16, 1.20]).

Movement-detection Task

Manipulation check. Independent samples *t*-tests on the self-reports indicated that participants with CLBP were more fearful to experience low back pain during the rest and the back movement condition than the control group, but not during the arm movement condition. Participants with CLBP reported a significantly higher back pain intensity than the control group during all movement conditions (back movement, arm movement, rest). Table 2 provides the means, standard deviations and statistics of the independent samples *t*-tests.

Table 2

CLBP and control participants' scores on the self-reported fear of back pain ratings and back pain ratings during the back movement (MovBack), the arm movement (MovArm), and rest (MovRest). Independent samples t-tests indicate whether both groups differed on these measures.

	CLBP		Control			
	M	*SD*	*M*	*SD*	*t(61)*	*p*
Fear back pain – MovBack	3.08	2.59	1.62	1.88	2.47	.016
Fear back pain – MovArm	1.20	1.65	0.90	1.52	0.73	.466
Fear back pain – MovRest	2.03	2.47	0.59	1.12	2.88	.006
Back pain – MovBack	2.66	2.28	1.06	1.74	3.02	.004
Back pain – MovArm	2.34	2.25	1.00	1.62	2.62	.011
Back pain – MovRest	2.40	2.19	1.03	1.64	2.72	.009

Movement latencies. The overall mean movement latency was 1466 ms (*SD* = 314.62). Paired samples *t*-tests showed that, overall, participants executed the back movement (*M* = 1582, *SD* = 319) slower than the arm movement (*M* = 1351, *SD* = 322, *t*(57) = 14.37, *p* < .001). A repeated measures ANOVA was performed with Movement (back, arm) as a within-subject factor and Group (CLBP, control) as a between-subjects factor, and latency (in ms) as the dependent variable. There was a significant main effect of Movement, indicating that participants executed the back movement (*M* = 1582, *SD* = 319) slower than the arm movement (*M* = 1351, *SD* = 322; *F*(1, 57) = 214.39, *p* < .001). There was

no significant main effect of Group, showing that participants of the CLBP group (*M* = 1499, *SD* = 315) were not slower than participants of the control group (*M* = 1432, *SD* = 316; *F*(1, 57) = 0.66, *p* = .419). The Movement x Group interaction was borderline significant (*F*(1,57) = 3.47, p = .067). Independent-samples *t*-tests revealed that individuals with CLBP (*M* = 1629, *SD* = 326) did not execute the back movement significantly slower as compared to the control group (*M* = 1533, *SD* = 310, *t*(57) = 1.16, *p* = .250). Also, individuals with CLBP (*M* = 1369, *SD* = 311) did not execute the arm movement significantly slower than the control group (*M* = 1332, *SD* = 338, *t*(57) = 0.45, *p* = .658). Within the CLBP group, arm movements were executed significantly faster than back movements (*t*(57) = 14.62, *p* < .001). Within the control group, arm movements were also executed significantly faster than back movements (*t*(57) = 7.67, *p* < .001).

Tactile detection accuracy. Overall, participants correctly detected 56.68% of the stimuli (*SD* = 14.82%). A repeated measures ANOVA was performed with Stimulus Intensity (low, medium, high), Movement (rest, arm, back), and Stimulus Location (chest, arm, back) as within-subject factors, Group (control, CLBP) as a between-subjects factor, and the proportion accurately detected stimuli as the dependent variable. Of particular importance to test the hypothesis that participants of the CLBP group would show less sensory suppression on the back during back movements as compared to the control group, was the three-way interaction effect Movement x Location x Group. However, this interaction proved to be not significant. Below, other relevant main effects and interaction effects are described.

Main effects*.* The analyses revealed a significant main effect of Intensity (*F*(1.48,56) = 237.30, *p* < .001). This effect was further explored by means of paired samples *t*-tests, which indicated that stimuli were detected better when the stimulus intensity was high (*M* = 0.67, *SD* = 0.15) as compared to when stimulus intensity was low (*M* = 0.44, *SD* = 0.15; *t*(58) = 17.24, *p* < .001; *d* = 1.53, 95% CI [1.28, 1.79]) or medium (*M* = 0.59, *SD* = 0.16; *t*(58) = 10.99, *p* < .001; *d* = 0.51, 95% CI [0.40, 0.61]). Stimuli of medium intensity were also detected significantly

better than stimuli of a low intensity ($t(58) = 14.10$, $p < .001$; $d = 0.96$, 95% CI [0.81, 1.12]).

There was also a significant main effect of Movement ($F(1.68,56) = 254.63$, $p < .001$). This effect was further explored by means of paired samples *t*-tests. These revealed that stimuli were detected significantly worse during the arm movement ($M = 0.50$, $SD = 0.22$) and the back movement ($M = 0.24$, $SD = 0.24$) than during rest ($M = 0.91$, $SD = 0.07$; resp. $t(58) = 14.24$, $p < .001$; $d = 2.39$, 95% CI [1.76, 3.02] and $t(58) = 18.81$, $p < .001$; $d = 3.79$, 95% CI [2.76, 4.82]). The stimuli were significantly better detected during the arm movement as compared to the back movement ($t(58) = 9.40$, $p < .001$; $d = 1.12$, 95% CI [0.89, 1.35]).

Moreover, there was a significant main effect of Location ($F(2,56) = 3.56$, $p = .035$). This effect was further explored by means of paired samples *t*-tests. These revealed that stimuli on the back ($M = 0.61$, $SD = 0.23$) were significantly better detected than stimuli on the chest ($M = 0.53$, $SD = 0.19$; $t(58) = 2.56$, $p = .013$; $d = 0.38$, 95% CI [0.06, 0.69]), but did not differ with the detection of stimuli on the arm ($M = 0.54$, $SD = 0.22$; $t(58) = 1.75$, $p = .086$; $d = 0.31$, 95% CI [-0.01, 0.63]). The stimuli on the arm were not significantly better detected than stimuli on the chest ($t(58) = 0.29$, $p = .465$; $d = 0.05$, 95% CI [-0.23, 0.33]).

Finally, there was a significant main effect of Group ($F(1,57) = 4.27$, $p = .043$), indicating that participants with CLBP ($M = 0.60$, $SD = 0.14$) were overall better in detecting the tactile stimuli than control participants ($M = 0.53$, $SD = 0.15$).

Two-way interaction effects. The Movement x Location interaction proved to be significant ($F(4,54)=28.66$, $p<.001$). Indices of sensory suppression (SS) were calculated in order to further explore how tactile detection on the different body locations was differently affected by the arm and the back movement. The indices of SS during arm movements were calculated by subtracting the proportion accurately detected stimuli during arm movements from the proportion accurately detected stimuli during rest for the different locations separately. The indices of SS during back movements were calculated by subtracting the proportion accurately detected stimuli during back movements from the proportion accurately detected stimuli during rest for the different locations separately. Significant effects are indicated on Figure 3.

Paired-samples *t*-tests indicated that during back movements, there was less SS for stimuli at the back (*M* = 0.52, *SD* = 0.29) as compared to stimuli at the chest (*M* = 0.69, *SD* = 0.27; *t*(58) = 4.49, *p* < .001; *d* = 0.61, 95% CI [0.36, 0.85]) and stimuli at the arm (*M* = 0.63, *SD* = 0.29; *t*(58) = 3.22, *p* = .002; *d* = 0.38, 95% CI [0.16, 0.60]). SS did not significantly differ between stimuli at the arm and stimuli at the chest (*t*(58) = 1.45, *p* = .151; *d* = 0.21, 95% CI [0.02, 0.41]). During arm movements, there was less SS for stimuli at the back (*M* = 0.21, *SD* = 0.24) as compared to stimuli at the arm (*M* = 0.53, *SD* = 0.30; *t*(58) = 9.02, *p* < .001; *d* = 1.16, 95% CI [0.83, 1.50]) and stimuli at the chest (*M* = 0.48, *SD* = 0.28; *t*(58) = 7.71, *p* < .001; *d* = 1.03, 95% CI [0.71, 1.35]). SS did not significantly differ between stimuli at the arm and stimuli at the chest (*t*(58) = 1.51, *p* = .135; *d* = 0.17, 95% CI [-0.08, 0.42]). Furthermore, paired-samples *t*-tests revealed that SS on the back was larger during back movements as compared to arm movements (*t*(58) = 8.83, *p* < .001; *d* = 1.15, 95% CI [0.82, 1.49). Also, SS on the arm was larger during back movements as compared to arm movements (*t*(58) = 4.68, *p* < .001; *d* = 0.34, 95% CI [0.20, 0.48]), and SS on the chest was larger during back movements as compared to arm movements (*t*(58) = 6.96, *p* < .001; *d* = 0.76, 95% CI [0.54, 0.99]).

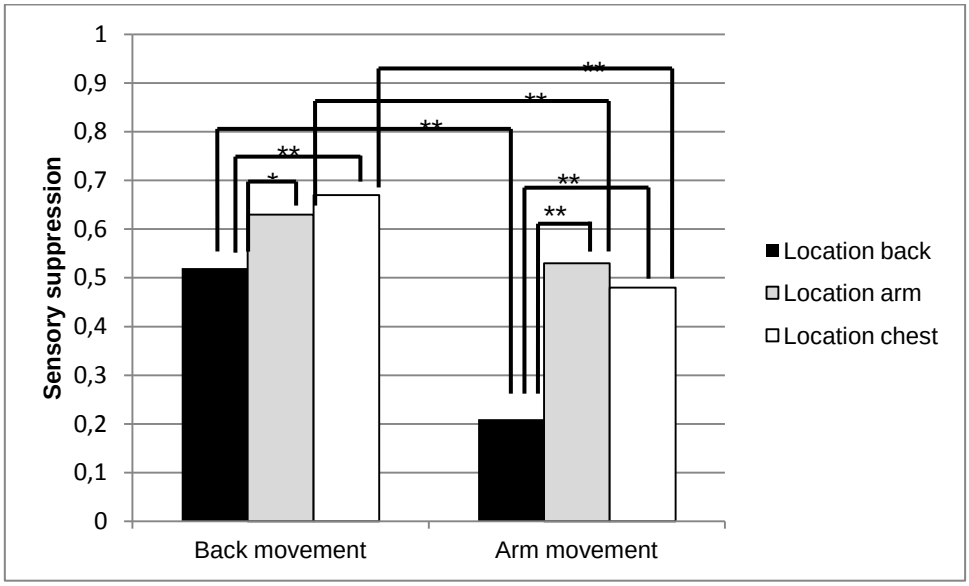

Figure 3. Indices of sensory suppression as a function of Movement (arm, back) and Location (chest, arm, back). [Note: * *p* < .05. ***p* < .001.]

The Intensity x Movement interaction proved to be significant ($F(3.21,54) = 13.33$, $p < .001$; see Figure 4). Again, indices of SS were calculated in order to further explore how the intensity of the tactile stimuli differently affected the amount of SS. The indices of SS during arm movements were calculated by subtracting the proportion accurately detected stimuli during arm movements by the proportion accurately detected stimuli during rest by for the different stimulus intensities separately. The indices of SS during back movements were calculated by subtracting the proportion accurately detected stimuli during arm movements by the proportion accurately detected stimuli during rest by for the different stimulus intensities separately. Significant effects are indicated on Figure 4.

Paired-samples *t*-tests revealed that for low intense, for medium intense, and for high intense stimuli, there was more SS during back movements as compared to arm movements (resp. $t(58) = 6.94$, $p < .001$; $d = 0.65$, 95% CI [0.45, 0.85], $t(58) = 8.94$, $p < .001$; $d = 0.58$, 95% CI [0.37, 0.79], $t(58) = 8.58$, $p < .001$; $d = 0.82$, 95% CI [0.61, 1.05]). There was more sensory suppression for stimuli of a low as compared to a high intensity, both during back movements ($t(58) = 3.07$, $p = .003$; $d = 0.31$, 95% CI [0.11, 0.50]) and during arm movements ($t(58) = 5.63$, $p < .001$; $d = 0.56$, 95% CI [0.35, 0.78]). Also, there was more sensory suppression for stimuli of a medium as compared to a high intensity, both during back movements ($t(58) = 5.57$, $p < .001$; $d = 0.33$, 95% CI [0.20, 0.46]) and during arm movements ($t(58) = 4.73$, $p < .001$; $d = 0.34$, 95% CI [0.20, 0.48]). During arm movements, there was more sensory suppression for stimuli of a low as compared to a medium intensity ($t(58) = 2.51$, $p = .015$; $d = 0.20$, 95% CI [0.03, 0.38]). However, during back movements, there was no difference in sensory suppression between stimuli of a low and a medium intensity ($t(58) = 1.03$, $p = .309$; $d = 0.08$, 95% CI [-0.06, 0.21]).

All other two-way interaction terms were not significant.

***Three- and four-way interactions*.** None of the interaction terms proved to be significant.

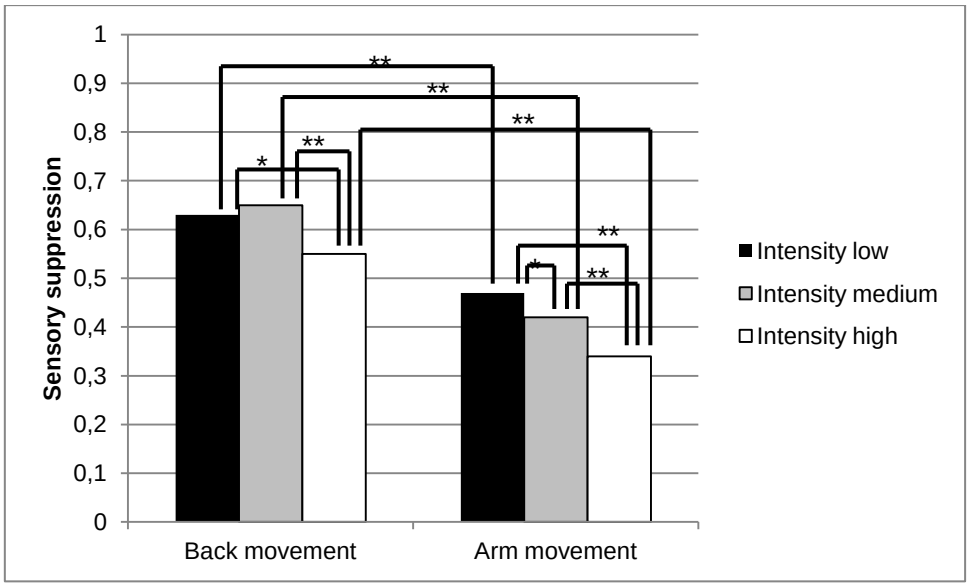

Figure 3. Indices of sensory suppression as a function of Movement (arm, back) and Intensity (low, medium, high). [Note: *$p < .05$. **$p < .001$]

Correlations

Pearson correlations were calculated for the CLBP group only, including the self-report measures of hypervigilance, pain-related fear, fear of back pain during the different movement conditions, and back pain ratings during the different movement conditions, and indices of sensory suppression on the different body locations during arm and back movements. An overview of these correlations is provided in Table 3. Overall, the pattern of these correlations suggest that higher back pain ratings are associated with less sensory suppression during movement. However, not all these correlations reached significance, and correlations were substantially lower in the context of the back movement. Furthermore, higher scores on the PVAQ and on the TSK were consistently associated with less sensory suppression, although only a small number of these correlations reached statistical significance.

Table 3

Pearson correlation matrix for the CLBP group.

	SS Mback Lback	SS Mback Larm	SS Mback Lchest	SS Marm Lback	SS Marm Larm	SS Marm Lchest
Fear back pain - Mback	.20	.29	.22	.06	.26	.19
Fear back pain - Marm	-.24	-.16	-.31	-.05	-.23	-.09
Fear back pain - Mrest	-.04	-.28	-.05	.03	-.32	-.14
Back pain - Mback	-.12	-.23	-.18	-.06	-.40*	-.08
Back pain - Marm	-.36*	-.40*	-.41*	-.35	-.52**	-.29
Back pain - Mrest	-.35	-.42*	-.45*	-.31	-.53**	-.32
BVS	-.00	-.11	.33	-.17	-.13	.13
PVAQ	-.29	-.38*	-.14	-.50**	-.33	-.32
TSK	-.28	-.25	-.20	-.50**	-.27	-.21

DISCUSSION

The aim of the current study was to investigate whether individuals with chronic low back pain exhibit heightened attention to somatosensory information during the execution of movements that are related to the painful body part. For this purpose, both participants with chronic low back pain and control participants engaged in a movement-detection task in which they were instructed to (1) perform a back movement, an arm movement, or no movement, and (2), at the same time, detect the presence or absence of a tactile stimulus on the back, the chest, or the arm. The following results were found. First, as expected, there was sensory suppression, i.e., tactile stimuli were detected worse during movement than during rest. This is in line with several other studies showing sensory suppression during movements (Chapman & Beauchamp, 2006; Juravle et al., 2011; Kemppainen et al., 2001; Williams et al., 1998; Williams & Chapman, 2000, 2002; Van Hulle et al., 2013, in preparation; Voss et al., 2008). Second, the hypothesis that sensory suppression of somatosensory information at the back during the execution of back movements would be reduced in the chronic low back pain group, as compared with the control group, was not confirmed.

Previous studies in healthy volunteers have demonstrated that in a context of bodily threat, attention is directed toward the body part where pain is expected (Vanden Bulcke, Van Damme, Durnez, & Crombez, submitted; Van Hulle, Van Damme, Durnez, & Crombez submitted), also during movements that are expected to induce pain (Van Hulle et al., in preparation). The present study indicates that these findings do not generalize towards individuals with CLBP, as we found no evidence that the CLBP group was more attentive for tactile stimuli at the back during back movements than the control group. Before drawing firm conclusions, however, it should be noted that although self-report measures revealed that participants in the CLBP group reported to be more fearful of pain on the back during back movements than the control group, their fear ratings were quite low. Furthermore, the CLBP group was also more fearful of pain on the back than the control group during the rest condition. Consequently, it may be that the required back movement was not that threatening to the participants with CLBP, thereby not resulting in a heightened level of attention to the back in the context of this movement.

Particularly intriguing was the finding that participants with CLBP were overall better in detecting tactile stimulation than matched control participants, regardless of movement or location. It is unlikely that this is the result of individual differences in sensitivity for somatosensory information, as in a pre-experimental phase, the intensities of the tactile stimuli were individually determined. One possible explanation for this finding is that the fearful expectation of pain may have elicited a general higher alertness in individuals with low back pain, as such leading to a better detection of tactile information that is unrelated to the pain region and independent of the specific movements. Supporting this idea, the results also showed that participants' scores on the PVAQ (McCracken, 1997) and the BVS (Smith et al., 1997) - questionnaires that inquire attention to somatosensory sensations, but not specifically with regard to the pain region or movement - were higher in the CLBP group as compared to the control group.

Exploratory correlation analyses in the CLBP group revealed that higher levels of back pain were associated with overall lower sensory suppression, i.e., a better detection of tactile information during movement execution. This finding seems to be at odds with two lines of research. First, is has been shown that in healthy samples, tonic pain reduces the perception of tactile information at the pain location, a phenomenon referred to as 'touch gating' (Apkarian, Stea, & Bolanowski, 1999; Bolanowski, Maxfield, Gescheider, & Apkarian, 2000). Second, it has been found that in individuals with CLBP, tactile thresholds and two-point discrimination thresholds at the back are reduced (Moseley, 2008). Our study indicates that back pain rather improves tactile perception, not necessarily on the back but also on other body parts not related to the painful region. This facilitative effect is intriguing, and may indicate a generalized alerting function of pain. A similar argument was provided by Ploner, Pollok, and Schnitzler (2004), who showed that in healthy volunteers, tactile processing in the somatosensory cortices was facilitated when tactile stimuli were shortly preceded by a phasic pain stimulus. Also in that study, the facilitative effect was not restricted to the painful location. It is possible that in our study, short increases in back pain due to movement, led to a temporarily change in the internal state of the body, allowing to prepare for the prioritized processing of threat-relevant signals. The overall negative correlations found between sensory suppression and self-reported measures of dispositional hypervigilance (PVAQ; McCracken, 1997) and fear of

pain/movement (TSK; Kori et al., 1990) in our CLBP group are in line with the suggestion of a generalized alerting effect of pain on tactile perception. However, more research is needed to investigate this idea.

Our study also replicates and further extends previous research on sensory suppression. In line with other studies (Van Hulle et al., in preparation; Williams and Chapman, 2000), we found that during movement, there was less sensory suppression for tactile stimuli of a higher intensity. Furthermore, we found that sensory suppression varies as a function of the distance between the site of the stimulation and the site of movement (Andreatta & Barlow, 2003; Williams et al., 1998; Post, Zompa, & Chapman, 1994). As may be expected, sensory suppression on the back was larger during back movements as compared to arm movements, since the back region was not involved in the execution of the arm movement. Sensory suppression of tactile stimuli on the arm was, perhaps surprisingly at first sight, more pronounced during back movements than during arm movements. However, for the arm movement, participants were only required to move the hands horizontally, whereas for the back movement they were not only required to move the back, but also the hands, and this in two directions (both horizontally and forward). It therefore makes sense that sensory suppression on the arm was larger during back movements than during arm movements. The fact that sensory suppression on the chest was rather high during both back movements and arm movements, may be explained by the fact that the muscles in the region of the chest were activated during both movements. Sensory suppression on the chest was even larger during back movements as compared to arm movements. This may be explained by the fact that during back movements, but not arm movements, the chest was passively moved forward (Williams & Chapman, 2002).

Another issue that needs to be addressed is that in the current paradigm, stimuli were administered to the participants' skin. Touch, coming from the external environment but involving the body, is considered to hold aspects from both interoceptive and exteroceptive processing (Haggard et al., 2013; Mehling et al., 2009). Future research may want to investigate whether patients with CLBP may be more attentive to 'entirely' interoceptive sensations, such as muscle contractions in the back, which may be considered to be more relevant signals of potential back damage.

In sum, the present study did not support the hypothesis that during back movements, individuals with chronic low back pain are hypervigilant to the region of the back, in comparison with a control group. Results did however show that individuals with chronic low back pain were overall better in detecting tactile information than matched controls, and that in CLBP patients more back pain during the experiment was associated with overall lower sensory suppression at all locations, possibly indicating a general alerting effect of pain. Future research is needed to identify which processes may account for this finding.

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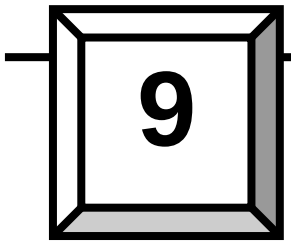

GENERAL DISCUSSION

PREFACE

In order to increase our understanding of chronic pain, a number of theories, such as the fear avoidance model (Vlaeyen & Linton, 2000) and the misdirected problem-solving model (Eccleston & Crombez, 2007), have been developed. One factor that often plays a central role in these theoretical models is hypervigilance. It is commonly assumed that individuals with chronic pain display hypervigilance for, or heightened attention to, pain-related information (Crombez, Van Damme, & Eccleston, 2005; Rollman, 2009). This hypervigilance is generally thought to result from a fearful appraisal and anticipation of pain (Chapman, 1978; Crombez et al., 2005; Eccleston & Crombez, 2007; Vlaeyen & Linton, 2000; Van Damme, Legrain, Vogt, & Crombez, 2010). However, despite the large amount of research investigating hypervigilance, convincing evidence for the idea that individuals with chronic pain are characterized by excessive attention to pain-related information is lacking. Moreover, the concept of hypervigilance suffers from an inconsistent conceptualization and operationalization.

In the current PhD thesis, hypervigilance was conceptualized as the prioritized attentional processing of somatosensory information in a context of multiple attentional demands (Crombez et al., 2005). By defining hypervigilance solely in terms of an attentional process, we stayed close to the original concept of Chapman (1978), who stated that "*… some individuals develop perceptual habits of vigilance for somatic distress signals, in particular pain sensations*". Furthermore, in our operationalization of hypervigilance, we only used behavioral paradigms in which pain-related information was presented in a context of competing attentional demands (Crombez et al., 2005). The aim of this thesis was threefold. First, we aimed to develop somatosensory attention paradigms by which priorities in the processing of somatosensory information can be assessed. Second, we aimed to investigate whether the threat of impending pain induces attentional prioritization of non-painful somatosensory information that is related to the pain, as it is often hypothesized that hypervigilance results from a fearful anticipation of pain. Finally, we tested the hypothesis that individuals with chronic pain are, as compared to healthy individuals, characterized by somatosensory hypervigilance.

SUMMARY OF THE MAIN FINDINGS

In **Part I** we investigated the value of a number of somatosensory paradigms to study the attentional processing of somatosensory information in a context of multiple demands. Participants' focus of attention was manipulated to either stimuli of a certain modality, if there were stimuli of different modalities, or to a certain body location, if there were multiple stimulated locations. In order to have utility in assessing somatosensory hypervigilance, our paradigms should be able to show that stimuli in the attended modality, or on the attended location, are detected better than stimuli in the unattended modality or at the unattended location. Three different paradigms were tested in samples of healthy persons, namely a modality cued signal detection task (Chapter 2), a tactile change detection task (Chapter 3), and a sensory suppression task (Chapter 4).

In ***Chapter 2***, participants engaged in a modality cued signal detection task. This task consisted of an un-speeded detection task in which weak somatosensory or auditory stimuli were administered. The focus of attention was manipulated by the presentation of a visual cue ("warmth" or "tone") which was predictive of the corresponding target in 2/3rd of the trials. It was found that cueing attention to a specific sensory modality resulted in a higher perceptual sensitivity for stimuli in the attended modality as compared to stimuli in the unattended modality. This suggests that the modality cued signal detection task is sensitive in detecting attentional prioritization of somatosensory information.

The results of the study described in ***Chapter 3***, in which participants performed a tactile change detection task in which they were instructed to detect changes between two consecutively presented tactile patterns, demonstrated that the manipulation of attention toward a specific location of the body resulted in a better detection of tactile changes occurring at the attended location than tactile changes at unattended body locations. This indicates that the tactile change detection paradigm is sensitive to detect attentional prioritization of body locations.

In ***Chapter 4***, participants engaged in a sensory suppression task, and were instructed to detect tactile stimuli presented at their upper or lower back, either during the execution of a back-bending movement or during rest. The findings showed that the perception of tactile information was reduced during movement execution, reflecting sensory suppression (e.g., Juravle, Deubel, & Spence, 2011; Williams & Chapman, 2000, 2002). Of particular importance was

the finding that, when participants' attention was strongly focused to one specific body location, tactile suppression was substantially reduced. This indicates that the sensory suppression paradigm is sensitive to detect attentional prioritization of body locations during movements.

In **Part II**, we examined the assumption that bodily threat leads to the attentional prioritization of non-painful somatosensory information. In two studies in healthy persons, the anticipation of pain on a specific body location was experimentally induced, either when sitting still (Chapter 5), or in the context of a pain-related movement (Chapter 6).

In ***Chapter 5***, the tactile change detection task was used to test the hypothesis that the threat of experimental pain on a specific location of the body would facilitate the detection of tactile changes on that particular body location. The results partly confirmed the hypothesis. Tactile changes were indeed detected better if they involved the threat location as compared to locations at other body parts. However, tactile changes that did not involve the exact threat location, but another location at the same body part, were also detected better than tactile changes at other body parts. These findings suggest that pain anticipation resulted in a higher awareness of tactile changes not only at the exact threatened location, but by extension at the whole body part on which pain was expected. As such, this study is supportive for the idea that the threat of pain affects the perception of non-painful somatosensory stimuli, although the spatial generalization of this effect to the whole body part was not expected.

In ***Chapter 6***, it was examined whether the expectation of pain during movement execution led to a reduced sensory suppression of tactile information on the body part where pain was expected. Participants engaged in a sensory suppression task in which they were instructed to (1) move both arms either to the left or to the right, or keep them at rest, and (2), at the same time, detect the presence or absence of a tactile stimulus on the left or the right forearm. One movement was made threatening by occasionally associating it with the administration of a painful stimulus on either the left or the right forearm. As hypothesized, during the execution of a threatening movement, tactile stimuli on the threatened body part were detected better than tactile stimuli on the neutral body part, indicating reduced sensory suppression as a result of pain anticipation.

However, in contrast to the hypothesis, tactile stimuli on the threatened body part were not detected better during the execution of a threatening as compared to a neutral movement. Instead, tactile stimuli at the neutral location were detected worse during the threatening than during the neutral movement. As such, this study is in line with the idea that the anticipation of pain during movement affects the perception of non-painful somatosensory stimuli, although the specific effects were not fully as expected.

In **Part III**, we examined the hypothesis that individuals with chronic pain are characterized by somatosensory hypervigilance in comparison with healthy controls. This was investigated in two different types of chronic pain, namely fibromyalgia (Chapter 7) and chronic low back pain (Chapter 8).

In ***Chapter 7***, individuals with fibromyalgia and matched control participants engaged in a tactile change detection task that was performed under two conditions. In the divided attention condition, tactile changes occurred equally often at all possible body locations. In the focused attention condition, participants were informed about which body location would be most likely to be involved in tactile changes. Although questionnaire scores suggested that participants with fibromyalgia were more attentive to pain and other bodily sensations as compared to the control group, this was not confirmed by the results on the behavioral measure. In neither condition, participants with fibromyalgia were better than the control participants in detecting tactile changes. This study thus failed to provide evidence for somatosensory hypervigilance in patients with fibromyalgia.

As hypervigilance is commonly assumed to be induced by fear of movement or (re)injury, ***Chapter 8*** investigated whether individuals with chronic low back pain are hypervigilant for somatosensory information during the execution of a back movement. Participants with chronic low back pain and matched controls engaged in a sensory suppression task in which they were instructed to (1) perform a back movement, an arm movement, or no movement, and (2), at the same time, detect the presence or absence of a subtle tactile stimulus on the back, the arm, or the chest. It was hypothesized that particularly during back movements, chronic low back pain patients would focus attention more strongly to the back than healthy controls, resulting in reduced sensory suppression of tactile stimuli at the back. Although questionnaire scores suggested

that individuals with chronic low back pain were characterized by somatosensory hypervigilance, the hypothesis that these persons would show less sensory suppression on the back during back movements than healthy controls, was not confirmed. However, the chronic low back pain group did show an overall better tactile detection performance than the control group, irrespective of which movement was performed or which body part was stimulated. This study did not support the idea that, during pain-related movements, chronic low back pain patients are hypervigilant for somatosensory information at the back.

INTEGRATIVE DISCUSSION AND THEORETICAL IMPLICATIONS

Somatosensory Attention Paradigms: Evaluation

The aim of the first part of this PhD thesis was to develop paradigms that are able to assess the attentional processing of somatosensory information. The results revealed that in all three paradigms, namely the modality cued signal detection task (Chapter 2), the change detection task (Chapter 3), and the sensory suppression task (Chapter 4), attention affected the processing of somatosensory information. More specifically, the results of the modality cued signal detection task demonstrated that when attention was directed toward either the somatosensory or the auditory modality, this led to a better detection performance of, respectively, somatosensory and auditory stimuli. By means of the tactile change detection task and the sensory suppression task, it was demonstrated that focused attention toward a specific location of the body enhanced the processing of somatosensory information that involved the attended body location. These findings are in line with previous research demonstrating that stimuli were responded to more rapidly when their modality or spatial location was cued (Spence, Nicholls, & Driver, 2001; Spence, Shore, & Klein, 2001; Spence & Paris, 2010; Yates & Nicholls, 2009, 2011). From these results, it may be concluded that these paradigms provide valuable tools to measure the prioritization of somatosensory information, and, therefore, to asses somatosensory hypervigilance.

These three paradigms all met our operationalization criteria of hypervigilance. First, it was argued that hypervigilance can only be investigated in a context in which there are multiple attentional demands (Crombez et al., 2005).

In the modality cued signal detection task, participants were informed that in each trial either a somatosensory, an auditory, or no stimulus, could be administered. In the tactile change detection task and the sensory suppression task, a task-environment with multiple demands was created by administering somatosensory stimuli at various locations of the body. In order to perform well on the task, which either involved detecting the presence or absence of a stimulus, or detecting the presence or absence of a change between tactile patterns, participants were thus required to divide their attention between information coming from multiple modalities or from multiple body locations. Particularly in such context, attentional preferences, resulting from task or other goals and concerns, should emerge, as only information that matches relevant features will be prioritized, while the processing of irrelevant stimuli will be inhibited (Corbetta & Shulman, 2002; Desimone & Duncan, 1995; Legrain et al., 2009). The studies reported here support this idea, as the task instructions to attend to stimuli of a certain modality (modality cued signal detection task) or on a certain location of the body (tactile change detection task and sensory suppression task), indeed led to a better detection of task-relevant as compared to task-irrelevant stimuli.

Second, all paradigms made use of somatosensory stimuli, which have been argued to have a higher ecological validity to measure heightened attentional processing of pain-related information as compared to other attentional bias paradigms, which generally utilize visual stimuli such as words or pictures. It has indeed been questioned whether visual representations of pain may sufficiently activate pain-related schemata in working memory (Crombez, Van Ryckeghem, Eccleston, & Van Damme, 2013; Van Damme et al., 2010). It should be noted, though, that studies that have investigated attention toward signals of impending pain, by associating simple visual (e.g., color) stimuli with a painful stimulus by means of classical conditioning, did show a clear effect of attentional bias toward pain-related information (Crombez et al., 2013; Van Damme, Crombez, & Eccleston, 2004; Van Damme, Crombez, Eccleston, & Koster, 2006). The utility of such approach in clinical populations is, however, unclear, as these studies were performed in undergraduate students.

Third, the three somatosensory attention paradigms reported here are based upon accuracy measures. Usually, the attentional bias paradigms used to investigate hypervigilance to pain-related information, such as the modified Stroop

task (Roelofs, Peters, Zeegers, & Vlaeyen, 2002), the dot probe task (Asmundson, Carleton, & Ekong, 2005), and the exogenous cueing task (Posner, 1978), have relied on reaction times to measure attentional processes. However, reaction times have been criticized as being less suitable to study attentional prioritization in chronic pain populations. These populations are typically characterized by cognitive impairment and psychomotor slowing (e.g., Dick, Eccleston, & Crombez, 2002; Glass, 2009; Veldhuijzen, Sondaal, & Oosterman, 2012), and it has been postulated that this may lead to a large reaction time variability and a decreased sensitivity for identifying attentional effects (Van Damme, Crombez, & Notebaert, 2008).

Finally, there is evidence that there is variation in somatosensory sensitivity between individuals, but also between different locations of the body (e.g., Weinstein, 1968). Therefore, in the tactile change detection task, the intensities of the tactile stimuli that were administered on the different body locations were individually matched. This way, the intensity of a stimulus administered on one location of the body was not perceived as more or less intense than a stimulus applied to another body location, a situation which would have confounded the sensitivity of the task to measure attention processes. In both the modality cued signal detection task and the sensory suppression task, participants were required to detect the presence or absence of subtle somatosensory stimuli, which were individually calibrated prior to the experiment (although the used calibration procedures differed somewhat across the different studies). As a result, we minimized the chance that increased perception of stimuli in one modality or at one body location could be attributed to individual differences in sensitivity, rather than to differences in the attentional processing of information.

Does the Threat of Impending Pain Induce Somatosensory Hypervigilance?

In Part II of this PhD thesis we aimed to investigate whether the anticipation of pain on a specific location of the body would lead to a better detection of somatosensory information presented at that location. A number of studies have investigated whether a context of bodily threat results in an attentional bias toward pain-related information in healthy volunteers. However, these studies, mostly involving the modified Stroop task (Roelofs et al., 2002), the dot probe task

(Asmundson et al., 2005), or the exogenous cueing task (Posner, 1978), have yielded mixed results. A recent meta-analysis by Crombez et al. (2013) showed that there was, overall, no evidence for an attentional bias towards pain-related words and pictures in healthy volunteers in a context of acute, procedural or experimental pain. There are, of course, some exceptions to this rule. A study of Van Damme, Crombez, et al. (2004), for example, demonstrated by means of a spatial cueing paradigm that healthy volunteers showed an attentional bias toward pain-related cues (Van Damme et al., 2006).

The results of both Chapter 5 and Chapter 6 provided evidence that the anticipation of pain on a specific location of the body prioritized the processing of non-painful somatosensory information that was presented on that body part. As discussed in more detail previously (Chapter 5 and 6), the results were however not straightforward. First, in Chapter 5, the manipulation of bodily threat on one particular location of the body was not limited to the prioritization of non-painful somatosensory information presented to the threatened body location, but also seemed to have affected other locations on the same body part. It is plausible that tactile changes in adjacent body regions, for instance the whole body part on which pain is expected, also become more salient. One could argue that this particular body part might have become an active feature in the attentional set, which may then have resulted in a better performance for detecting pattern changes involving this body site (Legrain et al., 2009; Van Damme et al., 2010). More research is however needed in order to explore the spatial boundaries of the attentional prioritization of tactile information that arises from the anticipation of pain.

Second, the results of Chapter 6 revealed that during the execution of a threatening movement, tactile stimuli on the threat location were detected better than tactile stimuli on the neutral body location. Also, and in contrast to what was expected, tactile stimuli on the threat location were not detected better during threatening movements as compared to neutral movements. Indeed, while our operationalization of hypervigilance presumed facilitated processing of pain-related somatosensory information, the results also demonstrated an inhibition of irrelevant information, i.e., tactile stimuli at a body part unrelated to pain. This was unexpected, but in keeping with a number of previous studies using reaction times as a measure of attention to painful information (Van Damme, Crombez, &

Eccleston, 2002; Van Damme, Crombez et al., 2004; Van Damme, Lorenz, Eccleston, Koster, De Clercq, & Crombez, 2004). More specifically, the study of van Damme, Crombez et al. (2004) showed that high pain catastrophizers showed a retarded disengagement from the location of visual cues that signaled pain as compared to low pain catastrophizers, although their attention was not shifted faster toward these pain cues. In addition, it should be noted that the results of this study were unexpectedly influenced by the between-subjects threat manipulation, as a result of which caution is warranted when interpreting these results.

It is important to note that we examined effects of anticipated, and not actual, pain on tactile perception. For this purpose, all trials in which a pain stimulus was administered, were excluded from the analyses. Indeed, pain itself may also have specific effects on tactile perception. Interesting from that perspective is a study of Ploner, Pollok, and Scnitzler (2004), who examined the effect of phasic pain stimuli on the processing of tactile stimuli that were applied 500 ms later. The results indicated that the experience of pain facilitated the processing of tactile stimuli, but this effect was not restricted to the painful location. The authors related this to a 'general alerting effect' evoked by the experience of salient stimuli. Nevertheless, the studies reported here rather investigated the effect of pain anticipation on the processing of tactile information on the location where the pain was expected.

Taken together, these results provide evidence that the anticipation of pain may lead to the prioritization of somatosensory information, as such lending support for general models that assume that there exists a salience-detection system in the brain by which attention is oriented and monitored to stimuli that may potentially threaten the integrity of the body (Haggard, Iannetti, & Longo, 2013; Legrain, Iannetti, Plaghki, & Mouraux, 2011; Moseley, Galace, & Spence, 2012). More specifically, the results also corroborate theories proposing that hypervigilance results from the anticipation of pain (Crombez et al., 2005; Vlaeyen & Linton, 2000). It was indeed assumed that these somatosensory stimuli would be prioritized by the attentional system because of their affective-motivational relevance (Legrain et al., 2009; Van Damme et al., 2010). The threat of impending pain may have activated location-specific features in participants' attentional set, as such resulting in a better detection of somatosensory information on the body part where the pain was expected. In fact, these results are in line with another

recent study that has indicated that the threat of pain at a certain body part enhances the processing of tactile stimuli at that body part (Vanden Bulcke, Van Damme, Durnez, & Crombez, submitted), and extend the findings of a recent study of Van Damme and Legrain (2012) in healthy volunteers, showing that in a context of bodily threat attention is prioritized to the location where pain stimuli are expected. However, future research needs to further confirm the present findings and explore the precise spatial boundaries of pain-related attentional prioritization of non-painful somatosensory stimuli.

The tactile change detection task and the sensory suppression task proved to be valuable methods to investigate the attentional prioritization of somatosensory information on a particular location of the body in the context of bodily threat. These paradigms were therefore further used to study somatosensory hypervigilance in chronic pain populations. Note that, in order to investigate the effect of pain anticipation on the processing of somatosensory versus auditory information, a number of experiments were performed in which the modality cued signal detection was used. Nonetheless, these experiments were not reported in this PhD thesis because of a number of methodological problems that could not be readily solved. For example, as has been mentioned in Chapter 2, the manipulation of attention to either the auditory or the somatosensory modality also involved a manipulation of attention to a specific location, as the stimuli of both modalities were associated with a specific location. Although this is a quite natural situation – imagine an individual with chronic low back pain who is especially preoccupied with somatosensory sensations in the region of the back – this paradigm did not allow to disentangle the processes of modality- or location-prioritization (e.g., Turatto, Galfano, Bridgeman, & Umiltà, 2004).

Somatosensory Hypervigilance in Individuals with Chronic Pain

The ultimate goal of this PhD was to investigate whether individuals with chronic pain are characterized by hypervigilance in comparison with healthy controls. We have mentioned earlier that despite the number of studies that have been devoted to the topic, evidence for this assumption is scarce and unconvincing (Crombez et al., 2013). The studies reported in Chapter 7 and Chapter 8 aimed to contribute to this field by investigating somatosensory

hypervigilance respectively in individuals with fibromyalgia by means of the tactile change detection task, and in individuals with chronic low back pain by means of the sensory suppression paradigm. It was hypothesized that individuals with chronic pain would be especially attentive to the region of the body where they usually are confronted with their pain complaints. Individuals with fibromyalgia, demonstrating widespread pain, were expected to be attentive to the whole body. However, individuals with chronic low back pain were expected to be especially attentive for somatosensory information that was presented in the region of the back. Indeed, from a cognitive-motivational perspective (Legrain et al., 2009; Van Damme et al., 2010) it may be expected that this information would have a higher informative and threat value concerning possible upcoming pain.

Although the results of Chapter 8 demonstrated that individuals with chronic low back pain were overall better in detecting tactile information, regardless of which body part was stimulated or which movement was performed, neither of our studies did, however, support the hypothesis that individuals with chronic pain were more attentive for somatosensory information at the painful region of the body. It is worth mentioning here the results of the few studies that also aimed to investigate the attentional prioritization of somatosensory sensations in these populations and showed similar results. Note, however, that these studies were based upon reaction time data, which have been proposed to be confounded in chronic pain populations (Van Damme et al., 2008). In the study of Tiemann et al. (2012), a group of individuals with fibromyalgia and a control group engaged in a visual reaction time task during which (calibrated) painful stimulation was administered. The results did not reveal differences in the amount of attentional disruption by pain between these two groups, as shown by both a behavioral (reaction times on the visual task) and a neurological measure (neuronal gamma oscillations). We extended this finding by showing that these patients also did not differ in the attentional processing of non-painful tactile stimuli. Also relevant is the study of Peters, Vlaeyen, & Kunnen (2002), who aimed to investigate hypervigilance in individuals with chronic low back pain. In one task, participants were only required to engage in an auditory reaction time task while, occasionally, (calibrated) non-painful stimuli were administered to the arm or to the back. It was tested whether the administration of non-painful stimuli at the back led to an increased disruption in task performance in individuals with chronic low back pain

as compared to healthy controls. In a second task, participants were, in addition to an auditory detection task, also required to detect the presence of the somatosensory stimuli that were administered on the arm or on the back. Here, it was tested whether individuals with chronic low back pain, as compared to healthy controls, showed an increased disruption on the auditory task during the administration of a stimulus at the back, and showed a facilitated detection of stimuli that were administered at the back as compared to the arm. The results revealed no differences in response times between the two groups, as such showing no evidence for hypervigilance in individuals with chronic low back pain. However, individuals with chronic low back pain who scored high on pain-related fear showed more disruption on the auditory task, regardless of the body location that was stimulated. Our study in individuals with chronic low back pain may add to the study of Peters et al. (2002), as we attempted to investigate the attentional processing of somatosensory information in a, for individuals with chronic low back pain, potential threat-evoking context.

Intriguingly, previous studies in healthy volunteers have demonstrated that in a context of bodily threat, attention is directed toward the body part where pain is expected (Chapter 5, Chapter 6, Vanden Bulcke et al., submitted), but these findings do not generalize to individuals with chronic low back pain or fibromyalgia. One reason may be that in studies investigating the effect of pain anticipation on the attentional processing of somatosensory information in healthy volunteers (Chapter 5, Chapter 6, Vanden Bulcke et al., submitted), the participants did not experience pain at the moment that the tactile information was administered. Moreover, trials in which a painful stimulus was administered were excluded for analyses, in order to prevent confusion between effects of anticipated and actual pain. In contrast, all individuals with chronic pain reported pain at the moment of testing. In addition, studies in healthy samples have shown that tonic pain reduces the perception of tactile information at the pain location, a phenomenon that has been referred to as “touch gating” (Apkarian, Stea, & Bolanowski, 1994; Bolanowski, Maxfield, Gescheider, & Apkarian, 2000). Moreover, in individuals with chronic low back pain, tactile thresholds and two-point discrimination thresholds at the back have been shown to be reduced (Moseley, 2008; Moseley, Gallagher, & Gallace, 2012). More specifically, in the study of Moseley, Gallagher et al. (2012), participants engaged in a temporal order judgement task in which

pairs of tactile stimuli were delivered in the affected area and elsewhere on the body. The results showed that the stimulus that was delivered in the affected region needed to be presented before the stimulus in the unaffected region of the body in order to be perceived as occurring simultaneously, which suggested that information presented at this affected region was neglected. A second reason could be found in studies showing evidence for an interfering effect of pain on cognitive functioning in individuals with chronic pain (Glass, 2009; Moore, Keogh, & Eccleston, 2012; Moriarty, McGuire, & Finn, 2011). As the nature of the tasks used here required the participants' full concentration, difficulties in cognitive functioning could be expected to result in a worse task performance in individuals with chronic pain. However, our results seem to contradict this, as in Chapter 7, the fibromyalgia and the control group performed equally well on the task, and in Chapter 8, individuals with chronic low back pain even demonstrated a better task performance as compared to healthy controls. A third reason why a context of bodily threat may not have led to the same pattern of attentional prioritization of somatosensory information in healthy individuals and individuals with chronic pain, may be that while pain anticipation was experimentally induced in healthy participants by means of phasic experimental pain stimuli, there may not have been an active anticipation of pain in individuals with chronic pain, as hypervigilance may only emerge in particular situations. This may have been especially the case in the study that aimed to investigate somatosensory hypervigilance in individuals with fibromyalgia. In the study in individuals with chronic low back pain, however, we aimed to induce a context in which individuals suffering from chronic low back pain would expect to experience pain by requiring them to perform back movements. Nevertheless, the self-report measures indicated that although individuals with chronic low back pain had higher pain expectancies as compared to healthy controls, their pain expectancy ratings were quite low. Perhaps, the required back movements were not threatening enough to activate the anticipation of pain. Finally, it is generally assumed that the fear of pain that is often reported in individuals with chronic pain is followed by a rigorously scanning of the body in order to detect signals of potential harm (Chapman, 1978; Crombez et al., 2005; Van Damme et al., 2010). However, it has been postulated that there are many different ways by which individuals may be worried or fearful about pain (Morley & Eccleston, 2004), as for example when one

is concerned about how the pain may affect social life. These concerns do not necessarily lead to a heightened attention at the perceptual level.

In both studies, the self-report measures of vigilance to painful and non-painful sensations indicated that individuals with chronic pain reported to be more attentive to painful sensations, as measured by the Pain Vigilance and Awareness Questionnaire (McCracken, 1997), as compared to control subjects. This finding is in line with the results of several other studies (Crombez, Eccleston, Van den Broeck, Goubert, & Van Houdenhove, 2004; Peters, Vlaeyen, & van Drunen, 2000; Roelofs, Peters, McCracken, & Vlaeyen, 2003; Tiemann et al., 2012). In addition, there was also some evidence that these patients reported more attention for a broader category of bodily sensations, as measured by the Body Vigilance Scale (Schmidt, Lerew, & Trakowski, 1997). It has been argued that the scores on these self-report measures may, at least partly, be biased as a result of the constant confrontation with pain and other somatic symptoms in individuals with chronic pain, perhaps rather reflecting the mere presence of multiple somatic complaints than an excessive attentional focus to these sensations (Crombez et al., 2004). As the findings that were obtained by the behavioral measures of attention did not show any evidence for somatosensory hypervigilance, it may be that the results obtained by these self-report measures may indeed have been affected by other processes than attention. However, more research is needed before any firm conclusions can be drawn.

One benefit that is especially related to the chronic low back pain study, is the attempt to measure somatosensory hypervigilance in a context of pain-related movements. There is already some consensus that hypervigilance may vary across individuals, as some people may show more or less pain-related fear (e.g., Asmundson, Kuperos, & Norton, 1997; Asmundson & Hadjistavropoulos, 2007; Barke, Baudewig, Schmidt-Samoa, Dechent, & Kröner-Herweg, 2012; Roelofs, Peters, Fassaert, & Vlaeyen, 2005), but studies investigating hypervigilance have somewhat neglected the possibility that the presence of hypervigilance may vary depending on the context. This is rather surprising as it has generally been assumed that fear of movement or (re)injury may lead to heightened attentional processing of pain-related information (Crombez, Eccleston, Baeyens, Van Houdenhove, & Van den Broeck, 1999; Roelofs et al., 2007; Vlaeyen & Linton,

2000, 2013). Although our results did not support this thesis, future research should further explore the role of hypervigilance in different contexts.

Recommendations for Future Research

Research investigating hypervigilance in individuals with chronic pain by means of somatosensory attention paradigms is still in its infancy. Based upon the current findings and upon a number of limitations, several recommendations for future research may be proposed.

A first limitation of the studies that aimed to investigate somatosensory hypervigilance in individuals with chronic pain is that in all paradigms participants received instructions to detect the presence or absence of somatosensory stimuli. This task goal to attend to somatosensory information may have activated somatosensory features in the attentional set, as such inducing a state of elevated attention toward the body (i.e., hypervigilance) in both the control and the clinical group. This makes it difficult to detect spontaneous differences in attentional prioritization between individuals with chronic pain and healthy individuals. Ideally, future studies should measure attentional prioritization of somatosensory information in a context in which the goal to attend to somatosensory information is not a task goal. Although difficult to achieve, a possible avenue for future research may consist of the use of portable tactile stimulators that can be worn by participants while they behave in their normal context. At certain, not previously announced, moments of the day, participants may then be asked to report whether they have perceived the presence of a stimulus that may, or may not, have been presented shortly before. This way, the task goal to attend to somatosensory information could be kept in the background.

Second, the studies reported here all used *tactile* somatosensory stimuli, with the exception of the thermal stimuli used in Chapter 2, that were quite subtle and had a duration of only 300ms. Given that somatosensory information can vary on a number of parameters, such as submodality (e.g., heat, vibration, touch, pressure, ...), intensity, or duration (phasic, tonic, fluctuating, ...), the generalizability of our findings is limited. Future research is needed to test whether other results would be obtained with other types of somatosensory stimulation. Moreover, future research may consider using alternative approaches in which

sensitivity for changes in the nature of a somatosensory stimulus (such as a changing intensity or frequency) may be measured, instead of investigating whether participants are able to detect the presence or absence of certain stimuli, or the presence or absence of changes in tactile pattern locations. It may be hypothesized that individuals with chronic pain are rather attentive to changes in the quality of a stimulus, as for example a body sensation that is increasing in intensity, as this may more likely signal upcoming pain. Relating to this, future research may want to investigate whether individuals with chronic pain would be more attentive to 'purely' interoceptive sensations. In the studies reported here, somatosensory stimuli were tactile stimuli applied to the participants' skin. Touch, coming from the external environment, but involving the body, is considered to hold aspects from both interoceptive and exteroceptive processing (Haggard et al., 2013; Mehling et al., 2009). It may be argued that 'purely' interoceptive sensations may be more relevant signals of potential damage. Future research could, for example, examine whether individuals with chronic low back pain are hypervigilant to subtle muscle contractions in the back. Also worth noting here is that a study of Kemppainen, Vaalamo, Leppällä, & Pertovaara (2001), which has shown that sensory suppression during jaw movements does not only occur for vibrotactile or electrical stimuli that are applied to the skin of the orofacial region (Andreatta & Barlow, 2003; Kemppainen, Leppänen, Waltimo, & Pertovaara, 1993), but also for electrical stimulation of the tooth pulpa. As individuals with persistent orofacial muscle pain have also been assumed to be fearful for movements that are related to the painful region (Visscher, Ohrbach, van Wijk, Wilkosz, & Naeije, 2010), it would be interesting to investigate sensory suppression of pulpal sensations in individuals with persistent orofacial muscle pain. Lastly, future research may want to investigate whether individuals with chronic pain have a higher cardiac awareness as compared to healthy controls (for a related study, see Werner, Duschek, Mattern, & Schandry, 2009). Although these sensations do not seem to be directly relevant to the pain that is experienced in these populations, some authors have proposed that individuals with chronic pain may be hypervigilant to a range of bodily sensations (e.g., McDermid, Rollman, & McCain, 1996).

Third, neither the results of the studies reported here, nor the results of a number of other studies (e.g., Peters et al., 2000, 2002; Tiemann et al., 2012) revealed a correspondence between behavioral and self-report measures of

attention to somatosensory sensations. Indeed, it may be questioned which processes are measured by means of these questionnaires. It has been proposed before that the scores on these questionnaires may rather reflect a report bias as a result of a constant confrontation with pain in individuals with chronic pain (Crombez et al., 2004). Future research may want to examine the validity of the existing self-report instruments in assessing the attentional processing of somatosensory information. Interestingly, a study of Mehling et al. (2009), examining the psychometric qualities of a number of questionnaires aiming to asses body awareness, revealed that most of these instruments did not have a clear operationalization of the concept of body awareness. Moreover, the questionnaires did not sufficiently differentiate between maladaptive, anxiety-related attention toward somatosensory information, and adaptive, i.e., non-judgmental, 'mindful', attentional processes. In addition, it is worth noting here that behavioral paradigms often suffer from reliability issues (e.g., Schmukle, 2005). It is unclear whether the paradigms reported here have to contend with the same concern, as the complexity of the tasks does not readily allow measuring internal consistency.

Fourth, recent studies have been investigating the potential predictive value of attentional bias paradigms with regard to pain outcomes such as pain severity and disability. Studies in acute and chronic pain have mostly measured the presence of an attentional bias by means of questionnaires (e.g., Lautenbacher et al., 2009), dot-probe tasks (e.g., Baum, Huber, Schneider, & Lautenbacher, 2011; Lautenbacher et al., 2010) or modified spatial cueing paradigms (Van Ryckehem et al., 2013). An interesting avenue for future research may therefore be to test the predictive value of the somatosensory attention paradigms described here, such as the sensory suppression or tactile change detection task.

Finally, it has been raised that the experience of pain interferes with one's personal goal pursuit (Van Damme, Crombez, Goubert, & Eccleston, 2009). On the one hand, this may lead to the goal to avoid or escape from this situation, and it has been proposed that hypervigilance is particularly activated in situations in which the goal to avoid pain is activated (Crombez et al., 2005). Indeed, from a motivational perspective, attention is assumed to be directed to goal-related information, while irrelevant information is inhibited (Van Damme et al., 2010). On the other hand, it has been proposed that the experience of pain may also lead to

goal persistence, meaning that individuals remain engaged in approaching (unreachable) non-pain goals. It has been postulated that in this situation, a person may become hypo-vigilant, i.e., a state in which all pain-related information is neglected (Van Damme et al., 2009). Future research may benefit from a motivational perspective in which the current goals that are present in an individual are taken into account.

CLINICAL IMPLICATIONS

As the aim of this PhD thesis was to study the attentional processing of somatosensory information in chronic pain on a quite fundamental level, direct clinical recommendations are limited. Nevertheless, a number of issues may be relevant for clinical practice.

First, there is, to date, still no clear evidence that individuals with chronic pain are indeed more attentive to pain-related information as compared to healthy controls (Crombez et al., 2013). Therefore, some prudence is warranted when targeting this hypervigilance in clinical practice. As hypervigilance may only be present in certain individuals, and in certain situations, it may not be useful to use distraction and attention training techniques in all individuals. Moreover, a recent study of Van Ryckeghem, Crombez, Van Hulle, and Van Damme (2012) has shown that the presence of an attentional bias toward pain-related information may hinder the efficacy of distraction.

Second, hypervigilance is generally considered to be a causal or maintaining factor that results in negative outcomes (e.g., Chapman, 1978; Vlaeyen & Linton, 2000; Eccleston & Crombez, 2007). However, it has been raised that an attentional focus toward bodily sensations should not necessarily be maladaptive (Mehling et al., 2009). This duality is also visible in clinical practice, where hypervigilance is often targeted by means of diverse psychological treatments of chronic pain given its popularity in a number of chronic pain theories. Some of these techniques aim to focus attention away from the pain. The attention bias modification (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002), for example, implicitly trains participants to focus their attention away from the pain by using a modified dot-probe task in which the probe is never followed by a pain stimulus, and has recently been investigated in acute and chronic pain populations

(Sharpe et al., 2012). However, there also exist other techniques that rather require patients to attend to bodily sensations. Mindfulness training, for example, is an increasingly popular technique that aims to focus one's attention in a nonjudgmental and accepting way towards what is experienced (Bishop et al., 2004), and has also been applied to chronic pain (e.g., Vago & Nakamura, 2011). Note however, that mindfulness has been proposed to consist of more than attention alone (Shapiro, Carlson, Astin, & Freedman, 2006).

CONCLUSION

In the current PhD thesis, a new approach to measure hypervigilance in chronic pain populations was proposed. Several paradigms were developed by which the attentional processing of somatosensory information could be assessed. First, studies with these paradigms provided some evidence that, in healthy volunteers, the anticipation of pain leads to heightened attention toward the location where pain is expected. Second, the studies reported here did not support the hypothesis that individuals with chronic pain are hypervigilant for somatosensory information in the region where they are confronted with their pain. However, as research investigating hypervigilance in individuals with chronic pain by means of somatosensory attention paradigms is still in its' infancy, it is too premature to draw any firm conclusions. Nevertheless, the current approach may have contributed to the field of chronic pain, and the current findings have triggered a number of future research questions.

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NEDERLANDSTALIGE SAMENVATTING

Pijn is een vaak voorkomend fenomeen en het aanhouden ervan kan een grote impact hebben op zowel individueel als maatschappelijk vlak (Breivik, Collett, Ventafridda, Cohen, & Gallacher, 2006; Reid et al., 2011). De voorbije jaren groeide de consensus dat pijn best bekeken wordt vanuit een biopsychosociaal perspectief (Gatchel, Peng, Peters, Fuchs, & Turk, 2007), waarbij er naast de invloed van medische factoren ook ruimte wordt voorzien voor psychologische en sociale factoren. Een van deze psychologische factoren die ook het onderwerp van studie vormt van het huidige doctoraatsproject is aandacht. Een functionele visie op aandacht (Allport, 1989) maakt snel duidelijk dat pijn en aandacht nauw met elkaar verbonden zijn. Zo is het enerzijds belangrijk dat de continuïteit van een gedrag niet steeds doorbroken wordt door irrelevante prikkels. Anderzijds is het van groot belang dat de aandachtsfocus onderbroken wordt zodat adequaat kan worden gereageerd op meer belangrijke informatie die de zintuigen bereikt. Heel wat onderzoek documenteerde reeds het intrinsiek aandachtsopeisend karakter van pijn (e.g., Crombez, Eccleston, Baeyens, & Eelen, 1996; Dowman & ben-Avraham, 2008; Vancleef & Peters, 2006). Volgens het cognitief-affectief model van Eccleston en Crombez (1999) is dit evolutionair adaptief: een pijnsignaal waarschuwt ons voor mogelijke lichamelijke schade en zet zo aan tot (re)actie. Verschillende zaken, zoals karakteristieken van de stimulus (e.g., de intensiteit of voorspelbaarheid van de pijn), moduleren dit *bottom-up* richten van de aandacht. Meer en meer gaat men ervan uit dat de verwerking van sensorische informatie het resultaat is van een interactie tussen bottom-up (stimulus-gedreven) en top-down (doel-gedreven) factoren (Corbetta & Shulman, 2002; Desimone & Duncan, 1995). Er wordt verondersteld dat de doelen, gedachten en intenties die een persoon heeft de aandacht richten naar doelrelevante stimuli via actieve representaties in het werkgeheugen. Irrelevante informatie wordt genegeerd of geïnhibeerd. Toegepast op pijn houdt dit in dat gedachten en bekommernissen omtrent pijn het verwerken van pijngerelateerde

informatie faciliteren (Legrain et al., 2009; Van Damme, Legrain, Vogt, & Crombez, 2010). Een persoon met chronische lage rugpijn, bijvoorbeeld, die verwacht dat het uitvoeren van een bepaalde beweging hevige pijn zal uitlokken, zal volgens deze redenering meer aandachtig zijn voor sensaties ter hoogte van de rug.

Een vaak gestelde hypothese luidt dat personen met chronische pijn overmatig aandachtig of *hypervigilant* zijn voor somatosensorische informatie (Chapman, 1978; Crombez, Van Damme, & Eccleston, 2005; Van Damme et al., 2010). Over het algemeen wordt aangenomen dat hypervigilantie ontstaat vanuit de angstige verwachting dat pijn zal optreden en/of verergeren (Eccleston & Crombez, 2007; Vlaeyen & Linton, 2000). Het concept hypervigilantie wordt echter geplaagd door een inconsistente conceptualisatie en operationalisatie (Van Damme et al., 2010). Hier wordt hypervigilantie gedefinieerd in termen van een aandachtsproces dat leidt tot de prioritisatie van somatosensorische informatie in een context bestaande uit meerdere omgevingseisen (Crombez et al., 2005). Deze visie maakt een expliciet onderscheid tussen hypervigilantie als causaal mechanisme, en fenomenen die daar mogelijk uit resulteren, zoals hyperalgesie, allodynie of hyperresponsitiviteit (Crombez et al., 2005; Gonzalés et al., 2010; Van Damme et al., 2009, 2010). Ook is er ondanks een veelheid aan studies nog steeds geen overtuigende evidentie voor de idee dat personen met chronische pijn gekenmerkt worden door een overmatige aandacht voor pijngerelateerde informatie. Een meta-analyse (Crombez, Van Ryckeghem, Eccleston, & Van Damme, 2013) toonde recent aan dat personen met chronische pijn een aandachtsbias vertoonden voor pijngerelateerde informatie, maar dat dit effect klein was, en niet verschillend van gezonde vrijwilligers. Ook toonden de resultaten weinig evidentie voor de idee dat lichamelijke dreiging resulteert in een aandachtsbias voor pijngerelateerde informatie, hoewel de resultaten wel wezen op een verhoogde aandacht voor cues die de aanwezigheid van pijn voorspelden (e.g., Van Damme, Crombez, & Eccleston, 2004). De vraag rijst of de visuele pijngerelateerde stimuli die meestal worden gebruikt voor het meten van pijngerelateerde aandacht wel voldoende effectief zijn in het oproepen van schemata met betrekking tot ‘lichamelijke dreiging’ (Crombez et al., 2013; Van Damme et al., 2010). Vanuit deze redenering werd het gebruik van somatosensorisch stimulusmateriaal reeds aanbevolen.

Het doel van het huidige doctoraatsproject was drievoudig. Een eerste objectief bestond uit het ontwikkelen van paradigma's die aandacht voor niet-pijnlijke somatosensorische informatie kunnen meten. Er wordt namelijk verondersteld dat somatosensorische stimuli een hogere ecologische validiteit en persoonlijke relevantie hebben dan visuele prikkelinformatie (Crombez et al., 2013; Van Damme et al., 2010). Cruciaal hierbij is dat aandacht gemeten wordt in een context van meerdere omgevingseisen (Crombez et al., 2005). Een tweede objectief was om na te gaan of de verwachting van pijn op een bepaalde lichaamslocatie leidt tot de facilitatie van niet-pijnlijke somatosensorische informatie die betrekking heeft op de bedreigde lichaamslocatie. Een derde objectief bestond uit het testen van de hypothese dat personen met chronische pijn, meer specifiek personen met fibromyalgie en chronische lage rugpijn, gekarakteriseerd worden door somatosensorische hypervigilantie, in vergelijking met een controlegroep.

In **Deel 1** werd de sensitiviteit onderzocht van drie nieuwe paradigma's in het meten van een aandachtsprioritisatie voor somatosensorische informatie in een context bestaande uit meerdere omgevingseisen. Er werd vooropgesteld dat indien deze paradigma's bruikbaar zouden zijn, er met deze paradigma's zou moeten worden aangetoond dat stimuli in de modaliteit waarnaar de aandacht werd gericht, of stimuli op de lichaamslocatie waarnaar aandacht werd gericht, beter worden gedetecteerd dan stimuli van een modaliteit of op een locatie waar de aandacht niet naar werd gericht. De verschillende paradigma's worden hier kort beschreven. In de *modality cued signal detection task* (***Hoofdstuk 2***) werden de participanten geïnstrueerd om de aanwezigheid van subtiele somatosensorische en auditieve stimuli te detecteren. De aandachtsfocus werd gemanipuleerd door middel van een cue (het woord 'warm' of 'toon') die voorafgaand aan de stimulus werd gepresenteerd, en die de stimulus in twee derde van de gevallen correct voorspelde. In de *tactile change detection task* (***Hoofdstuk 3***) dienden de participanten veranderingen te detecteren tussen twee opeenvolgende patronen van tactiele informatie. In de ene helft van de trials waren deze twee patronen gelijk, en in de andere helft van de trials verschilde één van de gestimuleerde lichaamslocaties tussen het eerste en het tweede patroon. Er werd nagegaan of het manipuleren van de aandachtsfocus naar één bepaalde lichaamslocatie

resulteerde in een betere detectie van veranderingen die betrekkingen hadden op deze lichaamslocatie. In de *sensory suppression task* (***Hoofdstuk 4***), ten slotte, voerden de participanten tegelijkertijd een bewegingstaak uit, waarbij ze ofwel een rugbeweging dienden uit te voeren ofwel niet mochten bewegen, en een detectietaak waarbij ze de aanwezigheid van tactiele stimuli op de boven- of onderrug dienden te detecteren. Over het algemeen worden tactiele stimuli minder goed gedetecteerd tijdens het uitvoeren van een beweging, i.e., sensorische suppressie (e.g., Juravle, Deubel, & Spence, 2011; Williams & Chapman, 2000, 2002). In deze studie werd onderzocht of het richten van aandacht naar een bepaalde locatie een effect had op het detecteren van tactiele stimuli ter hoogte van deze locatie tijdens beweging.

Samengevat wezen de bevindingen er op dat bij alle drie de paradigma's het richten van aandacht een invloed had op het verwerken van somatosensorische informatie. Meer specifiek toonden de resultaten van de *modality cued signal detection task* aan dat wanneer de aandacht werd gericht naar de somatosensorische of auditieve modaliteit, dit resulteerde in een betere detectie van respectievelijk somatosensorische en auditieve stimuli. Door middel van de *tactile change detection task* en de *sensory suppression task* werd aangetoond dat het richten van de aandacht op een bepaalde lichaamslocatie leidt tot een betere verwerking van somatosensorische informatie die wordt toegediend op deze locatie van het lichaam. Bijgevolg kon worden besloten dat de hierboven beschreven paradigma's bruikbaar bleken voor het meten van aandachtsprioritisatie.

In **Deel 2** werd vervolgens onderzocht of de verwachting van pijn op een bepaalde locatie van het lichaam zou leiden tot een betere detectie van somatosensorische informatie die werd toegediend op deze specifieke locatie. De achterliggende idee (zie Legrain et al., 2009; Van Damme et al., 2010) was dat in deze context pijngerelateerde gedachten zouden leiden tot het richten van aandacht naar stimuli die bepaalde karakteristieken gemeenschappelijk hebben met actieve representaties in het werkgeheugen, zoals de modaliteit (somatosensorisch) of de locatie (de locatie waar een pijnlijke prikkel kon worden toegediend). In ***Hoofdstuk 5*** werd met behulp van de *tactile change detection task* onderzocht of de dreiging van experimentele pijn op een bepaalde lichaamslocatie

zou leiden tot een betere detectie van tactiele veranderingen die betrekking hadden op deze lichaamslocatie in vergelijking met veranderingen die geen betrekking hadden op deze dreiglocatie. De resultaten bevestigden dat tactiele veranderingen op de exacte dreiglocatie beter werden gedetecteerd, maar in tegenstelling tot de verwachtingen werden ook veranderingen die betrekking hadden op de andere locatie op het bedreigde lichaamsdeel beter gedetecteerd. In ***Hoofdstuk 6*** werd door middel van een *sensory suppression task* het effect van de verwachting van pijn op een specifieke locatie tijdens het uitvoeren van een specifieke beweging onderzocht. Hoewel de interpretatie werd bemoeilijkt omwille van een onverwacht interactie-effect (voor meer gedetailleerde informatie, zie Hoofdstuk 6), leken de resultaten erop te wijzen dat, zoals verwacht, tijdens een bedreigende beweging, tactiele stimuli op de bedreigde locatie beter werden gedetecteerd dan tactiele stimuli op de neutrale locatie. In tegenstelling tot de verwachtingen werden tactiele stimuli op de bedreigde lichaamslocatie niet beter gedetecteerd tijdens het uitvoeren van een bedreigende beweging in vergelijking met een neutrale beweging, maar werden tactiele prikkels op de neutrale locatie slechter gedetecteerd tijdens het uitvoeren van de bedreigende in vergelijking met de neutrale beweging.

Samengevat kan worden gesteld dat, hoewel de resultaten niet volledig eenduidig zijn, deze bevindingen wel in lijn lijken te zijn met algemene theorieën die uitgaan van het bestaan van een saillantie-detectie systeem waarlangs aandacht wordt georiënteerd en gemonitord naar prikkels die potentieel bedreigend zijn voor de integriteit van het lichaam (Haggard, Iannetti, & Longo, 2013; Legrain, Iannetti, Plaghki, & Mouraux, 2011; Moseley, Gallace, & Spence, 2012). Meer specifiek lijken deze bevindingen de idee te bevestigen dat hypervigilantie resulteert vanuit een angstige verwachting dat pijn zal optreden en/of verergeren (Crombez et al., 2005; Vlaeyen & Linton, 2000).

In **Deel 3**, ten slotte, werd onderzocht of personen met chronische pijn gekenmerkt worden door somatosensorische hypervigilantie in vergelijking met een pijnvrije controlegroep. Er werd verondersteld dat personen met chronische pijn vooral aandachtig zouden zijn voor het lichaamsdeel waar ze normaal gezien worden geconfronteerd met hun pijnklachten. Gezien personen met fibromyalgie verspreid over het ganse lichaam pijn ervaren werd verwacht dat zij overmatig

aandachtig zouden zijn voor sensaties verspreid over het hele lichaam. Bij personen met chronische lage rugpijn werd verwacht dat ze voornamelijk hypervigilant zouden zijn voor somatosensorische informatie ter hoogte van de rug. ***Hoofdstuk 7*** onderzocht aan de hand van de *tactile change detection task* of personen met fibromyalgie somatosensorische hypervigilantie vertoonden. De taak werd uitgevoerd onder twee condities. In de verdeelde aandachtsconditie konden tactiele veranderingen optreden ter hoogte van alle lichaamslocaties. In de gefocuste aandachtsconditie werd de aandacht gemanipuleerd naar één bepaalde lichaamslocatie. Hoewel de vragenlijstscores aangaven dat personen met fibromyalgie meer aandacht voor lichamelijke sensaties rapporteerden in vergelijking met de controlegroep, volgden de resultaten van de gedragsmaat deze bevinding niet. In geen van beide condities waren personen met fibromyalgie beter in het detecteren van tactiele veranderingen in vergelijking met de controlegroep. ***Hoofdstuk 8*** onderzocht door middel van de *sensory suppression task* of personen met chronische lage rugpijn hypervigilant waren voor somatosensorische informatie tijdens het uitvoeren van een, verondersteld bedreigende, rugbeweging. Een groep personen met chronische lage rugpijn en een pijnvrije controlegroep voerden een *sensory suppression task* uit bestaande uit enerzijds een bewegingstaak waarbij ze een rugbeweging, armbeweging, of geen beweging dienden te maken, en anderzijds een detectietaak waarbij ze de aanwezigheid van een tactiele stimuli op de rug, arm, of borst dienden te detecteren. Hoewel verondersteld werd dat personen met chronische lage rugpijn voornamelijk tijdens het uitvoeren van een rugbeweging beter zouden zijn in het detecteren van lichamelijke sensaties ter hoogte van de rug in vergelijking met controlepersonen, ondersteunden de resultaten dit niet. Wel waren personen met lage rugpijn over het algemeen, dus ongeacht de beweging en ongeacht de lichaamslocatie, beter in het detecteren van tactiele informatie. Opnieuw was het zo dat de klinische groep hoger scoorde op vragenlijsten die peilden naar aandacht voor lichamelijke sensaties.

De bovenstaande bevindingen bieden geen evidentie voor de hypothese van somatosensorische hypervigilantie bij personen met chronische pijn. Dit is in lijn met de weinige studies gericht op het meten van aandacht voor pijnlijke en niet-pijnlijke lichamelijke sensaties in personen met fibromyalgie of chronische lage rugpijn (Tiemann et al., 2012; Peters, Vlaeyen, & Kunnen, 2002). Deze

bevindingen zijn intrigerend gezien voorgaand onderzoek bij gezonde vrijwilligers reeds aantoonde dat de verwachting dat pijn zal optreden wel lijkt te leiden tot een verhoogde aandacht voor de lichaamslocatie waar de pijn wordt verwacht (Hoofdstuk 5, Hoofdstuk 6, Vanden Bulcke, Van Damme, Durnez, & Crombez, submitted). Bovendien lijkt er geen consistentie te zijn tussen zelfrapportage- en gedragsmaten van hypervigilantie. In Hoofdstuk 9 worden deze zaken meer gedetailleerd bediscussieerd en worden er zinvolle richtingen voor verder onderzoek aangegeven.

Het huidige doctoraatsproject trachtte bij te dragen tot onderzoek omtrent hypervigilantie via het ontwikkelen van somatosensorische aandachtsparadigma's. Enerzijds suggereerden de bevindingen dat lichamelijke dreiging leidt tot een prioritisatie van somatosensorische informatie ter hoogte van de pijnlocatie bij gezonde vrijwilligers. Anderzijds vonden we aan de hand van de ontwikkelde aandachtsparadigma's, in tegenstelling tot de zelfrapportagematen, geen evidentie voor somatosensorische hypervigilantie bij personen met chronische pijn in vergelijking met gezonde controles. Toekomstig onderzoek zal zich verder moeten richten op het uitzuiveren van deze discrepantie, alsook op het bestuderen van hypervigilantie in ecologisch valide situaties.

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