UNIVERSITEIT GENT

FACULTEIT PSYCHOLOGIE EN PEDAGOGISCHE WETENSCHAPPEN

How pain control attempts guide attention: An experimental analysis

Wouter Durnez

Promotor: prof. dr. Stefaan Van Damme

Proefschrift ingediend tot het behalen van de academische graad van Doctor in de Psychologie

2015

Table of contents

General introduction **7**

The (Pre)history of Pain *8*

Biopsychosocial ABCs *12*

Aching for Attention *14*

Motivation Matters *19*

Clinical Context *22*

Distilling Direction *29*

References *39*

Trying to fix a painful problem: the impact of pain control attempts on the attentional prioritization of a threatened body location **51**

Introduction *52*

Method *54*

Results *63*

Discussion *69*

Disclosures *75*

References *75*

Spatial prioritization of somatosensory information during pain control: A paradigmatic exercise **79**

Introduction *80*

Method *83*

Results *94*

Discussion *98*

Disclosures *102*

References *102*

On attention, pain control and monitoring strategies: a set of follow-up experiments **107**

Introduction *108*

Experiment 1 ..... *112*

Interim discussion *128*

Experiment 2 ..... *131*
Discussion *139*
Conclusion *142*
Disclosures *143*
References *143*

Getting out of a bad spot: Pain control pursuit modulates attentional prioritization of a stimuli at a threatened location 147
Introduction *148*
Method *151*
Results *165*
Discussion *172*
Disclosures *178*
References *179*

Let it be? Attention to somatosensory input is amplified by the threat of pain and pain control attempts 183
Introduction *184*
Method *188*
Results *199*
Discussion *206*
Disclosures *211*
References *211*

Mind over matter? Investigating the moderating potential of pain catastrophizing in attentional redirection due to the anticipation of pain and attempts to control its manifestation 215
Introduction *216*
Method *219*
Results *224*
Discussion *237*
Disclosures *242*
References *242*

General discussion 245
PRIMARY PREMISES (what we set out to do) *246*
RALLYING RESULTS (what we found) *248*

INTEGRATION, IMPLICATIONS AND THEORETICAL THROWBACK (what this means for contemporary pain theories) *253*
ADDED ANNOTATIONS (what we haven't mentioned yet) *262*
CLINICAL CONNECTION (how everything ties in with the real world) *265*
LINGERING LIMITATIONS (what can be expanded upon) *271*
OPEN OPPORTUNITIES (what can be done in the future) *273*
CLOSING CONCLUSION (how we can draw the curtains) *275*
References *276*

Addendum: Thoughts on adaptive procedures **283**
Introduction *283*
Methodology *284*
Closing words *289*
References *290*

Acknowledgements **291**
Data storage fact sheets **297**
Data storage fact sheet, Chapter 1 ..... *297*
Data storage fact sheet, Chapter 2 ..... *299*
Data storage fact sheet, Chapter 3 ..... *301*
Data storage fact sheet, Chapter 4 ..... *303*
Data storage fact sheet, Chapter 5 ..... *306*
Data storage fact sheet, Chapter 6 ..... *308*

Nederlandstalige samenvatting **311**
Inleiding *311*
Doelstellingen *313*
Bevindingen *314*
Conclusie *319*
Bibliografie *320*

1 General introduction

If you are trying to assemble a puzzle, identifying the corner pieces should come first. The purpose of this dissertation involves, in itself, a marriage of several psychological ideas – all of which are distinguished candidates for the longest tradition in academic literature. The following paragraphs will serve to shed some light on each of these components. We will show how they fit together to birth a robust theoretical framework which informs our experimental work.

« Everybody hurts. »

— Michael Stipe

THE (PRE)HISTORY OF PAIN

At our beginning, there was pain. From an evolutionary point of view, it can easily be argued that nociceptive ability – that is, the ability to feel pain – has been a critical ally in the survival of mammalian species. The sensation of pain serves as a neurobiological smoke detector (Nesse, 2001), in the sense that it warns us of looming physical harm. This, in turn, allows us to engage in appropriate coping responses. Pain incites us to withdraw from dangerous situations and to protect already compromised bodily areas from further harm (Chapman, Tuckett, & Song, 2008; Eccleston & Crombez, 1999). In addition, it teaches us to avoid similar experiences in the future, solidifying our capacity for nociception as a most efficient adaptive trait (Dawkins, 1995).

In spite of the seeming simplicity of pain itself, scientific literature has long struggled with its understanding. The earliest of

pain theories, inspired by the likes of Plato and Aristotle, upheld a strictly, dualistic viewpoint (Moayedi & Davis, 2012). Descartes understood the body to be a material apparatus, decisively separated from the immaterial mind. Pain, then, was no more than a mechanical issue, which could be relayed to the brain across our nerves (Descartes, 1662). This reductionist tradition was carried on in successor theories (box 1), ever equating pain to the mere manipulation of its presumed physiological substrate.

Box 1 A handful of intermediary pain theories

Specificity theory (Bell, 1811), which originated in the 19th century, was mainly centered on the identification of unique physical substrates that governed distinct sensory perceptions, such as touch or taste. Likewise, a specific part of the nerve system that governed pain perception. In this theory, nociceptive information was thought to be relayed through specific receptor mechanisms and transfer pathways from the periphery of our body, through our spinal cord and to our cortex.

Intensive theory (cited in Dallenbach, 1939) suggested that, at the core of a pain experience, there is overstimulation of the senses. As such, it was argued that any type of sensory input that was sufficiently intense could trigger pain. This explained how pain could – for instance – be caused by excessively bright light, other than by visible physical harm.

Pattern theory (Sinclair, 1955; Weddell, 1955) proposed, contrary to specificity theory, that there was no neural system specifically dedicated to the perception of pain. Instead, it suggested that pain resulted from the temporal organization of signals being submitted by common sensory receptors. Similar to intensity theory, it assumed that temporal patterns that are associated with a painful experience only occurred as a result of intense stimuli. This explained how somatosensory events could be painful (such as being slapped) or painless (such as being kissed).

Still, a one-to-one relationship between tissue damage and pain perception left a string of questions unanswered. How then could intrinsically innocuous stimuli, such as tender touch or soft sounds, cause excruciating pain in some individuals (Katzenell & Segal, 2001; Livingston, 1943)? Why would a dreadfully wounded soldier, having just barely escaped the battlefield with his life, rationally deny feeling any pain (Beecher, 1959)? How was it possible for an amputee to feel pain in a limb that was no longer there (Melzack, 1992; Mitchell, 1871)? The sum of these and other observations dumbfounded then contemporary pain theorists.

The advent of the gate control theory of pain heralded a stirring breakthrough in this regard (Melzack & Wall, 1965). In no small part, their theory was one of integration. The gate control theory embraced the existence of pain-specific neural pathways, which it called nociceptive fibers. It expanded on this idea by proposing a mechanism in which innocuous input is capable of inhibiting painful input, and

vice versa. When we rub a smacked cheek, for instance, the receptors responsible for touch and pressure can send inhibitory signals that interfere with nociceptive activation, allowing momentaneous pain relief. This is referred to as the gate control mechanism. However, gate control theory's greatest merit lies in its conceptualization of the role of the central nervous system. Apart from a neural route from the damaged body part, through inhibitory and transmission cells and up the spinal cord to the brain, Melzack and Wall envisioned a more direct connection from the injury to the brain – essentially circumventing the aforementioned neuronal interplay. This route can eventually be used to reciprocal effect, contingent on several cortical parameters. In other words, it permits our brain to modulate the aforementioned gate control function. Essentially, this explains why psychological factors such as attention, emotion and memory – functions that can be situated in the brain – can modulate how sensory input is eventually perceived. Later, Melzack and Casey expanded gate control theory in order to capture these facets in more detail, adding sensory-discriminative and motivational-affective systems to the model (Melzack & Casey, 1968). It is these pivotal ideas that carried pain theory's transition from a biomedical to a biopsychosocial perspective (Gatchel, Peng, Peters, Fuchs, & Turk, 2007). The door was opened to a new array of scientists. Psychologists finally got to dig in.

« Pain is personal. It really belongs to the one feeling it. Probably the only thing that is your own. I like mine. »

— Henry Rollins

BIOPSYCHOSOCIAL ABCs

Currently, perhaps the most cited definition of pain is the one provided by the International Association for the Study of Pain. It delineates pain as "*an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage*" (Merskey & Bogduk, 1994). As a token of the current biopsychosocial perspective on pain, this definition reflects prior lessons. Rather than restricting pain to a physical component, it indicates how affective parameters may factor into the resulting experience. It also suggests that tissue damage is not necessarily a (sole) prerequisite for pain perception. While the substantial role of biological factors is – of course – undeniable, the body of evidence for psychological and social influences has steadily grown in the past decades. Case in point, it has been extensively shown that affective states can effectively alter pain experiences in a variety of ways (Keefe, Lumley, Anderson, Lynch, & Carson, 2001; Robinson & Riley III, 1999). More specifically, various forms of emotional distress can modulate perceived pain intensity (Keefe, Brown, Wallston, & Caldwell, 1989) and tolerance for acute pain (Rhudy & Meagher, 2000), and may even serve to perpetuate the painful experience (Eccleston & Crombez, 2007; Lethem, Slade, Troup, & Bentley, 1983; Vlaeyen & Linton, 2000). Affective states that are known to be

potential modulators include depression, anger and anxiety (Boyle, 2003; Fernandez, 2002; Rhudy & Meagher, 2000). Foreshadowing the clinical connection of this dissertation, particular patterns of cognitions related to negative affect – such as worry and catastrophic thinking – play a substantial role in contemporary theories of chronic pain. These models will be discussed more extensively in a forthcoming section.

As mentioned above, researchers have been amassing evidence on the role of these psychological factors in pain perception over the past few decades. One such factor – attention – has proven to be particularly interesting, both from a theoretical and a clinical perspective. How, then, does attention tie in with pain perception? And why does it matter? The aim of the following sections will be to convey the deserved prominence of attention in contemporary pain theories. In addition, we will expand on the reason why investigating the construct of attention further could prove to be of significant worth to in clinical contexts. Before proceeding with these intentions, however, it seems wise to agree on what it is that we are talking about, exactly.

« Everyone knows what attention is. »

— William James (James, 1890)

ACHING FOR ATTENTION

Attention is without a doubt a most essential concept in cognitive psychology. As a psychological construct, it is notorious among academic acolytes. One reason for this is that attention can be related to just about every facet of cognition (e.g., selection for action, automaticity, intentional control, consciousness, perception, etc.) (Styles, 2006). As such, it may appear easy to get lost in conceptualization. In contrast, a straightforward definition was offered by Allport, who equated attention to 'selection-for-action' (Allport, 1989). Allport argued that an adequate description of attention should include two important antagonistic principles. On the one hand, our current goals need to be shielded from irrelevant distractors, allowing us to successfully pursue them. If a PhD student is intent on writing a decent dissertation, he or she ought not to be distracted by random Internet videos of comically acting cats, lest the final manuscript never see the light of day. On the other hand, though, it is vital that we be able to interrupt our activities when threatening cues arise. Certain events require action, such as the sudden and spontaneous combustion of a large stack of research papers on the student's desk. If attentional focus on the task at hand were absolute and impenetrable, mankind may have already succumbed to voracious predators, house fires, careless drivers and – in general – Darwin (Darwin, 1859). In

sum, an appropriate balance of these functions shepherds behavior towards the most primordial of concerns: survival.

Roughly, this dual functionality of attention translates to a distinction that is typically made in cognitive psychology between two modes of attentional selection (Sarter, Givens, & Bruno, 2001; Yantis, 2000). The first is referred to as bottom-up capture of attention. It is stimulus-driven and unintentional. The second is top-down selection. This mode of attentional selection is intentional, and is determined by the goals one is pursuing at the time. Below, we expand on how this duality applies to pain. We also expand on how these modes of attentional selection interact, and why this is of importance ton the current dissertation.

Bottom-up

We can easily imagine how visual, auditory or olfactory stimuli can serve as indications of threat, seizing attention in a bottom-up fashion (Öhman & Mineka, 2001). For instance, our hunter-gatherer ancestors may have spotted a tiger lurking about their encampment. Perhaps they heard its roar, or felt its bad breath in their neck. None of these warnings are, of course, as pressing as the sensation of sharp teeth penetrating skin. Pain is indeed the quintessential red flag, imposing a strong claim for attention. Pain wants to be dealt with. It demands action, triggering an intrinsic urge of escape. In an effort to further outline these principles, Eccleston and Crombez developed their cognitive-affective model of bottom-up attention to pain. The model further describes how the interruptive potential of pain may depend on several stimulus parameters (Eccleston & Crombez, 1999).

The attentional demand of pain has been extensively investigated using the *primary-task paradigm*, in which subjects perform a cognitive task while receiving painful stimulation. Rather than measuring attention to pain itself, this paradigm measures the extent to which pain interferes with a primary mental task (Walker, 1971). The reasoning is, then, that the amount of interference can be used as an index of the interruptive ability of the painful stimulation. Results from several such studies have indicated deterioration in primary task performance, evidencing pain's claim over attentional resources (Crombez, Eccleston, Baeyens, & Eelen, 1996, 1997). In addition, pain's bottom-up demand for attention was shown to be moderated by the pain stimulus' intensity (Eccleston, 1994), its novelty (Crombez, Baeyens, & Eelen, 1994) and (un)predictability (Lin, Hsieh, Yeh, & Niddam, 2014).

In more recent studies, attentional capture by pain has been demonstrated using a modified Posner's exogenous cueing task (Posner, 1978). In this paradigm, participants are required to quickly detect in which of two locations a visual stimulus is presented. One of these locations is preceded by a cue. In a congruent trial, the location of the cue matches that of the stimulus. In an incongruent trial, it does not. When the cue was predictive of impending pain (Van Damme, Crombez, & Eccleston, 2004; Van Damme, Crombez, Eccleston, & Koster, 2006), or when the cue itself was nociceptive (Van Damme, Crombez, & Lorenz, 2007), attenuated responses were apparent in incongruent trials. As such, this exogenous cueing effect is thought to reflect attentional capture by pain-related information that is irrelevant for the current task.

Suppose – strictly for illustrative purposes – that a PhD student is writing up a dissertation as quickly as possible, while sitting on an electric chair. The primary task, in this case, is ensuring the swift delivery of a satisfactory script. In line with the aforementioned research findings, we can expect that the student's typing speed, as a token measure of attention to the primary task, will decrease when an electrocutaneous shock is experienced. The more intense the stimulus, the more writing output can be expected to suffer. Similarly, the student's output can be expected to suffer when he or she is suddenly slapped across the cheek, as this pain could be considered novel and – more than likely – unexpected.

Top-down

To focus exclusively on pain as a source of bottom-up interference is to only divulge half of the story. The modulation of attentional selection by top-down factors should be taken into account as well. The neurocognitive model of attention to pain – a spiritual successor of the earlier mentioned cognitive-affective model (Eccleston & Crombez, 1999) – is particularly informative in this regard (Legrain et al., 2009) (see fig. 1). In this model, top-down modulation is determined by two key mechanisms: attentional load and attentional set. The former suggests that the more attention is directed towards a primary goal, the more difficult it is for a bottom-up pain stimulus to grasp attention (the *attentional load hypothesis*). For instance, it has been convincingly shown that presenting someone with a more demanding alternative task may reduce pain perception (Legrain, Bruyer, Guérit, & Plaghki, 2005; Van Damme, Crombez, & Eccleston, 2008). Attentional set, on the other hand, refers to the idea

that stimuli that share features with a goal-relevant focal stimulus will more easily capture attention (the *attentional set hypothesis*).

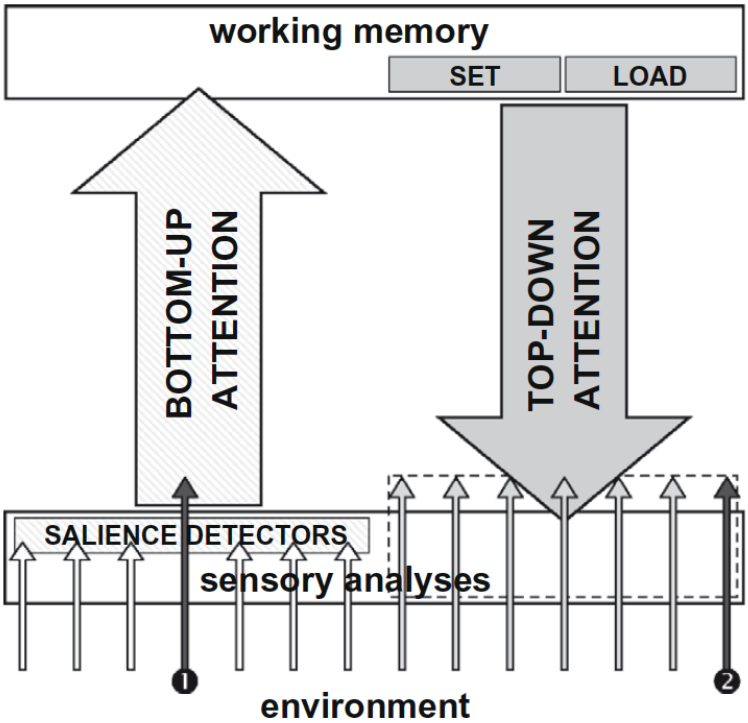


***Figure 1*: The neurocognitive model of attention to pain (taken from Legrain et al., 2009)**

The attentional set hypothesis has roots in theories of visual attention, which proposed that pre-attentive processing produces a so-called 'salience map' of stimulus features. These features can then guide attention, ensuring the selection of important information (Treisman & Gelade, 1980). Importantly, it has been suggested that this salience map can be further shaped by top-down task goals (Cave & Wolfe, 1990). For example, pain can grasp attention more easily when it occurs on a location where task-relevant stimuli are expected to occur, as the primary goal ensures that attention favors stimuli with that spatial feature (Legrain, Guérit, Bruyer, & Plaghki, 2002). Conversely, when pain is expected to occur on specific body site,

innocuous stimuli have been shown to interrupt performance on a primary task to a greater extent (Crombez, Eccleston, Baeyens, & Eelen, 1998a). This finding is of particular relevance to the current dissertation, as – in this experimental setting – the anticipation of pain was not related to the primary task. In other words, this result demonstrates that the contents of the attentional set are not necessarily solely determined by the principal goal. Instead, they suggest that the mere expectation – and relatedly, fear – of an imminent pain stimulus is, in itself, capable of redirecting attention to pain-related stimulus features.

The aforementioned findings make a convincing case that top-down factors ought to play a central part in contemporary pain research. However, it is only fairly recently that these components have received due attention in pain literature. In the following paragraphs, we will highlight some milestones in the context of this dissertation's purposes. In particular, we will focus on the goals that pop up in parallel with the presence of pain.

« I want to get away. I want to fly away. (Yeah yeah yeah). »

— Lenny Kravitz

MOTIVATION MATTERS

When positing his view on attention, Allport already hinted at the fundamental role that is reserved for goal pursuit (Allport, 1989).

Goals can be defined as internal representations of desired states (Austin & Vancouver, 1996). They represent an endpoint that impacts evaluations, emotions and behavior (Fishbach & Ferguson, 2007). There is evidence that attention is attuned to goal attainment, as it favors the selection of goal-relevant information, whilst inhibiting goal-irrelevant information (Johnson, Chang, & Lord, 2006). The strength with which a set of goals are pursued may, in turn, modulate the amount of attention that is allocated to pertinent stimuli (Förster, Liberman, & Friedman, 2007). In sum, goals can be potent top-down moderators of pain-related attention.

Acknowledging this fact, attention to pain was recently reframed in a motivational account (Van Damme, Legrain, Vogt, & Crombez, 2010). Central to this view is the idea that pain always occurs within a motivational context. First, the goals one presently pursues may be unrelated to pain. We have already described how a sudden surge of pain may capture attention in a bottom-up manner, depending on different parameters of the pain stimulus (Eccleston & Crombez, 1999). The motivational account accentuates, however, that the occurrence of attentional capture also depends on characteristics of the focal goal. If this goal is considered to be of inordinate importance, attention may shield this goal from painful interference (Achtziger, Gollwitzer, & Sheeran, 2008). For example, a boxer who is fixated on winning his bout may be numb to the pain inflicted by his adversary. This principle has been evidenced in pain research, as it was shown that non-pain goal pursuit can inhibit pain's claim for attention (Schrooten et al., 2012) and even reduce the perceived intensity of the pain (Verhoeven et al., 2010).

Second, current goals may be specifically related to pain. In one set of studies (Van Damme, Crombez, Eccleston, & Goubert, 2004; Van Damme, Crombez, & Eccleston, 2002), participants were required to detect whether a painful stimulus or a tone was presented. At the start of each trial a word was cued that either correctly or incorrectly predicted the modality of the following stimulus. Interestingly, reaction time on tone trials suffered if the cue predicted pain. A similar attenuation was found in pain trials that were cued for a tone, but to a significantly smaller extent, suggesting that the goal to detect pain was held in higher priority than tone detection. This, amongst other research findings (Bushnell, Duncan, Dubner, Jones, & Maixner, 1985), may serve as evidence that pursuing a focal goal that is centered on pain prioritizes attention towards pain-related information.

Third and finally, we can imagine a scenario in which urgent pain overrides presently pursued purposes. Once pain hits an individual's nociceptive pathways, pain control may present itself as the new primary concern, while putting other motives on hold. We have extensively argued the adaptive value of pain, due to its intrinsic inception of the urge to escape or otherwise control the sore sensation. In fact, there is some evidence that our tendency to exhibit such pain avoidance behavior is biologically hardwired. Flexor withdrawal reflexes evidence this – a set of spinal reflexes that foster immediate withdrawal from painful stimulation (Berntson & Cacioppo, 2008). These reflexes develop early, are among the most prominent, and are very difficult to interrupt. They are specifically tuned to protect the organism from further harm. While such physiological mechanisms cannot be equated to conscious goal pursuit, their premotivational disposition can serve as a clear precursor to intentional pain control

actions. It is then safe to conclude that, whenever pain becomes part of a situation, the emergence of goal pursuit seems utterly unavoidable.

« Ya runnin' and ya runnin' and ya runnin'
But ya can't run away from yourself. »
— Bob Marley

CLINICAL CONTEXT

In the words of colleague researcher Roland Nigbur: "the quest for knowledge is in itself worthwhile" (paraphrased). While this may arguably be the case, it is comforting to know that one's research may eventually be of some practical use – however distant that practical use may be. In that sense, the present dissertation is no mere product of academic pursuit. Its research questions are to no small degree inspired by the clinical conundrum of chronic pain. The fact that the present dissertation does not boast studies including actual chronic pain patients, does not nullify its capacity to contribute. Taking a page out Descartes' book, if you want to know what is wrong with a machine, it is useful to know how it is supposed to operate in the first place.

Chronic pain can be loosely defined as pain that persists for three or more months (Gatchel et al., 2007). While the reported prevalence of chronic pain conditions is subject to significant variability (Ospina & Harstall, 2002) – in part due to the lack of a

universally agreed upon demarcation that separates it from acute pain – it is without doubt a major health concern (Jensen, Turner, Romano, & Karoly, 1991). Interestingly, the pain of these patients often has no clearly discernable biomedical basis (Crombez, Van Damme, & Eccleston, 2005). Riding on the back of the aforementioned biopsychosocial perspective, a number of explanatory efforts have attributed a significant role to dysfunctional styles of attention. In the interest of underlining the clinical bearing of the current dissertation, we will briefly review two such models and – crucially – draw conclusions with regard to the involvement of maladaptive motivational factors.

Fear-avoidance model

The conception of the fear-avoidance model dates back over three decades (Lethem et al., 1983). It focuses on the motivational-affective component of pain perception by critically upholding two key concepts. First, the model ascribes a central role to the concept of 'fear of pain'. Second, when someone is confronted with such fear, there are several possible responses. When the pain is confronted, this more often than not leads to its gradual extinction. When pain avoidance becomes the go-to response, on the other hand, this may in turn lead to the conservation or even aggravation of fear. Fueled by a disconnect between the purpose of the avoidance behavior and the failure to avert painful sensations, pain perception may be increased inadvertently. Completing the cycle, this heightened pain perception serves as feedback to support and strengthen the validity of the initial fearful beliefs.

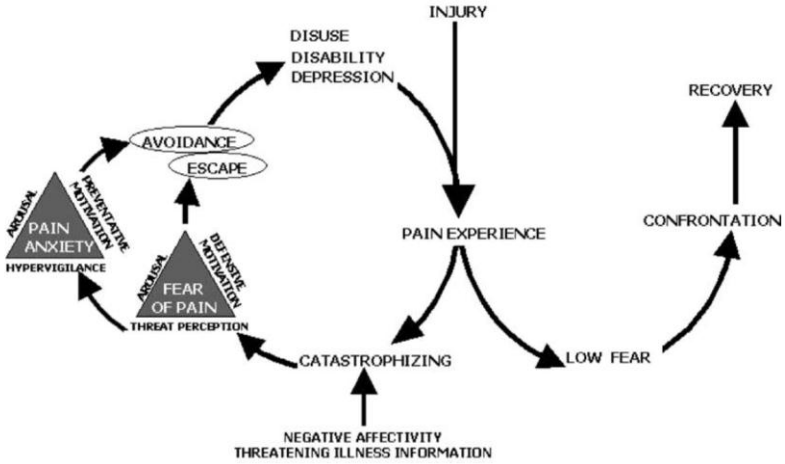


***Figure 2*: The fear-avoidance model of chronic pain (taken from Leeuw et al., 2007)**

In later versions of the model, the cognitive components of the fear-avoidance loop have been outlined further (Leeuw et al., 2007; Vlaeyen, Kole-Snijders, Boeren, & van Eek, 1995; Vlaeyen, Kole-Snijders, Rotteveel, Ruesink, & Heuts, 1995) (see fig. 2). For instance, it is suggested that fear of pain can be determined by cognitive-affective precursors, such as catastrophic thinking. In addition, the model predicts that pain-related fear may interfere with cognitive functioning by forcefully shifting attention towards likely signals of threat. This hypervigilant state – that is, the emphasis of attention towards pain and pain-related information (Crombez et al., 2005) – could then dysfunctionally promote disuse and disability, solidifying the pain experience and perpetuating the cycle (Leeuw et al., 2007; Vlaeyen & Linton, 2000).

Misdirected problem solving model

Similar to the fear-avoidance model, the misdirected problem solving model proposes that chronic pain may be governed, in part, by a spiral of negative cognition and ill-adjusted goal pursuit (Eccleston & Crombez, 2007). The model departs from the observation that chronic pain sufferers exist in a world of persistent pain, which continuously demands attention. This fuels worry, as the pain raises questions concerning its causes and consequences. These negative thoughts may trigger excessive attention, or hypervigilance, to pain, further exacerbation its interruptive quality. In addition, the pain is often framed as a biomedical problem, primarily seeking its root in medical science. When this approach fails to take the pain away, worry increases, ironically strengthening the goal to solve the problem. And so, a perseverance loop of harmful thoughts and misdirected problem solving is initiated, which can only be lifted by either discovering the biological substrate of the pain, or by reframing the problem to include factors that are not strictly medical in nature.

As may be evident from the previous paragraphs, these models have a couple of core features in common. For one, both the fear-avoidance model and the misdirected problem solving model consider some form of maladjusted motivation to be a driving force in the problem's perpetuation. In the former model patients are excessively occupied with avoidance goals, while the latter model proposes that they are intensely motivated to solve their health problem. Secondly, both models include hypervigilance to pain-related information in the description of their respective dysfunctional cycles. Crucially,

hypervigilance is portrayed as a key mechanism in the strengthening of pain perception, as well as the subsequent negative cognition.

Third, cognitive processes that are laden with negative affect are important space to either model. The misdirected problem solving model proposes that worry is the driving force behind a chronic pain patient's persistent efforts to solve the problem (Eccleston & Crombez, 2007) (see fig. 3). Quite similarly, the fear-avoidance model describes how catastrophic thought may give way to an increase in pain-related fear, excessive attention to pain-related information and ultimately, to persistent yet dysfunctional avoidance or control attempts. Notably, the potential impact of pain catastrophizing on attention has already been evidenced in several studies. For example, it was shown that strong pain catastrophizers have more difficulty to disengage their attention from pain-threatening signals (Van Damme, Crombez, & Eccleston, 2002). More recently, in a diary study, chronic pain patients reported who more pain catastrophizing also devoted more attention to their pain (Crombez, Viane, Eccleston, Devulder, & Goubert, 2013). In sum, it may be particularly interesting to investigate how pain catastrophizing can influence attention to pain.

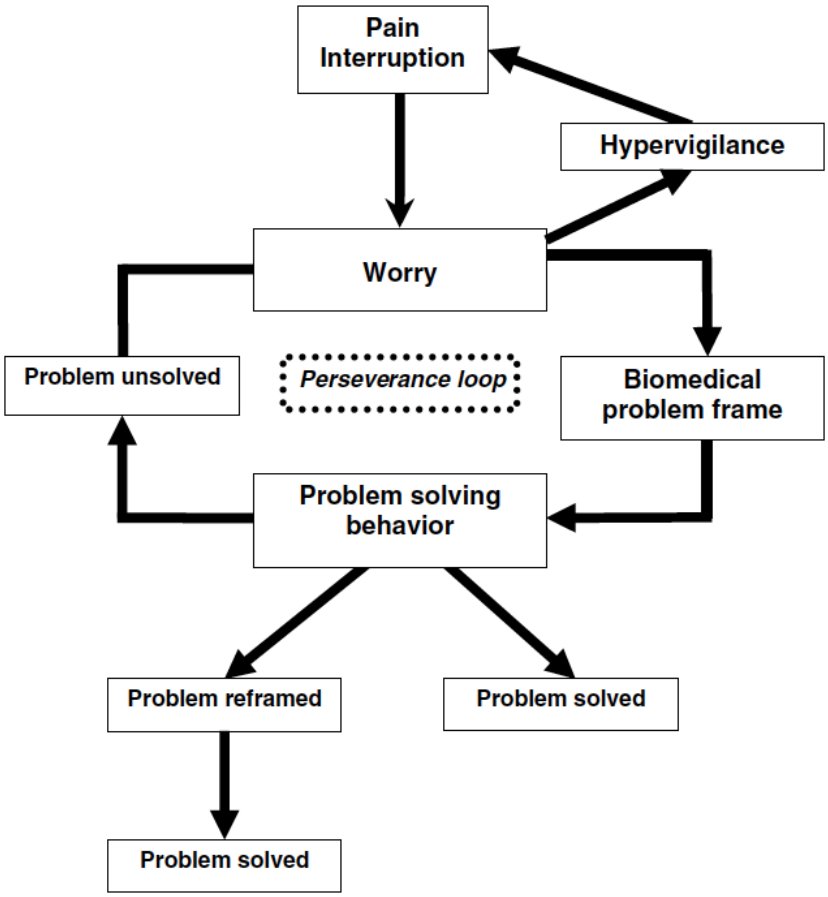


***Figure 3*: The misdirected problem solving model (taken from Eccleston & Crombez, 2007)**

It is with regard to precisely these notions that this dissertation aspires to be helpful. As we detailed in the final section of this introduction, the main mission of this thesis is to investigate the connection between (dysfunctional) attempts to control pain and attention to pain-related information. Such exploration has the potential to lend support to theoretical models such as the ones mentioned earlier, and may ultimately help guide us towards the development of more effective interventions for the mitigation or management of pain.

Pain catastrophizing

Pain catastrophizing refers to an inflation of cognitions laden with negative affect, triggered by anticipated or actual pain (Sullivan et al., 2001). As we discussed above, it is a critical component in contemporary conceptualizations of the fear-avoidance model of chronic pain (Leeuw et al., 2007; Vlaeyen & Linton, 2000). In the model, pain catastrophizing aggravates pain-related fear, which in turn may lead to a hypervigilant mental state with regard to pain-related information. Additionally, an increased fear of pain may bolster efforts to avoid its recurrence.

Pain catastrophizing is akin to the construct of worry, which is defined as "a chain of thoughts and images, negatively affect laden and relatively uncontrollable" (Borkovec, Robinson, Pruzinsky, & DePree, 1983). Worry takes up a crucial role in an explanatory model of chronic pain – the misdirected problem solving model (Eccleston & Crombez, 2007). In a comparable fashion to pain catastrophizing, worry is thought to elicit persistent attempts to solve the problem of pain, even in spite of the oftentimes maladaptive nature of such efforts. In addition, worry is suggested to induce excessive attention – or hypervigilance – to pain. Interestingly, one study identified pain catastrophizing as a mediator between worry and pain (Lackner & Quigley, 2005). Chronic pain patients who reported more worry also engaged in pain catastrophizing more, which in turn was found to aggravate their pain suffering.

The paragraphs above illustrate the importance of negative affect in precursor mechanisms of attention to pain. There is some support for this assertion. Interestingly, catastrophic thinking has been shown

to moderate attention to pain-related features, brought on by the threat of pain (Crombez, Eccleston, Baeyens, & Eelen, 1998b; Van Damme, Crombez, & Eccleston, 2002, 2004). This further substantiates the potential role of catastrophizing in investigations of pain-related attention. As such, it would be useful to further investigate pain catastrophizing in the context of the present dissertation.

« Where do we go now ? »

— Lenny Crabbe

DISTILLING DIRECTION

Up to this point, our discourse has touched upon a number of different topics. Before synthesizing them into a set of aims, we will offer a few added observations that were crucial in the conceptualization of the studies that lie ahead.

Modeling pain control efforts

While there have been ample studies on pain-related attention, those that modeled actual pain control attempts are few and far between. Studies that do investigate effects of (perceived) pain control, on the other hand, typically focus on various pain-related responses. For instance, failure to control pain has been shown to increase anger and heart rate responses (Janssen, Spinhoven, & Arntz, 2004). Conversely, the perception of controllability was demonstrated to

reduce experienced pain intensity (Scharff, Turk, & Marcus, 1995; Vancleef & Peters, 2011). Also, exerted control over pain has been suggested to modulate the sensation of relief (Mohr, Leyendecker, Petersen, & Helmchen, 2012). Finally, from a neuroimaging point of view, the analgesic effect of expected and perceived control has been associated with activation in the anterolateral prefrontal cortex (Wiech et al., 2006). Notably, studies that investigate effects of pain control behavior on attention are scarcer yet. An interesting exception is the study performed by Notebaert and colleagues, in which it was found that attempts to control pain prioritize attention towards visual signals of pain (Notebaert et al., 2011). This study confirms the importance of modeling pain control motivation, as well as the possibility to act on this motivation, in investigations of attention.

Somatosensory paradigms

It is evident that – from the perspective of external validity, in particular – there is greater value in the use of actual pain stimuli in experiments, rather than the use of verbal or visual indications of physical harm or threat. Remarkably, a significant proportion of past experiments have been characterized by precisely the latter (Crombez, Van Ryckeghem, Eccleston, & Van Damme, 2013). This may be due to the fact that the majority of the paradigms that are used in studies on attention to pain are adopted from related branches of psychopathology. For instance, different types of anxiety and phobia can arguably be related to clinical pain problems – such as chronic pain – in the sense that they have all been associated with an attentional bias for information that is considered threatening (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn,

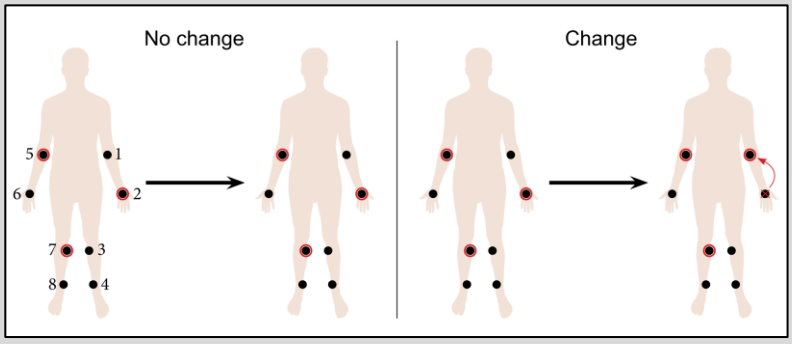
2007). Consequently, a paradigm that is serviceable in investigating how anxiety leads to an attentional bias for threatening information – such as the Stroop task (Martin, Williams, & Clark, 1991)– may be easily adapted to investigate if chronic pain does induce a bias towards pain descriptors (Pearce & Morley, 1989)

While experiments investigating effects of pain-related variables on visual attention are worthwhile indeed, it would be interesting to examine how these factors influence somatosensory attention – that is, attention directed towards somatosensory sensations. Somatosensory paradigms would also enable us to accommodate individual differences in pain perception, such as one's threshold for pain (Fillingim, Edwards, & Powell, 1999). In addition, such paradigms would be particularly informative in the context of hypothesized hypervigilance to pain, as conceptualized in explanatory models of chronic pain.

In the upcoming chapters, we describe a series of experiments in which we investigate attention to pain-related information. In line with the above observations, these experiments all feature paradigms in which the use of somatosensory stimuli is central. Two major paradigms are used in the body of this work: the tactile change detection task (Gallace, Tan, & Spence, 2006) and the temporal order judgment task (Zampini et al., 2007) (box 2).

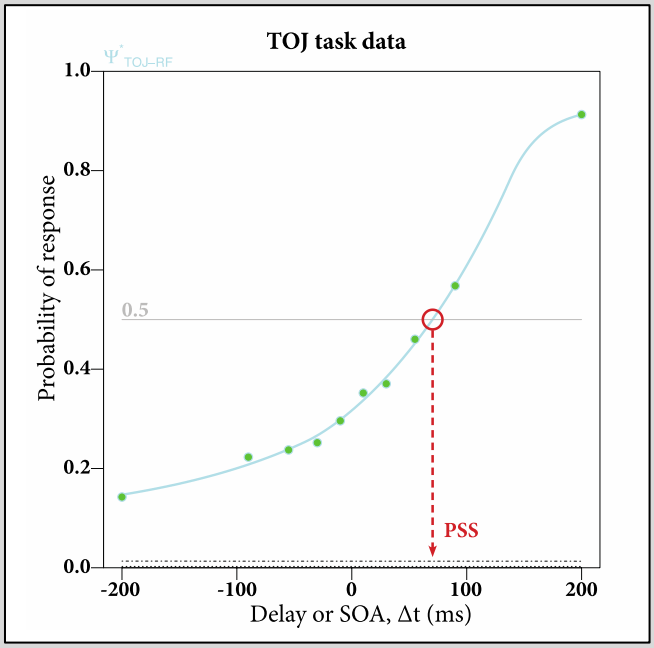
Box 2 – A brief explanation of presently used paradigms

In the **tactile change detection task**, participants are asked to judge whether or not they perceive a difference between two patterns of vibrotactile stimuli, presented in short succession (with a 110 ms interval). The first pattern, in our case, consists of the simultaneous activation of tactors on three separate body locations out of a total of eight. The second pattern can either be identical to the first, or different. In case of a change trial, the activation of one of these tactors is exchanged for activation of a different tactor, previously not included in the pattern. We gauge attention to a specific location by measuring the accuracy with which a participant can detect changes at that body site, with respect to the conditions under which this detection takes place (for instance, while under threat of pain).



Temporal order judgment and **synchrony judgment** paradigms present participants with two successive stimuli, separated by one of a number of possible stimulus onset asynchronies (SOAs). It is the participant's task to judge the order of these stimuli, often by stating which one he or she perceived first. Typically, this is indicated by reporting the

position of this stimulus, or in some cases, its modality. When the experiment is completed, a proportion of responses per SOA. For example, the participant may have given the response 'left first' 17 out of 30 times when the left stimulus preceded the right stimulus with 30 ms., leading to a proportion of .57 ms. These proportions – all values between 0 and 1 – are then fitted with a psychometric function. This function is often based on Gaussian or Logarithmic function. In this dissertation, however, we will mainly use functions based on the independent channels model.



This curve can then be used to calculate the point of subjective simultaneity (PSS), a virtual data point that indicates what interval should separate the stimuli in order for them to be perceived as simultaneous. An example of this is given in the graph (for a TOJ study). The PSS is indicated in red. As a measure, it gives us information with regard to the respective

speed with which each of these stimuli is processed, indicating possible attentional prioritization.

Second, all these experiments will investigate the effect of pain control motivation, by encouraging actual attempts to avoid the experimental pain. Prior to outlining the remainder of the dissertation, we wish to acknowledge that pain control behavior can take on many forms, avoidance being just one of them. We can just as easily imagine that pain is already present, in which case a swift escape may become of the essence instead. Finally, when neither avoidance nor escape can be considered a valid option any longer, the person who is suffering may become motivated to minimize the pain. In this instance, distraction techniques (Van Damme et al., 2010) or acceptance therapies (Kohl, Rief, & Glombiewski, 2012) may become an advisable course of action.

The choice of avoidance behavior was in part a practical one, as implementing this in an experiment's design is a more straightforward affair. Still, there is growing evidence that safety behavior – such as a fixation on pain avoidance – may be linked with increasing levels of fear (Dymond, Dunsmoor, Vervliet, Roche, & Hermans, 2014; Volders, Meulders, De Peuter, Vervliet, & Vlaeyen, 2012). This is particularly relevant to the present thesis, as we have discussed previously how pain-related fear may be instrumental in the shaping of attention (Leeuw et al., 2007; Vlaeyen & Linton, 2000).

Aims

The mission statement of this PhD thesis is to investigate whether and how (dysfunctional) motivation to control pain can

enhance attention to pain-related information. Our research questions were inspired by the attentional set hypothesis, as mentioned in neurocognitive model of attention to pain (Legrain et al., 2009). To reiterate, this hypothesis suggests that top-down factors, such as the goal that one pursues at the present time, determine which stimulus features should be selected by attention with priority (Van Damme et al., 2010).

First, as we argued in the preceding paragraphs, the presence of pain can be associated with the instinctively emerging goal of pain control (Eccleston & Crombez, 1999). We thus hypothesize that the mere expectation of pain would shape the attentional set, so that pain features will be prioritized by attention.

Second, we propose that focal pain control motivation spotlights the features of pain in the attentional set further. In other words, we predict that individuals who are actively attempting to control pain would exhibit enhanced prioritization of stimulus features pertinent to the pain they are trying to control.

With regard to the predicted prioritization effects, we examine two stimulus features in greater detail. Pain is a somatosensory event. In addition, it is generally associated with a specific part of the body. Hence, we expect that the anticipation of pain will prioritize attention (1) towards somatosensory information and (2) towards the location where the pain is expected to occur. In addition, we hypothesize that allowing participants to act upon the urge to deal with the pain will further emphasize its features in the attentional set, as a direct result of the – now active – goal pursuit.

Third, we investigate how one's individual disposition to engage in pain catastrophizing may moderate these effects. We hypothesize

that higher levels of pain catastrophizing will be associated with stronger prioritization, as catastrophic thinking may strengthen the effect of threat, as well as lead to more persistent efforts to control the – essentially uncontrollable – painful stimulation.

Outline

In the ***first chapter***, we investigated whether attempts to control pain prioritized attention towards the location where this pain was expected. To this purpose, we used a tactile change detection task, in which participants are required to judge whether or not they felt a change between two subsequent patterns of somatosensory stimulation. In half of all trials, a specific part of participants' bodies was threatened with a painful electrocutaneous stimulus. Half of the participants were given the opportunity to attempt to avoid the pain, whereas the other half were not. We expected that the anticipation of pain would direct attention towards the threatened location. This should result in increased detection of changes occurring on this particular body site. More so, we predicted this enhanced detection to be more pronounced in participants who actively sought pain control.

Parallel hypotheses were investigated in the ***second chapter***, yet by means of an alternative paradigm. In this experiment, a synchrony judgment setup was used. Participants judged the order in which two somatosensory stimuli were presented by stating which they perceived first – the left hand or right hand stimulus. If they did not perceive a difference, participants could report this as well. Again, in half of all trials one of both stimulus locations was threatened with a painful stimulus. Participants were divided in a pain control group and a comparison group. We expected stimuli applied to the threatened

location to be processed more swiftly when pain was anticipated. Crucially, we hypothesized that this attentional advantage would be stronger in the pain control group.

Following up on earlier results, the ***third chapter*** details our testing of a novel idea. Inspired by critical review of our first experiment's design, we hypothesized attentional prioritization effects in the pain control group to be the result of a somatosensory monitoring strategy. Thus, we reasoned that providing participants with feedback regarding the success of their pain control attempts would nullify the need for such monitoring, and consequently, would annul its effects on attention. To test this prediction, we modified the design of the original tactile change detection study to include feedback messages. These messages informed participants in pain control group – prior to the presentation of the somatosensory stimuli – about whether or not their avoidance action was successful. In addition, this chapter details a replication of the experiment described in chapter one.

In the ***fourth chapter***, we used a temporal order judgment paradigm to investigate whether the spatial prioritization of a threatened location is modality-specific, that is, if it is restricted to somatosensory information. Similar to the previous synchrony judgment study, participants judged the order of two stimuli, one presented on the right hand and one on the left hand. In this study, however, the 'simultaneous' response was no longer an option. In half of the experiment blocks the presented stimuli were visual, while in the other half somatosensory stimuli were administered. Once more, half of all trials were associated with the threat of pain, and half of all

participants were encouraged to attempt pain control. If the prioritization of a body site threatened with pain is restricted to the somatosensory modality, only somatosensory trials should exhibit such a shift in attention. If not, we would expect a similar processing speed advantage to be evident in visual trials. We hypothesized that all of these effects would be more enhanced in the pain control group.

We revisited the temporal order judgment paradigm in the ***fifth chapter***. In this experiment, however, trials were bimodal. This means that while participants again had to judge the order of a pair of stimuli, they were required to state which stimulus type they perceived first – a light or a vibration – rather than say which location was stimulated first. Threat was again present in half of all trials. These threat trials predicted that there was a chance for participants to experience painful stimuli to occur on all stimulus locations simultaneously, so as not to favor a particular body site. We hypothesized that the presence of threat would cause somatosensory information to be processed more quickly than visual information. In line with earlier hypotheses, we predicted this attentional benefit to be more pronounced when participants actively engaged in pain control behavior.

Finally, in the ***sixth chapter***, we investigated the moderating potential of pain catastrophizing by revisiting data from all aforementioned studies. We pooled data from equivalently designed experiments when applicable. Then, we conducted additional data analyses to investigate whether pain catastrophizing could help explain individual differences with regard to the effects of pain (control) on attention.

Note that the studies described in these chapters were not necessarily conducted in chronological order. Chapters one through five were originally prepared as stand-alone articles. Consequently, there may be some overlap between these chapters. Despite the fact that the material presented here has undergone revisions over time and according to the criteria employed by different journals, we have made efforts to maintain consistency in the use of notation throughout.

References

Achtziger, A., Gollwitzer, P. M., & Sheeran, P. (2008). Implementation intentions and shielding goal striving from unwanted thoughts and feelings. *Personality and Social Psychology Bulletin*, *34*(3), 381–393.

Allport, A. (1989). Visual Attention. In M. I. Posner (Ed.), *Foundation of Cognitive Science* (pp. 631–682). Hillsdale, NJ: Erlbaum.

Austin, J. T., & Vancouver, J. B. (1996). Goal constructs in psychology: Structure, process, and content. *Psychological Bulletin*, *120*(3), 338–375.

Baddeley, A. D. (1992). Working memory. *Science*, *110*(11), 16–7. doi:10.1097/01.NAJ.0000390505.77157.63

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: a meta-analytic study. *Psychological Bulletin*, *133*(1), 1–24. doi:10.1037/0033-2909.133.1.1

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using S4 classes. R package version 1.1-6. *R*. Retrieved from http://cran.r-project.org/package=lme4

Beecher, H. K. (1959). *Measurement of subjective responses.* New York, NY: Oxford University Press.

Bell, C. (1811). Idea of a new anatomy of the brain; submitted for the observation of his friends. In P. F. Cranefield (Ed.), *The way in and the way out: François Magendie, Charles Bell and the roots of the spinal nerves.* New York: Futura.

Berntson, G. G., & Cacioppo, J. T. (2008). The Neuroevolution of Motivation. In J. Y. Shah & W. L. Gardner (Eds.), *Handbook of Motivation Science* (pp. 188–200). New York, NY: The Guilford Press.

Bolanowski, S. J., Gescheider, G. A., Fontana, A. M., Niemiec, J. L., & Tromblay, J. L. (2001). The effects of heat-induced pain on the detectability, discriminability, and sensation magnitude of vibrotactile stimuli. Somatosensory & motor research (Vol. 18). doi:10.1080/08990

Borkovec, T. D., Robinson, E., Pruzinsky, T., & DePree, J. A. (1983). Preliminary exploration of worry: Some characteristics and processes. *Behaviour Research and Therapy*, *21*(1), 9–16.

Boyle, G. J. (2003). Anxiety, depression, and anger in pain: Research findings and clinical options. *Journal of Health Psychology*, *8*(4), 477–478.

Bushnell, M. C., Duncan, G. H., Dubner, R., Jones, R. L., & Maixner, W. (1985). Attentional influences on noxious and innocuous cutaneous heat detection in humans and monkeys. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *5*(5), 1103–1110.

Cave, K. R., & Wolfe, J. M. (1990). Modeling the role of parallel processing in visual search. *Cognitive Psychology*, *22*(2), 225–271. doi:10.1016/0010-0285(90)90017-X

Chapman, C. R., Tuckett, R. P., & Song, C. W. (2008). Pain and Stress in a Systems Perspective: Reciprocal Neural, Endocrine, and Immune Interactions. *Journal of Pain*, *9*(2), 122–145. doi:10.1016/j.jpain.2007.09.006

Crombez, G., Baeyens, F., & Eelen, P. (1994). Sensory and temporal information about impending pain: The influence of predictability on pain. *Behaviour Research and Therapy*, *32*(6), 611–622. doi:10.1016/0005-7967(94)90015-9

Crombez, G., Eccleston, C., Baeyens, F., & Eelen, P. (1996). Disruptive nature of pain: An experimental investigation. *Behaviour Research and Therapy*, *34*(11-12), 911–918. doi:10.1016/S0005-7967(96)00058-7

Crombez, G., Eccleston, C., Baeyens, F., & Eelen, P. (1997). Habituation and the interference of pain with task performance. *Pain*, *70*(2-3), 149–154. doi:10.1016/S0304-3959(96)03304-0

Crombez, G., Eccleston, C., Baeyens, F., & Eelen, P. (1998a). Attentional disruption is enhanced by the threat of pain. *Behaviour Research and Therapy*, *36*(2), 195–204. doi:10.1016/S0005-7967(97)10008-0

Crombez, G., Eccleston, C., Baeyens, F., & Eelen, P. (1998b). When somatic information threatens, catastrophic thinking enhances attentional interference. *Pain*, *75*(2-3), 187–198. doi:10.1016/S0304-3959(97)00219-4

Crombez, G., Eccleston, C., De Vlieger, P., Van Damme, S., & De Clercq, A. (2008). Is it better to have controlled and lost than never to have controlled at all? An experimental investigation of control over pain. *Pain*, *137*(3), 631–9. doi:10.1016/j.pain.2007.10.028

Crombez, G., Eccleston, C., & Van Damme, S. (2004). Hypervigilance and attention to pain, 1–4. Retrieved from http://opus.bath.ac.uk/6665/

Crombez, G., Van Damme, S., & Eccleston, C. (2005). Hypervigilance to pain: an experimental and clinical analysis. *Pain*, *116*(1-2), 4–7. doi:10.1016/j.pain.2005.03.035

Crombez, G., Van Ryckeghem, D. M. L., Eccleston, C., & Van Damme, S. (2013). Attentional bias to pain-related information: a meta-analysis. *Pain*, *154*(4), 497–510. doi:10.1016/j.pain.2012.11.013

Crombez, G., Viane, I., Eccleston, C., Devulder, J., & Goubert, L. (2013). Attention to pain and fear of pain in patients with chronic pain. *Journal of Behavioral Medicine*, *36*(4), 371–378. doi:10.1007/s10865-012-9433-1

Dallenbach, K. M. (1939). Pain: history and present status. *The American Journal of Psychology*, *52*(3), 331–347.

Darwin, C. (1859). On the Origin of the Species. Darwin (Vol. 5).

Dawkins, R. (1995). *River out of eden: A Darwinian view of life*. New York, NY: Basic Books.

De Ruddere, L., Goubert, L., Stevens, M., Williams, A. C. de C., & Crombez, G. (2013). Discounting pain in the absence of medical evidence is explained by negative evaluation of the patient. *Pain*, *154*(5), 669–76. doi:10.1016/j.pain.2012.12.018

Descartes, R. (1662). *De Homine—Figuris et Latinitate Donatus Florentio Schuyl.* Leiden, Germany: Leffer & Moyardus.

Dowman, R., & Ben-Avraham, D. (2008). An artificial neural network model of orienting attention toward threatening somatosensory stimuli. *Psychophysiology*, *45*(2), 229–239. doi:10.1111/j.1469-8986.2007.00614.x

Dymond, S., Dunsmoor, J. E., Vervliet, B., Roche, B., & Hermans, D. (2014). Fear Generalization in Humans: Systematic Review and Implications for Anxiety Disorder Research. *Behavior Therapy*. doi:10.1016/j.beth.2014.10.001

Eccleston, C. (1994). Chronic pain and attention: a cognitive approach. The British Journal of Clinical Psychology / the British Psychological Society, 33 (Pt 4), 535–547.

Eccleston, C., & Crombez, G. (1999). Pain demands attention. *Psychological Bulletin*, *125*(3), 356–366.

Eccleston, C., & Crombez, G. (2007). Worry and chronic pain: a misdirected problem solving model. *Pain*, *132*(3), 233–236. doi:10.1016/j.pain.2007.09.014

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion (Washington, D.C.)*, *7*(2), 336–53. doi:10.1037/1528-3542.7.2.336

Fernandez, E. (2002). *Anxiety, depression and anger in pain: Research implications.* Dallas, TX: Advanced psychology resources.

Fillingim, R. B., Edwards, R. R., & Powell, T. (1999). The relationship of sex and clinical pain to experimental pain responses. *Pain*, *83*(3), 419–425.

Fishbach, A., & Ferguson, M. J. M. (2007). The goal construct in social psychology. In A. W. K. E. T. Higgins (Ed.), *Social psychology: Handbook of basic principles (2nd ed.)* (pp. 490–515). Guilford Press. Retrieved from http://melissaferguson.squarespace.com/storage/fishbachferguson 2007.pdf

Folk, C. L., & Remington, R. W. (2008). Bottom-up priming of top-down attentional control settings. *Visual Cognition*, *16*(2-3), 215–231. doi:10.1080/13506280701458804

Förster, J., Liberman, N., & Friedman, R. S. (2007). Seven principles of goal activation: a systematic approach to distinguishing goal priming from priming of non-goal constructs. *Personality and Social Psychology Review : An Official Journal of the Society for Personality and Social Psychology, Inc*, *11*(3), 211–233.

Gallace, A., Tan, H. Z., & Spence, C. (2006). The failure to detect tactile change: a tactile analogue of visual change blindness. *Psychonomic Bulletin & Review*, *13*(2), 300–303.

Gatchel, R. J., Peng, Y. B., Peters, M. L., Fuchs, P. N., & Turk, D. C. (2007). The biopsychosocial approach to chronic pain: scientific advances and future directions. *Psychological Bulletin*, *133*(4), 581–624. doi:10.1037/0033-2909.133.4.581

Harper, D. E., & Hollins, M. (2012). Is touch gating due to sensory or cognitive interference? *Pain*, *153*(5), 1082–1090. doi:10.1016/j.pain.2012.02.011

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*(2), 65–70.

James, W. (1890). *The principles of psychology, Vol I. New York Holt* (Vol. 1). Henry Holt and Co. Retrieved from

http://psychclassics.yorku.ca/James/Principles/index.htm\nhttp://content.apa.org/books/11059-000

Janssen, S. A., Spinhoven, P., & Arntz, A. (2004). The effects of failing to control pain: an experimental investigation. *Pain*. Retrieved from http://ac.els-cdn.com/S0304395903004548/1-s2.0-S0304395903004548-main.pdf?_tid=a38bc4aa-3cb7-11e4-9d0a-00000aacb361&acdnat=1410772194_a6f9d3220649a9bbcd9ada8b5c83d307

Jensen, M. P., Turner, J. A., Romano, J. M., & Karoly, P. (1991). Coping with chronic pain: a critical review of the literature. *Pain*.

Johnson, R. E., Chang, C.-H., & Lord, R. G. (2006). Moving from cognition to behavior: What the research says. *Psychological Bulletin*, *132*(3), 381–415. doi:10.1037/0033-2909.132.3.381

Katzenell, U., & Segal, S. (2001). Hyperacusis: review and clinical guidelines. Otology & Neurotology : Official Publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology, 22(3), 321–326; discussion 326–327. doi:10.1097/00129492-200105000-00009

Keefe, F. J., Brown, G. K., Wallston, K. A., & Caldwell, D. S. (1989). Coping with rheumatoid arthritis pain: catastrophizing as a maladaptive strategy. *Pain*, *37*(1), 51–56.

Keefe, F. J., Lumley, M., Anderson, T., Lynch, T., & Carson, K. L. (2001). Pain and emotion: New research directions. *Journal of Clinical Psychology*, *57*(4), 587–607.

Kohl, A., Rief, W., & Glombiewski, J. A. (2012). How effective are acceptance strategies? A meta-analytic review of experimental results. *Journal of Behavior Therapy and Experimental Psychiatry*, *43*(4), 988–1001. doi:10.1016/j.jbtep.2012.03.004

Kroenke, K., Spitzer, R. L., & Williams, J. B. W. (2002). The PHQ-15: validity of a new measure for evaluating the severity of somatic symptoms. *Psychosomatic Medicine*, *64*(2), 258–266.

Lackner, J. M., & Quigley, B. M. (2005). Pain catastrophizing mediates the relationship between worry and pain suffering in patients with irritable bowel syndrome. *Behaviour Research and Therapy*, *43*(7), 943–957. doi:10.1016/j.brat.2004.06.018

Leeuw, M., Goossens, M. E. J. B., Linton, S. J., Crombez, G., Boersma, K., & Vlaeyen, J. W. S. (2007). The fear-avoidance model of musculoskeletal pain: current state of scientific evidence. *Journal of Behavioral Medicine*, *30*(1), 77–94. doi:10.1007/s10865-006-9085-0

Legrain, V., Bruyer, R., Guérit, J. M., & Plaghki, L. (2005). Involuntary orientation of attention to unattended deviant nociceptive stimuli is modulated by concomitant visual task difficulty. Evidence from laser evoked potentials. *Clinical Neurophysiology*, *116*(9), 2165–2174. doi:10.1016/j.clinph.2005.05.019

Legrain, V., Guérit, J. M., Bruyer, R., & Plaghki, L. (2002). Attentional modulation of the nociceptive processing into the human brain: Selective spatial attention, probability of stimulus occurrence, and target detection effects on laser evoked potentials. *Pain*, *99*(1-2), 21–39. doi:10.1016/S0304-3959(02)00051-9

Legrain, V., Van Damme, S., Eccleston, C., Davis, K. D., Seminowicz, D. A., & Crombez, G. (2009). A neurocognitive model of attention to pain: behavioral and neuroimaging evidence. *Pain*, *144*(3), 230–2. doi:10.1016/j.pain.2009.03.020

Lethem, J., Slade, P. D., Troup, J. D. G., & Bentley, G. (1983). Outline of a fear-avoidance model of exaggerated pain perception. *Behaviour Research and Therapy*, *21*(4), 401–408. doi:10.1016/0005-7967(83)90009-8

Levitt, H. (1970). Transformed up-down methods in psychoacoustics. *The Journal of the Acoustical Society of America.*

Lin, C.-S., Hsieh, J.-C., Yeh, T.-C., & Niddam, D. M. (2014). Predictability-mediated pain modulation in context of multiple cues: An event-related fMRI study. *Neuropsychologia*, *64*, 85–91. doi:10.1016/j.neuropsychologia.2014.09.021

Livingston, W. K. (1943). *Pain mechanisms.* New York, NY: Macmillan.

Martin, M., Williams, R. M., & Clark, D. M. (1991). Does anxiety lead to selective processing of threat-related information? *Behaviour Research and Therapy*, *29*(2), 147–160. doi:10.1016/0005-7967(91)90043-3

Melzack, R. (1992). Phantom limbs. *Scientific American*, *266*(4), 120–126.

Melzack, R., & Casey, K. L. (1968). Sensory, motivational, and central control determinants of pain. A new conceptual model. *The Skin Senses. Chapter 20.*

Melzack, R., & Wall, P. D. (1965). Pain Mechanism: A new Theory. *Science*, *150*(3699), 971 – 979. doi:10.1126/science.150.3699.971

Merskey, H., & Bogduk, N. (1994). Classification of Chronic Pain. Descriptions of Chronic Pain Syndromes and Definitions of Pain Terms. (H. Merskey & N. Bogduk, Eds.)IASP Press. IASP Press.

Mitchell, S. W. (1871). Phantom limbs. Lippincott's Magazine of Popular Literature and Science, 8, 563–569.

Moayedi, M., & Davis, K. D. (2012). Theories of pain: from Specificity to Gate Control. *Journal of Neurophysiology*, (October 2012), 5–12. doi:10.1152/jn.00457.2012

Mohr, C., Leyendecker, S., Petersen, D., & Helmchen, C. (2012). Effects of perceived and exerted pain control on neural activity during pain relief in experimental heat hyperalgesia: a fMRI study. *European Journal of Pain (London, England)*, *16*(4), 496–508. doi:10.1016/j.ejpain.2011.07.010

Moore, D. J., Keogh, E., & Eccleston, C. (2013). The effect of threat on attentional interruption by pain. *Pain*, *154*(1), 82–88. doi:10.1016/j.pain.2012.09.009

Moseley, G. L., Gallace, A., & Spence, C. (2009). Space-based, but not arm-based, shift in tactile processing in complex regional pain syndrome and its relationship to cooling of the affected limb. *Brain : A Journal of Neurology*, *132*(Pt 11), 3142–51. doi:10.1093/brain/awp224

Moseley, G. L., Gallagher, L., & Gallace, A. (2012). Neglect-like tactile dysfunction in chronic back pain. *Neurology*, *79*(4), 327–332. doi:10.1212/WNL.0b013e318260cba2

Nesse, R. M. (2001). The smoke detector principle. Natural selection and the regulation of defensive responses. *Annals of the New York Academy of Sciences*, *935*, 75–85. doi:10.1119/1.2340316

Notebaert, L., Crombez, G., Vogt, J., De Houwer, J., Van Damme, S., & Theeuwes, J. (2011). Attempts to control pain prioritize attention towards signals of pain: an experimental study. *Pain*, *152*(5), 1068–1073. doi:10.1016/j.pain.2011.01.020

Ohman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: detecting the snake in the grass. *Journal of Experimental Psychology. General*, *130*(3), 466–478. doi:10.1037/0096-3445.130.3.466

Öhman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: toward an evolved module of fear and fear learning. *Psychological Review*, *108*(3), 483–522. doi:10.1037/0033-295X.108.3.483

Ospina, M., & Harstall, C. (2002). Prevalence of chronic pain: An overview. *Alberta Heritage Foundation for Medical Research*, *9*(1), 36–38. Retrieved from http://www.ihe.ca/documents/prevalence_chronic_pain_0.pdf

Pearce, J., & Morley, S. (1989). An experimental investigation of the construct validity of the McGill Pain Questionnaire. *Pain*, *39*(1), 115–121. doi:10.1016/0304-3959(89)90182-6

Posner, M. I. (1978). Chronometric Explorations of Mind. *Oxford, Oxford University Pres*, 286. Retrieved from

http://books.google.com/books?id=tQwHAAAACAAJ&printsec=frontcover\
npapers2://publication/uuid/775A7210-14E1-4951-AB23-C49663FEDD23

Rhudy, J. L., & Meagher, M. W. (2000). *Fear and anxiety: divergent effects on human pain thresholds. Pain* (Vol. 84). doi:10.1016/S0304-3959(99)00183-9

Robinson, M. E., & Riley III, J. L. (1999). The role of emotion in pain. In R. J. Gatchel & D. C. Turk (Eds.), *Psychosocial factors in pain: Critical perspectives* (pp. 74–88). Guilford Press.

Sarter, M., Givens, B., & Bruno, J. P. (2001). The cognitive neuroscience of sustained attention: Where top-down meets bottom-up. *Brain Research Reviews*, *35*(2), 146–160. doi:10.1016/S0165-0173(01)00044-3

Scharff, L., Turk, D. C., & Marcus, D. A. (1995). The relationship of locus of control and psychosocial-behavioral response in chronic headache. *Headache*, *35*(9), 527–533. doi:10.1111/j.1526-4610.1995.hed3509527.x

Schrooten, M. G. S., Van Damme, S., Crombez, G., Peters, M. L., Vogt, J., & Vlaeyen, J. W. S. (2012). Nonpain goal pursuit inhibits attentional bias to pain. *Pain*, *153*(6), 1180–1186. doi:10.1016/j.pain.2012.01.025

Sinclair, D. C. (1955). Cutaneous sensation and the cotrine of specific nerve energies. *Brain*, *78*, 584–614.

Stevens, M., Lammertyn, J., Verbruggen, F., & Vandierendonck, A. (2006). Tscope: A C library for programming cognitive experiments on the MS windows platform. *Behavior Research Methods*, *38*(2), 280–286. doi:10.3758/BF03192779

Styles, E. A. (2006). *The Psychology of Attention*. New York: Psychology Press. doi:10.1038/041460a0

Sullivan, M. J. L., Bishop, S., & Pivik, J. (1995). The pain catastrophizing scale: Development and validation. *Psychological Assessment*, *7*, 524–535.

Sullivan, M. J. L., Thorn, B., Haythornthwaite, J. A., Keefe, F., Martin, M., Bradley, L. A., & Lefebvre, J. C. (2001). Theoretical perspectives on the relation between catastrophizing and pain. *The Clinical Journal of Pain*, *17*(1), 52–64. doi:10.1097/00002508-200103000-00008

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*(1), 97–136. doi:10.1016/0010-0285(80)90005-5

Van Damme, S., Crombez, G., Bijttebier, P., Goubert, L., & Van Houdenhove, B. (2002). A confirmatory factor analysis of the Pain Catastrophizing Scale: invariant factor structure across clinical and non-clinical populations. *Pain*, *96*, 319–324. Retrieved from http://www.sciencedirect.com/science/article/pii/S0304395901004638

Van Damme, S., Crombez, G., & Eccleston, C. (2002). Retarded disengagement from pain cues: The effects of pain catastrophizing and pain expectancy. *Pain*, *100*(1-2), 111–118. doi:10.1016/S0304-3959(02)00290-7

Van Damme, S., Crombez, G., & Eccleston, C. (2004). The anticipation of pain modulates spatial attention: evidence for pain-specificity in high-pain catastrophizers. *Pain*, *111*(3), 392–399. doi:10.1016/j.pain.2004.07.022

Van Damme, S., Crombez, G., & Eccleston, C. (2008). Coping with pain: A motivational perspective. *Pain*, *139*(1), 1–4. doi:10.1016/j.pain.2008.07.022

Van Damme, S., Crombez, G., Eccleston, C., & Goubert, L. (2004). Impaired disengagement from threatening cues of impending pain in a crossmodal cueing paradigm. *European Journal of Pain*, *8*(3), 227–236. doi:10.1016/j.ejpain.2003.08.005

Van Damme, S., Crombez, G., Eccleston, C., & Koster, E. H. W. (2006). Hypervigilance to Learned Pain Signals: A Componential Analysis. *Journal of Pain*, *7*(5), 346–357.

Van Damme, S., Crombez, G., & Lorenz, J. (2007). Pain draws visual attention to its location: experimental evidence for a threat-related bias. *The Journal of Pain : Official Journal of the American Pain Society*, *8*(12), 976–82. doi:10.1016/j.jpain.2007.07.005

Van Damme, S., Legrain, V., Vogt, J., & Crombez, G. (2010). Keeping pain in mind: a motivational account of attention to pain. *Neuroscience and Biobehavioral Reviews*, *34*(2), 204–213. doi:10.1016/j.neubiorev.2009.01.005

Van Hulle, L., Van Damme, S., Spence, C., Crombez, G., & Gallace, A. (2013). Spatial attention modulates tactile change detection. *Experimental Brain Research*, *224*(2), 295–302. doi:10.1007/s00221-012-3311-5

Van Ryckeghem, D. M. L., Crombez, G., Eccleston, C., Liefooghe, B., & Van Damme, S. (2012). The interruptive effect of pain in a multitask environment: an experimental investigation. *The Journal of Pain : Official Journal of the American Pain Society*, *13*(2), 131–8. doi:10.1016/j.jpain.2011.09.003

Vancleef, L. M. G., & Peters, M. L. (2011). The influence of perceived control and self-efficacy on the sensory evaluation of experimentally induced pain. *Journal of Behavior Therapy and Experimental Psychiatry*, *42*(4), 511–7. doi:10.1016/j.jbtep.2011.05.006

Vanden Bulcke, C., Van Damme, S., Durnez, W., & Crombez, G. (2013). The anticipation of pain at a specific location of the body prioritizes tactile stimuli at that location. *Pain*, *154*(8), 1464–8. doi:10.1016/j.pain.2013.05.009

Verbruggen, F., & Aron, A. R. (2010). Theta burst stimulation dissociates attention and action updating in human inferior frontal cortex. *Proceedings of the*

National Academy of Sciences, *107*(31), 13966–13971. doi:10.1073/pnas.1001957107/-/DCSupplemental.www.pnas.org/cgi/doi/10.1073/pnas.1001957107

Verhoeven, K., Crombez, G., Eccleston, C., Van Ryckeghem, D. M. L., Morley, S., & Van Damme, S. (2010). The role of motivation in distracting attention away from pain: An experimental study. *Pain*, *149*(2), 229–234. doi:10.1016/j.pain.2010.01.019

Vlaeyen, J. W. S., Kole-Snijders, A. M., Boeren, R. G., & van Eek, H. (1995). Fear of movement/(re)injury in chronic low back pain and its relation to behavioral performance. *Pain*, *62*(3), 363–372.

Vlaeyen, J. W. S., Kole-Snijders, A. M., Rotteveel, A. M., Ruesink, R., & Heuts, P. H. T. G. (1995). The role of fear of movement (re)injury in pain disability. *Journal of Occupational Rehabilitation*, *5*(4), 235–252. doi:10.1007/BF02109988

Vlaeyen, J. W. S., & Linton, S. J. (2000). Fear-avoidance and its consequences in chronic musculoskeletal pain: A state of the art. *Pain*, *85*(3), 317–332. doi:10.1016/S0304-3959(99)00242-0

Volders, S., Meulders, A., De Peuter, S., Vervliet, B., & Vlaeyen, J. W. S. (2012). Safety behavior can hamper the extinction of fear of movement-related pain: An experimental investigation in healthy participants. *Behaviour Research and Therapy*, *50*(11), 735–746. doi:10.1016/j.brat.2012.06.004

Walker, J. (1971). Pain and distraction in athletes and non-athletes. *Perceptual & Motor Skills*, *33*(3), 1187–1190.

Weddell, G. (1955). Somesthesis and the chemical senses. *Annual Review of Psychology*, *6*, 119–136.

Weinstein, S. (1968). Intensive and extensive aspects of tactile sensitivity as a function of body part, sex and laterality. In D. R. Kenshalo (Ed.), *The Skin Senses* (pp. 195–200). IL: Thomas Springfield.

Wiech, K., Kalisch, R., Weiskopf, N., Pleger, B., Stephan, K. E., & Dolan, R. J. (2006). Anterolateral prefrontal cortex mediates the analgesic effect of expected and perceived control over pain. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *26*(44), 11501–9. doi:10.1523/JNEUROSCI.2568-06.2006

Yantis, S. (2000). Goal-directed and stimulus-driven determinants of attentional control. *Control of Cognitive Processes: Attention and Performance*, *18*, 73–103.

Zampini, M., Bird, K. S., Bentley, D. E., Watson, A., Barrett, G., Jones, A. K., & Spence, C. (2007). "Prior entry" for pain: Attention speeds the perceptual

processing of painful stimuli. *Neuroscience Letters*, *414*(1), 75–79. doi:10.1016/j.neulet.2006.12.006

Trying to fix a painful problem: the impact of pain control attempts on the attentional prioritization of a threatened body location[1]

2

Abstract Motivational accounts of pain behavior and disability suggest that persisting attempts to avoid or control pain may paradoxically result in heightened attention to pain-related information. We investigated whether attempts to control pain prioritized attention to the location where pain was expected, using a Tactile Change Detection paradigm. Thirty-seven undergraduate students had to detect changes between two consecutively presented patterns of tactile stimuli at various body locations. One of the locations was made threatening by occasionally administering a pain-eliciting stimulus. Half of the participants (pain control group) were encouraged to actively avoid the administering of pain by pressing a button as quickly as possible, whereas the other participants (comparison group) were not. The actual amount of painful stimuli was the same in both groups. Results showed that in the comparison group, the anticipation of pain resulted in better detection of tactile changes at the pain location than at the other locations, indicating an attentional bias for the threatened location. Crucially, the pain control group showed a similar attentional bias irrespective of the actual presentation of threat. This suggests that while threat briefly prioritized the threatened location, the goal to control pain did so in a broader, more context-driven manner.

[1] This chapter is based on:

Durnez, W., & Van Damme, S. (2015). Trying to fix a painful problem: The impact of pain control attempts on the attentional prioritization of a threatened body location. *The Journal of Pain, 16*(2), 135–143.

Introduction

Pain is perhaps the most universally understood motivator. As an evolutionary threat indicator, it is prone to automatically demand attentional resources and to redirect one's current goal pursuit toward the higher order goal of self-protection (Dowman & Ben-Avraham, 2008; Eccleston & Crombez, 1999; Ohman, Flykt, & Esteves, 2001). Pain is thus capable of automatically interrupting ongoing attentional processes, allowing the initiation of adaptive responses such as escaping, avoiding or controlling the threat. Such bottom-up interruptions have been well documented, particularly when pain is intense or unexpected (Legrain et al., 2009; Moore, Keogh, & Eccleston, 2013; Van Ryckeghem, Crombez, Eccleston, Liefooghe, & Van Damme, 2012).

We have an increasing understanding of how and when pain-related information that is irrelevant for one's ongoing tasks or goals captures attention (Eccleston & Crombez, 1999). However, when pain persists, pain control or avoidance itself may become one's focal goal (Crombez, Eccleston, & Van Damme, 2004; Eccleston & Crombez, 2007; Van Damme et al., 2010). It is largely unknown how pain-related information is processed when such pain goal is pursued. According to the neurocognitive model of attention to pain, attentional prioritization of pain-related information may also occur in a top-down fashion, i.e., driven by goals (Legrain et al., 2009). Goals are believed to direct attention through the activation of attentional control settings – a set of stimulus features kept in working memory to facilitate processing of goal-relevant information (Folk & Remington, 2008). All stimuli relevant to a focal goal will then be prioritized (Fishbach & Ferguson, 2007). When the focal goal is pain-related, this top-down influence should translate into heightened attention

to stimuli that share features with the attentional set defined by the pain goal, such as somatosensory modality and body location where pain is expected. It has been shown that the mere expectation of pain facilitates somatosensory processing at the threatened body part (Van Damme, Crombez, & Eccleston, 2004; Van Hulle, Van Damme, Spence, Crombez, & Gallace, 2013; Vanden Bulcke, Van Damme, Durnez, & Crombez, 2013). However, it is yet unclear to what extent such effect is modulated by the goal to control pain, as this goal has rarely been activated in a laboratory situation. An exception is the study by Notebaert and colleagues (2011), in which it was shown that attempting to avoid pain increased attentional bias to visual cues signaling pain. However, that study does not allow any conclusions about the extent to which attention was directed to the threatened body location.

The scarcity of studies using somatosensory paradigms is remarkable. A noteworthy number of theoretical models maintain that dysfunctional attentional processes play a significant part in chronic pain (Crombez et al., 2005; Eccleston & Crombez, 2007; Vlaeyen & Linton, 2000). Triggered by a strong fixation on pain control goals, chronic pain patients have been suggested to be hypervigilant to somatosensory cues, i.e., to allocate an excessive amount of attention to bodily changes, which in turn, may exacerbate their condition (Crombez et al., 2005). Studying the effects of pain control motivation on attention for somatosensory stimuli could further our understanding of dysfunctional attentional mechanisms in these patients.

The aim of the present study was to investigate if attention is prioritized to a body location where pain is expected, and whether this prioritization is more pronounced when the goal to control pain is actively pursued. In order to measure attention to the threatened body location, we

used a Tactile Change Detection paradigm (TCD) (Gallace et al., 2006; Van Hulle et al., 2013). This paradigm requires participants to judge whether two subsequently presented tactile stimulation patterns are the same or not. In half of the trials, the same pattern was presented twice. In the other half, one stimulus location was changed between patterns. One of the locations was made threatening by occasionally administering a pain stimulus. Half of the participants (pain control group) were encouraged to actively avoid the administering of pain by pressing a button as quickly as possible, whereas the other participants (comparison group) were not. We expected that – when under threat – tactile changes at the threatened location would be better detected than changes at the other locations (hypothesis 1). Crucially, we expected that this effect would be more pronounced in the pain control group than in the comparison group (hypothesis 2).

Method

Participants

Thirty-seven Ghent University students participated in this study, in exchange for course credits. Twenty-seven of them were female. Seven of the participants were left-handed. All of the participants had normal or corrected-to-normal vision and normal hearing. The study protocol was approved by the Ethics Committee of the Faculty of Psychology and Educational Sciences of Ghent University. The experiment took approximately 1 hour and 15 minutes.

Apparatus and stimulus material

The experiment was conducted in a normally illuminated room, with participants sitting on a chair in front of a laptop screen (HP Compaq nc6120 – Notebook, 15" TFT display). Tactile stimuli consisted of vibrations, 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 could be administered on eight different body locations, four of which were situated on each side of the body: the back of the hand, close to the elbow joint on the inner arm, above the knee, and above the inner side of the ankle (fig. 1). Tactors were attached directly to the skin surface by means of double-sided tape rings and were amplified by a custom-built device. Tactor frequency was set to 200 Hz, while the stimulus duration was set to 200 ms. Two electrodes were also taped to one of the tactor locations. The selection of this location was counterbalanced across participants. Similar to the tactor settings, the electrostimulator (DS5, Digitimer, 2000) was set to a 200 Hz frequency and a duration of 200 ms. Amplitude for each of the devices was determined by means of adaptive procedures, as described in the procedure section. Participants wore headphones (WeSC Oboe), which played white noise at a moderate volume (58 dB) to prevent any interference from outside distractors.

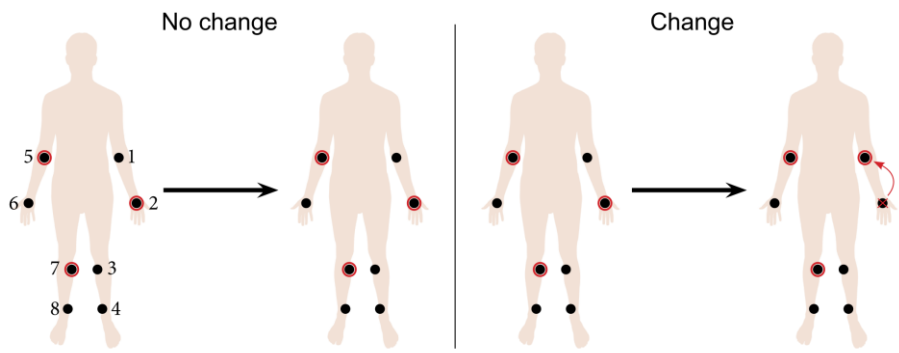


***Figure 1*: Example of typical trial without change in the tactile pattern (left hand side) and trial with change (right hand side). Tactor locations are numbered (see table 1 for mean intensities).**

Tactile Change Detection paradigm

The experiment was programmed in the programming language C, using the Tscope library package (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). Participants were instructed to keep their eye on the black screen for the duration of the experiment. Ahead of each trial, a fixation cross was presented in the center of the screen for 500 ms. After that, one of two possible cues was presented (500 ms) in the form of a colored circle (blue or yellow, matched in luminance). This was followed by a blank interval of 750 ms. The TCD task consisted of two tactile stimulus patterns, separated by a 110 ms interval. A pattern consists of the simultaneous activation of three tactor locations for 200 ms. The first pattern was a random and counterbalanced selection of a possible combination of locations, in such a way that every pattern was presented one time per block. For each of these patterns, a possible change was randomly selected. This means that one of the stimulated locations in the first pattern was no longer stimulated in the second pattern, whereas another location was stimulated instead. Change occurred in half of the

trials. In the other half of the trials, the second pattern was identical to the first one. Participants were instructed to detect whether or not they thought the patterns were the same. They then responded 'yes' or 'no' by pressing the corresponding response keys ('f' and 'j' on the AZERTY keyboard) with one index finger on each button. The program awaited a response for up to 5000 ms. Accuracy was stressed over speed.

Procedure

Participants were given a brief description of the experiment and asked to fill in an informed consent. Then, they were asked to fill in a custom-made pre-test questionnaire, which gauged for pre-existing pain-related conditions are episodes. Tactors were attached to their body on the above-described locations (see fig. 1). 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). This was accomplished by means of a custom-made adaptive procedure, which worked as follows.

Participants were first given a reference stimulus on their left hand, at 25 percent of the maximum capacity (and thus with a Power of 0,10625 watt). They were told that this stimulus represented the maximum power with which vibrotactile stimuli would be administered, representing a maximum of five of a five-point scale. Immediately after that, a new stimulus was presented on the same location. Participants were asked to rate the perceived intensity of this stimulus on the same scale. Using a double random staircase procedure (Levitt, 1970) with 20 trials, the intensity was determined for which participants were expected to give a rating of three on the scale. The reference stimulus for the remainder of the procedure thus became a tactile stimulus on the left hand, at that specific intensity level. We

then matched stimulus intensity for the remainder of the locations, using a similar procedure. Now however, the second stimulus was to be rated on a new scale, asking whether the participants perceived this stimulus to be stronger, equal or less strong compared to the reference. This was repeated 20 times for each location by means of a double random staircase procedure. The continuous coupling of reference stimuli and to-be-rated stimuli was intended to ensure participants would adequately compare both sensations, making sure there was no gradual shift in memory of how the reference stimulus was perceived. In the end, we obtained tactor intensities for each location that were perceived to be equally intense (i.e., matched) by the participant. The means are displayed in table 1.

Table 1

Tactor intensities per location (as indicated in fig. 1).

Location	M (watt)	SD (watt)
1	0.10	< 0.01
2	0.15	< 0.01
3	0.29	0.01
4	0.35	0.02
5	0.07	< 0.01
6	0.21	0.01
7	0.27	0.01
8	0.31	0.01

In a next step, electrodes were attached to one of eight possible locations, corresponding with the tactor positions. The choice of location for the electrodes to be attached to was balanced over participants. As our equipment did not allow us to give both electrocutaneous and tactile stimuli on exactly the same place, we placed the electrodes as close to the relevant tactor as possible. We continued under the assumption that the distance between the tactor and electrodes was negligible in the context of attentional prioritization (Vanden Bulcke et al., 2013). Using a similar procedure as the one used for the tactor locations, we determined an adequate intensity level for the electrocutaneous stimulus. In a double random staircase procedure of 26 steps, we individually selected an intensity that was scored by the participants as 7 on a 10-point scale, with 10 meaning unbearable pain. We obtained a mean intensity value of 0.28 V (SD 0.16 V).

In the last step of the procedure, the TCD paradigm was introduced. TCD trials were modified with a threat component, which was tied to the color cue. Participants were instructed that these cues signified either a threatening situation or a safe situation (within variable, balanced). The threat condition implied the possible administration of a painful stimulus, concurrent with one of the patterns of the TCD trial. In the safe condition the cue was with certainty never followed by a painful stimulus. The threat value of both cues was balanced over participants. A threat cue was followed by an electrocutaneous stimulus (200ms) at a chance level of 10%. This stimulus was administered at the same time as one of the patterns. The pattern with which the stimulus co-occurred (i.e., either the first or the second pattern) was randomly selected, to keep the participants from feeling safe before the trial was ended.

Additionally, participants were divided into two groups (between subjects variable). In the pain control group (19 subjects), we aimed to

induce the presence of a pain control goal. The participants were told that pressing the spacebar in the event of a threatening cue served to avoid a more intense painful stimulus. Instructions were in Dutch. Translated to English, they were as follows:

"You can avoid the occurrence of a MORE INTENSE painful stimulus. To do so, you must press the space bar as soon as you see this color *(picture of a circle, colored according to experiment parameters for that participant)*. Over the course of the experiment your reaction time to these cues is being monitored. If the average reaction time to the last four such trials is SLOWER than a previously determined value, the more INTENSE stimulus will be presented (tolerance level). It is therefore important that you keep responding as QUICKLY AS POSSIBLE."

The more intense stimulus was referred to as being close to absolute tolerance level, a statement which was given credibility by the way in which pain intensity levels were determined (using the adaptive procedure). Pressing the button, however, did not have an actual effect on the frequency or intensity of the painful stimuli.

In the comparison condition (18 subjects), participants were also instructed to press a button in the event of a threatening cue. However, these participants were told this served to measure ongoing attentional processes. No instructions related to pain control were given.

Self-report measures

After each test phase, participants had to rate several questions about their pain experience ("How painful did you find the electrocutaneous stimuli?"), anxiety ("How anxious were you during this block?"), attention to painful/tactile stimuli ("To what extent did you pay attention to the painful/tactile stimuli?"), concentration ("To what extent did you put effort

into this task?", "To what extent did you concentrate on this task?"), and fatigue ("To what extent did you find this task tiresome?") on 11-point numerical rating scales (anchored 0 = not at all and 10 = very strongly). As a manipulation check, we were especially interested in the ratings of fear ("To what extent were you afraid that the blue/yellow cue would be followed by a painful stimulus?"), expectations ("To what extent did you expect that the blue/yellow cue would be followed by a painful stimulus?"), perceived control ("To what extent did you feel like you could avoid the painful stimulus?") and control attempts ("To what extent did you try to avoid the painful stimus?"). Before starting the main portion of the experiment, a few more questionnaires were presented to the participant. Multiple somatic complaints were checked with the Patient Health Questionnaire (PHQ) (Kroenke, Spitzer, & Williams, 2002) Additionally, pain catastrophizing was assessed with the Pain Catastrophizing Scale (PCS) (Sullivan, Bishop, & Pivik, 1995; Van Damme, Crombez, Bijttebier, Goubert, & Van Houdenhove, 2002). Data stemming from these questionnaires will be primarily used in future meta-analysis.

Statistical analyses

Analyses were conducted on the binary variable of response accuracy (correct vs. incorrect). In these analyses, we only used change trials. The rationale behind this is that we were interested in comparing changing patterns that critically involved the pain location with changing patterns not involving this location. To specify this further, change trials critically involving the pain location were defined as trials types where either the first pattern included a stimulus on the pain location and the second pattern did not, or vice versa. In other words, these trials either see a somatosensory

sensation added to the pain location or removed from it over the trial course.

To begin, we eliminated all trials in which a painful stimulus was given, as the possible impact on task performance rendered these trials useless. Next, we ascertained that the data showed no significant outliers in terms of response accuracy. To this effect, we defined outliers as participants with an average response accuracy that fell outside of the interquartile range. As a result, one participant was excluded from the dataset (fig. 2).

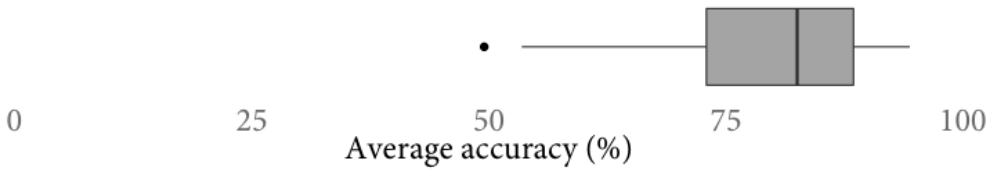


***Figure 2*: Boxplot showing distribution of mean response accuracy, including outlier (black dot) according to interquartile range criterion.**

We analyzed response accuracy using a linear mixed-effects model with a logit link function, as implemented in the R package 'lme4' (Bates, Maechler, Bolker, & Walker, 2014). Statistical modeling consisted of a number of steps. First, all relevant factors and their interactions were entered in the model as fixed factors. These included *Threat* (threat trials vs. safe trials), *Location* (threatened location involved vs. not involved in pattern change) and *Control* (pain control goal vs. comparison). By default, a random effect was added introducing adjustments to the intercept conditional on the *Subject* variable. We then assessed whether it was necessary to add a random effect for each of the fixed within-subject factors in the analysis. If a random effect increased the model's goodness of fit, it was included in the final model. A second step consisted of seeking out the

most parsimonious model that significantly fitted the data. To achieve this, we systematically restricted the full model, comparing the goodness of fit using likelihood-ratio tests. Finally, in a third step, we inspected the ANOVA table of the final model and tested specific hypotheses about possible main effects or interactions (see De Ruddere, Goubert, Stevens, Williams, & Crombez, 2013; Verbruggen & Aron, 2010, for a similar approach). Significant interactions were investigated using post-hoc contrast analyses. We corrected for multiple testing according to the Holm-Bonferroni corrections (Holm, 1979).

Our first hypothesis (hypothesis 1) predicts a significant interaction between the Location variable and the Threat variable. More specifically, we expected that somatosensory changes be detected more accurately at body site that is under immediate threat of pain. Our second hypothesis (hypothesis 2) predicts that the previous effect will be most pronounced in participants who are attempting to control the painful stimulation. Statistically, this requires a three-way interaction effect between the Threat, Location and Group variables. More explicitly, we expected higher change detection accuracy at the location of the painful stimulus for the pain control group compared to the comparison group, when threat was presented.

Results

Self-report data and manipulation check

On average, participants described their general health to be "very good". None of the participants reported having a current medical or mental disorder. Twenty participants reported to have experienced some

form of pain during the previous 6 months (M 25.5 days, SD 29.91 days). This pain had an average intensity rating of 4.8 (SD 1.94), and an average disability rating of 3.05 (SD 2.54), both of which they indicated on a 10-point scale. We found no evidence that these participants significantly altered our results. Two participants reported having taken a pain killer earlier that day. This was controlled for in the subsequent analyses and proved of no statistical importance. Seven participants reported feeling pain at the moment of testing, but the average rating of the intensity of the pain for these 7 participants was low (M 2.29, SD 1.39) on a Likert scale where 0 indicated "no pain" and 10 indicated "worst possible pain". None of the participants had pain of a severity that warranted exclusion from further steps. Additionally, none of the participants reported pain at the location of any of the tactors/electrodes. There was no significant difference between groups for PCS scores (comparison: M 12.556, SD 8.920; pain control: M 14.58, SD 11.19) (t_{35} = -0.61, p = .55). Finally, the PHQ showed no significant group differences (comparison: M 6.56, SD 4.72; pain control: M 6.47, SD 5.49) (t_{35} = 0.05, p = .96).

Over the course of the experiment, participants rated the electrocutaneous stimulus as moderately painful (M 5.01, SD 2.40). To determine whether the threat manipulation was successful, we performed an analysis of variance with the factors *Cue* (safe versus threatening) and *Group* (pain control versus comparison) on fear and pain expectancy ratings. We found was a main effect of Cue, both on fear ratings (χ^2 = 167.58, p < .01) and on pain expectancy ratings (χ^2 = 22.39, p < .01). This indicates that participants felt more fearful upon seeing the threatening cue (M 5.62, SD 0.83), as compared with the safe cue (M 0.41, SD 2.25) (d = 3.04 [95% CI 2.35-3.74]). Furthermore, it shows that they expected painful stimuli more

during threat trials (M 6.79, SD 2.08), as compared to safe trials (M 3.61, SD 3.55) (d = 1.10 [95% CI 0.59-1.60]). The main effect of the *Group* factor was (marginally) significant only for pain expectancy (χ^2 = 3.51, p = .06), indicating higher pain expectancy in the pain control group (M 5.89, SD 3.32) compared to the comparison group (M 4.56, SD 3.15) (d = 0.41 [95% CI 0.07-0.88]). Importantly, we found no difference in perceived control ratings (pain control group: M 3.86, SD 2.33; comparison group: M 3.69, SD 2.52). However, there was a significant group difference in attempted control, showing higher ratings for participants in the pain control group (M 4.33, SD 2.51) compared to the comparison group (M 1.68, SD 2.15) (d = 1.1. [95% CI 0.39-1.88]). Finally, we found significant difference in overall nervous tension (pain control group: M 4.37, SD 2.61; comparison group: M 3.13, SD 2.33).

TCD data

The model that demonstrated the best fit included all fixed factors and interactions, a random subject-based intercept, and one random effect (*Location*). In this final model, we found a significant three-way interaction effect (χ^2 = 5.24, p = .02) (fig. 3). This removed the necessity to further restrict the model.

Table 2

Step 1 – Determine random structure.

Model	Test	Random	Log L	df	χ^2	p
1	Initial fit	1	-3052.5	9		
2	Random *Location* (1 vs 2)	1 + *Location*	-3038.6	11	27.81	< .01

3	Random *Threat* (1 vs 3)	1 + *Threat*	-3052	11	0.95	.62
4	Random *Location* and *Threat* (2 vs 4)	1 + *Location* + *Threat*	-3038.1	14	0.95	.81

Decision test model 2: add random *Location*; decision test model 3: retain current model; decision test model 4: retain current model

Table 3

Step 3 – Evaluate final model.

Factor	$\widehat{ß}$	$SE(\widehat{ß})$	χ^2	p
Intercept	*0.97*	*0.18*	*28.80*	*< .01*
Threat	*-0.05*	*0.04*	*1.67*	*.20*
Location	*0.20*	*0.06*	*9.21*	*<.01*
Group	*0.26*	*0.18*	*2.03*	*.15*
Threat x *Location*	*0.10*	*0.04*	*7.25*	*<.01*
Threat x *Group*	*0.02*	*0.04*	*0.26*	*.61*
Location x *Group*	*0.03*	*0.06*	*0.20*	*.65*
Threat x *Location* x *Group*	*-0.09*	*0.04*	*5.24*	*.02*

With regard to our group-dependent hypothesis (hypothesis 2), we investigated whether addition of a control option significantly impacted task performance for threat trials that included the threatened location. To accomplish this, we tested the contrast for these trials (*Threat* present; *Location* involved) between groups (pain control group versus comparison group). This test did not reach significance ($\chi^2 = 0.31$, $p = .58$).

In order to disentangle the three-way interaction, we examined data for **both groups independently**. In any of the following statistical models, the same random effect structure was preserved (as in step 1, see table 2). Both groups of data were subjected to the next analyses steps, as discussed in the Method section.

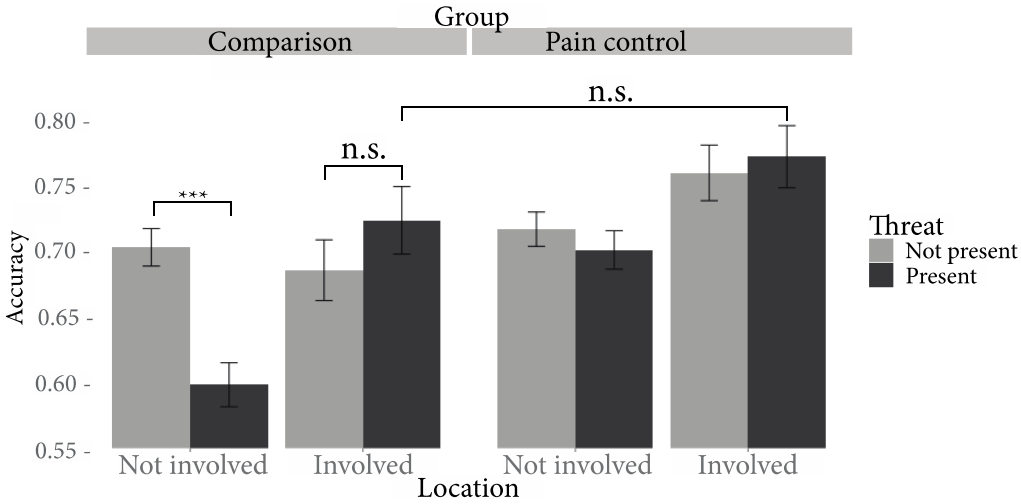


***Figure 3*: Plot showing distribution of response accuracy per condition for both experimental groups, including two-sided standard error bars. Additional contrast analyses are indicated. ($p \leq .001$ ***; $p \leq .01$ **; $p \leq .05$ *; $p < .05$: n.s.)**

In the **comparison group**, the full model proved to be the most parsimonious, eliminating the need to further trim down the model. We found a significant main effect of *Location* ($\chi^2 = 4.14$, $p = .04$) and a significant interaction between *Location* and *Threat* ($\chi^2 = 13.54$, $p < .01$) (table 4). Contrast analysis showed no difference in change detection for safe trials, when comparing changes involving the threatened location and changes not involving that location ($\chi^2 = 1.15$, $p = .28$). Analogous contrast analysis for trials involving threat, however, did show a significant difference ($\chi^2 = 16.29$, $p < .01$), indicating that change detection in threat

trials is better when the pain location was involved than when it was not involved. As such, we found evidence in the comparison group for hypothesis 1. Additionally, task performance was worse for threat trials compared to safe trials when the threatened location was not involved (χ^2 = 26.93, p < .01), but there was no difference when change occurred at the threatened location (χ^2 = 1.76, p = .19).

Table 4

Step 3 – Evaluate final model (comparison group).

Factor	$\widehat{ß}$	$SE(\widehat{ß})$	χ^2	p
Intercept	0.70	0.27	6.82	<0.01
Threat	-0.07	0.05	1.79	0.28
Location	0.15	0.07	4.14	0.04
Threat x *Location*	0.19	0.05	13.54	<0.01

In the **pain control group**, the most parsimonious model did not include the interaction effect (table 5). There was only a significant main effect of *Location*, indicating a better detection of tactile changes involving the threatened location, irrespective of whether threat was cued or not (χ^2 = 5.27, p = .02) (table 6).

Table 5

Step 2 – Determine fixed effects (pain control group).

Model	Test	Fixed	Log L	df	χ^2	*p*
1	Initial fit	Threat + Location + Threat x Location	-1496.1	6		
2	Remove interaction *Threat x Location* (1 vs 2)	Threat + Location	-1496.1	7	0.07	.80
3	Remove *Threat* (2 vs 3)	Location	-1496.5	5	0.76	.38

Decision test model 2: remove interaction *Threat* x *Location*; decision test model 3: remove *Threat*

Table 6

Step 3 – Evaluate final model (pain control group).

Factor	$\widehat{ß}$	$SE(\widehat{ß})$	χ^2	*p*
Intercept	*1.25*	*0.24*	*26.16*	*<0.01*
Location	*0.24*	*0.11*	*5.27*	*0.02*

Discussion

The present study investigated if the threat of pain prioritizes attention to the body location where pain is expected, and particularly, whether this prioritization is more outspoken when subjects attempt to control pain. In line with the first hypothesis, our data showed that the mere

anticipation of pain caused attentional prioritization of the threatened body location (comparison group). However, the second hypothesis, i.e., that this effect would be more pronounced in the pain control group, was not fully supported. In the pain control group, the location-specific attentional bias did not appear to be influenced by the immediate presence of threat. Furthermore, the attentional bias was never more pronounced in the pain control group than in the comparison group – neither when threat was present, nor when it was absent. As such, our results fail to support the assertion that attempting to control pain increases attentional prioritization to the threatened location. Instead, the evidence suggests that the pain control goal prioritizes the pain-related location in a more generalized way, irrespective of whether pain was cued or not. Differently put, the attentional bias appears to be driven by the motivational context of the whole experiment (i.e., attempting to control pain), and seems to be rather insensitive to trial-by-trial changes in threat.

The neurocognitive model of pain (Legrain et al., 2009) proposes that top-down factors, such as the pursuit of pain control goals, may facilitate the attentional capture of sensory input that shares features with the attentional set. In our case, the crucial feature shared by both the pain stimulus and certain somatosensory stimuli, is the location where these stimuli are presented. Accordingly, we argue that inclusion of the pain location in the attentional set is essential in the significantly increased performance on trials that involve changes at this location. Furthermore, our results suggest that this somatosensory location bias was kept throughout the experiment, irrespective of whether there was immediate threat or not. This may indicate that attempts to bring pain under control cause our attentional set to adopt pain-related stimulus features in a durable, context-driven manner, as opposed to a momentaneous, threat-induced manner.

With respect to these results, we would like to discuss several additional issues. First, we wish to point out that the present study represents the first use of the Tactile Change Detection paradigm to provide evidence for attentional prioritization of somatosensory stimuli occurring at a threatened body location. These findings replicate and extend the aforementioned study by Vanden Bulcke and colleagues (2013), in which a Temporal Order Judgment (TOJ) task was used. The TOJ paradigm was chosen to investigate the relative speed with which our attentional system is able to process somatosensory stimuli at two different locations, one of which was made threatened. The present study involved stimuli occurring at a larger number of body sites (eight instead of two), further adding to the robustness of the phenomenon of attentional prioritization of threatened body locations. In addition, we investigated the accuracy with which subjects could detect somatosensory changes at the threatened location compared to other body regions, rather than the speed of processing. The present study thus presents an alternate way of evidencing an attentional bias for a body location where pain is expected.

Second, while we expected the threat-induced attentional bias in the comparison group to be a result of participants' improved change detection on the threatened location, it has to be noted that this effect appeared to be caused by reduced tactile change detection in trials *not* involving the threatened location. This is evidenced by our contrast analyses, which indicated that subjects in the comparison group performed significantly worse on threat trials compared to safe trials, but only when the pain location was *not* involved. If it *was* involved, change detection remained unaffected by threat. A possible explanation relates to the phenomenon of attentional disengagement. Previous studies have shown that the

anticipation of pain not only enhances attentional engagement to threat-related information, but also disengagement from these signals (Crombez, Eccleston, De Vlieger, Van Damme, & De Clercq, 2008; Van Damme et al., 2006). As most of these studies focus on visual cues that are associated with painful stimuli through conditioning procedures (Van Damme, Crombez, & Eccleston, 2004), they allow measuring disengagement from the location of a visual cue, but provide no information about disengagement from the actual body location where pain is expected. In the present study, however, the diminished detection of tactile changes not involving the pain location in threat trials may be the result of an impaired ability to disengage from the (anticipated) pain location. The impairment of task performance by threat is in itself not a novel finding. Interpreting fearful expectation as a brief state of anxiety, we can view these findings from the *Attentional Control Theory* (Eysenck, Derakshan, Santos, & Calvo, 2007). As a part of this theory, it is posited that anxiety negatively affects goal-directed attentional processes, by impairing the efficiency of the central executive (Baddeley, 1992). Additionally, anxiety is assumed to increase attention to threat-related stimuli by enhancing stimulus-driven attentional processes. Translated to the present study, we can thus argue that the anticipation of pain hinders the imposed goal (of performing the tactile change detection task), while increasing attention to somatosensory input at the location where that pain is expected.

Third, it has to be noted that while participants in the pain control group were given the opportunity to try and avoid painful stimuli, these avoidance attempts were never contingent with the actually administered amount of pain. It is therefore possible that, at a certain stage in the experiment, participants became aware of the ineffectiveness of their

avoidance behavior. This is also evidenced by the lack of difference in self-reports of perceived control between both groups. Nonetheless, this does not implicate our goal induction had no effect. Research that employed a very similar goal engagement strategy showed that participants in the pain control group pressed the button significantly faster than the comparison group, regardless of whether or not they believed in the effectiveness of this action (Notebaert et al., 2011). Our divergent findings for both experimental groups, along with the difference in control attempt reports, underline the importance of distinguishing actual perception of control from goal-driven attempts to gain control. Indeed, one can persist in attempting to have an effect on the manifestation of pain, even when attempts appear fruitless (Eccleston & Crombez, 2007). Moreover, previous research has suggested that such an ineffective type of behavioral strategy may elicit frustration, fuel distress, and enhance attention to pain (Crombez et al., 2008). This may be particularly relevant to the present study. As our results seem to suggest an attentional bias for the threatened location throughout the whole experiment, they perhaps indicate a persistent and dysfunctional allocation of attentional resources to pain-related features, even in relatively "safe" situations. However, this interpretation is speculative and merits additional exploration.

A fourth observation is that pain controllers do not share the same threat-induced performance impairment on trials not involving the pain location, as is evident by the lack of effects involving the threat variable. It could be argued that the pain control option moderated the fearful anticipation of pain, thereby altering its impact on attentional allocation mechanisms. However, this is unlikely, as participants in both groups reported no significant differences in fear for the threat-signaling cue. It is important to note, though, that participants were only informed of the

(supposed) successfulness of their pain control attempts by the following presence or absence of pain. While we would expect this to result in a feedback monitoring process that is specifically focused on the threatened location, it may have had a more general impact on participants' attention to somatosensory information. As such, it is a factor that merits additional investigation.

Fifth, previous research demonstrated that perception of tactile stimuli might in fact be reduced by *concomitant* pain, be it experimental (Bolanowski, Gescheider, Fontana, Niemiec, & Tromblay, 2001; Harper & Hollins, 2012) or chronic (Moseley, Gallace, & Spence, 2009; Moseley, Gallagher, & Gallace, 2012) in nature. However, the present study was designed to study the effects of *anticipated* pain. While our study investigates cognitive mechanisms, the former studies rather refer to sensory interactions between pain and tactile stimuli, such as touch gating. This refers to the phenomenon that tactile thresholds are elevated by the concomitant presence of pain, especially when they are presented in close proximity (Bolanowski et al., 2001; Harper & Hollins, 2012).

In sum, the present study provides new evidence for attentional prioritization of somatosensory information at a pain-related location. Additionally, we found that engaging in a pain control goal led to a similar bias, albeit one that was more robust and independent of the immediate presence of threat. We suggest that the threat-induced prioritization of a threatened location is brief and instantaneous in nature, while the induction of a motivational context aimed at controlling pain elicits a more pronounced, sustained attentional bias for that location. Such bias in situations where there is no immediate threat may become maladaptive. The present study may therefore serve as a step towards a better understanding

of attentional mechanisms involved in chronic pain. Chronic pain patients have been suggested to persevere in attempting to resolve their pain, thus putting the problem on the forefront of their attention and perpetuating it instead (Eccleston & Crombez, 2007; Vlaeyen & Linton, 2000). Our results also point in this direction, suggesting that attempting to control (uncontrollable) pain merely heightens attention for bodily sensations at pain-related locations, even in the absence of actual threat.

Disclosures

This study was supported by a research grant (BOF11/STA/004) by the Special Research Foundation of Ghent University (BOF) awarded to S. Van Damme. There are no conflicts of interest that may arise as a result of this research.

This research has benefitted from a statistical consult with Ghent University FIRE (Fostering Innovative Research based on Evidence).

References

Baddeley, A. D. (1992). Working memory. *Science*, *110*(11), 16–7. doi:10.1097/01.NAJ.0000390505.77157.63

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using S4 classes. R package version 1.1-6. *R*. Retrieved from http://cran.r-project.org/package=lme4

Bolanowski, S. J., Gescheider, G. A., Fontana, A. M., Niemiec, J. L., & Tromblay, J. L. (2001). The effects of heat-induced pain on the detectability, discriminability, and sensation magnitude of vibrotactile stimuli. Somatosensory & motor research (Vol. 18). doi:10.1080/08990

Crombez, G., Eccleston, C., De Vlieger, P., Van Damme, S., & De Clercq, A. (2008). Is it better to have controlled and lost than never to have controlled at all? An

experimental investigation of control over pain. *Pain*, *137*(3), 631–9. doi:10.1016/j.pain.2007.10.028

Crombez, G., Eccleston, C., & Van Damme, S. (2004). Hypervigilance and attention to pain, 1–4. Retrieved from http://opus.bath.ac.uk/6665/

Crombez, G., Van Damme, S., & Eccleston, C. (2005). Hypervigilance to pain: an experimental and clinical analysis. *Pain*, *116*(1-2), 4–7. doi:10.1016/j.pain.2005.03.035

De Ruddere, L., Goubert, L., Stevens, M., Williams, A. C. de C., & Crombez, G. (2013). Discounting pain in the absence of medical evidence is explained by negative evaluation of the patient. *Pain*, *154*(5), 669–76. doi:10.1016/j.pain.2012.12.018

Dowman, R., & Ben-Avraham, D. (2008). An artificial neural network model of orienting attention toward threatening somatosensory stimuli. *Psychophysiology*, *45*(2), 229–239. doi:10.1111/j.1469-8986.2007.00614.x

Eccleston, C., & Crombez, G. (1999). Pain demands attention. *Psychological Bulletin*, *125*(3), 356–366.

Eccleston, C., & Crombez, G. (2007). Worry and chronic pain: a misdirected problem solving model. *Pain*, *132*(3), 233–236. doi:10.1016/j.pain.2007.09.014

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion (Washington, D.C.)*, *7*(2), 336–53. doi:10.1037/1528-3542.7.2.336

Fishbach, A., & Ferguson, M. J. M. (2007). The goal construct in social psychology. In A. W. K. E. T. Higgins (Ed.), *Social psychology: Handbook of basic principles (2nd ed.)* (pp. 490–515). Guilford Press. Retrieved from http://melissaferguson.squarespace.com/storage/fishbachferguson 2007.pdf

Folk, C. L., & Remington, R. W. (2008). Bottom-up priming of top-down attentional control settings. *Visual Cognition*, *16*(2-3), 215–231. doi:10.1080/13506280701458804

Gallace, A., Tan, H. Z., & Spence, C. (2006). The failure to detect tactile change: a tactile analogue of visual change blindness. *Psychonomic Bulletin & Review*, *13*(2), 300–303.

Harper, D. E., & Hollins, M. (2012). Is touch gating due to sensory or cognitive interference? *Pain*, *153*(5), 1082–1090. doi:10.1016/j.pain.2012.02.011

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*(2), 65–70.

Kroenke, K., Spitzer, R. L., & Williams, J. B. W. (2002). The PHQ-15: validity of a new measure for evaluating the severity of somatic symptoms. *Psychosomatic Medicine*, *64*(2), 258–266.

Legrain, V., Van Damme, S., Eccleston, C., Davis, K. D., Seminowicz, D. A., & Crombez, G. (2009). A neurocognitive model of attention to pain: behavioral and neuroimaging evidence. *Pain*, *144*(3), 230–2. doi:10.1016/j.pain.2009.03.020

Levitt, H. (1970). Transformed up-down methods in psychoacoustics. *The Journal of the Acoustical Society of America.*

Moore, D. J., Keogh, E., & Eccleston, C. (2013). The effect of threat on attentional interruption by pain. *Pain*, *154*(1), 82–88. doi:10.1016/j.pain.2012.09.009

Moseley, G. L., Gallace, A., & Spence, C. (2009). Space-based, but not arm-based, shift in tactile processing in complex regional pain syndrome and its relationship to cooling of the affected limb. *Brain: A Journal of Neurology*, *132*(Pt 11), 3142–51. doi:10.1093/brain/awp224

Moseley, G. L., Gallagher, L., & Gallace, A. (2012). Neglect-like tactile dysfunction in chronic back pain. *Neurology*, *79*(4), 327–332. doi:10.1212/WNL.0b013e318260cba2

Notebaert, L., Crombez, G., Vogt, J., De Houwer, J., Van Damme, S., & Theeuwes, J. (2011). Attempts to control pain prioritize attention towards signals of pain: an experimental study. *Pain*, *152*(5), 1068–1073. doi:10.1016/j.pain.2011.01.020

Ohman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: detecting the snake in the grass. *Journal of Experimental Psychology. General*, *130*(3), 466–478. doi:10.1037/0096-3445.130.3.466

Stevens, M., Lammertyn, J., Verbruggen, F., & Vandierendonck, A. (2006). Tscope: A C library for programming cognitive experiments on the MS windows platform. *Behavior Research Methods*, *38*(2), 280–286. doi:10.3758/BF03192779

Sullivan, M. J. L., Bishop, S., & Pivik, J. (1995). The pain catastrophizing scale: Development and validation. *Psychological Assessment*, *7*, 524–535.

Van Damme, S., Crombez, G., Bijttebier, P., Goubert, L., & Van Houdenhove, B. (2002). A confirmatory factor analysis of the Pain Catastrophizing Scale: invariant factor structure across clinical and non-clinical populations. *Pain*, *96*, 319–324. Retrieved from http://www.sciencedirect.com/science/article/pii/S0304395901004638

Van Damme, S., Crombez, G., & Eccleston, C. (2004). The anticipation of pain modulates spatial attention: evidence for pain-specificity in high-pain catastrophizers. *Pain*, *111*(3), 392–399. doi:10.1016/j.pain.2004.07.022

Van Damme, S., Crombez, G., Eccleston, C., & Koster, E. H. W. (2006). Hypervigilance to Learned Pain Signals: A Componential Analysis. *Journal of Pain*, *7*(5), 346–357.

Van Damme, S., Legrain, V., Vogt, J., & Crombez, G. (2010). Keeping pain in mind: a motivational account of attention to pain. *Neuroscience and Biobehavioral Reviews*, *34*(2), 204–213. doi:10.1016/j.neubiorev.2009.01.005

Van Hulle, L., Van Damme, S., Spence, C., Crombez, G., & Gallace, A. (2013). Spatial attention modulates tactile change detection. *Experimental Brain Research*, *224*(2), 295–302. doi:10.1007/s00221-012-3311-5

Van Ryckeghem, D. M. L., Crombez, G., Eccleston, C., Liefooghe, B., & Van Damme, S. (2012). The interruptive effect of pain in a multitask environment: an experimental investigation. *The Journal of Pain: Official Journal of the American Pain Society*, *13*(2), 131–8. doi:10.1016/j.jpain.2011.09.003

Vanden Bulcke, C., Van Damme, S., Durnez, W., & Crombez, G. (2013). The anticipation of pain at a specific location of the body prioritizes tactile stimuli at that location. *Pain*, *154*(8), 1464–8. doi:10.1016/j.pain.2013.05.009

Verbruggen, F., & Aron, A. R. (2010). Theta burst stimulation dissociates attention and action updating in human inferior frontal cortex. *Proceedings of the National Academy of Sciences*, *107*(31), 13966–13971. doi:10.1073/pnas.1001957107/-/DCSupplemental.www.pnas.org/cgi/doi/10.1073/pnas.1001957107

Vlaeyen, J. W. S., & Linton, S. J. (2000). Fear-avoidance and its consequences in chronic musculoskeletal pain: A state of the art. *Pain*, *85*(3), 317–332. doi:10.1016/S0304-3959(99)00242-0

Weinstein, S. (1968). Intensive and extensive aspects of tactile sensitivity as a function of body part, sex and laterality. In D. R. Kenshalo (Ed.), *The Skin Senses* (pp. 195–200). IL: Thomas Springfield.

Spatial prioritization of somatosensory information during pain control: A paradigmatic exercise

3

Abstract Topical research efforts on attention to pain often take a critical look at the motivational factors involved. For instance, it has been shown that the fearful expectation of pain at a location of the body directs attention towards that body part. In several of these studies a temporal order judgment was used. This paradigm typically requires participants to judge the order in which two stimuli are presented by indicating which one they perceived first. As this constitutes a forced-choice response format, such studies are more easily subject to response bias. Furthermore, the majority of studies on this topic rarely model active attempts to exert control over the experimental pain stimuli. This is counterintuitive, as pain inherently urges one to engage in avoidance, escape or control behavior. The aim of the current study was to address these concerns. We used a ternary synchrony judgment paradigm, in which participants judged the order in which two somatosensory stimuli occurred. Critically, participants now also had the option to give a 'simultaneous' response when they did not perceive a difference. This way we eliminated the need for guessing, and thus reduced the risk of response biases. One location was threatened with the possibility of pain in half of the trials, as predicted by an auditory cue. Participants in the pain control group were encouraged to avoid these pain stimuli by executing a quick button press. Participants in the comparison group performed a similar action, albeit unrelated to the occurrence of pain. Our data did not support threat-induced spatial prioritization, nor did we find evidence that pain control attempts influenced attention in any way.

Introduction

In a recent surge of research endeavors, pain has been investigated as part of a motivational setting (Schrooten, Vlaeyen, & Morley, 2012; Van Damme, Legrain, Vogt, & Crombez, 2010; Wiech & Tracey, 2013). Indeed, aside from to its inherent capability of capturing attention in a bottom-up manner, it has long been clear that anticipating pain may trigger top-down modulation of attentional selection. More specifically, it is suggested that the imminent threat of physical harm – naturally evoking avoidance, escape or control behavior – leads to preferential allocation of attentional resources to stimuli that share features with the expected pain stimulus (Legrain et al., 2009).

Case in point, expecting pain to occur at a bodily location has been shown to direct attention towards that location. This was demonstrated using the temporal order judgment (TOJ) paradigm (Vanden Bulcke, Crombez, Spence, & Van Damme, 2014; Vanden Bulcke, Van Damme, Durnez, & Crombez, 2013). In this experimental setup, participants were requested to judge the order in which two somatosensory stimuli were presented by stating which one they perceived first. One of the stimulus locations was associated with a painful electrocutaneous stimulus in half of all trials. Data showed that the anticipation of pain at a specific body location caused tactile stimuli administered to that location to be perceived quicker, compared to tactile input stemming from the other location.

While this result appears to be convincing, the method with which it was obtained is not without controversy. A main criticism of the TOJ response format is that participants are forced to make a

(binary) choice, without being given the option to report that they did not perceive a temporal difference. This leaves the paradigm vulnerable to response bias, which could potentially contaminate the performance measures typically used in hypothesis testing (García-Pérez & Alcalá-Quintana, 2012; Spence & Parise, 2010). For instance, undecided participants might be inclined to respond with the pain location, due to its increased experimental salience. Performance measures would then show the impact of pain on the decision making process, rather than reflect an effect on somatosensory attention (Schneider & Bavelier, 2003). In contrast, synchrony judgment (SJ) formats allow participants to report the stimulus order as 'simultaneous' (an S response), effectively curbing the chances of measuring response bias. Consequently, SJ paradigms have been argued to be the superior choice when investigating the temporal perception of sensory events (García-Pérez & Alcalá-Quintana, 2012; Schneider & Bavelier, 2003; Spence, Baddeley, Zampini, James, & Shore, 2003; Spence & Parise, 2010; Zampini, Shore, & Spence, 2005). It would thus be interesting to attempt to demonstrate spatial prioritization of location threatened with pain using the SJ response format instead.

Aside from examining these methodological concerns, it may be worthwhile to investigate the role of active attempts to control pain. While several studies base their hypotheses on pain's tendency to implicitly activate the goal to control pain, few of them model actual pain control behavior (Bandura, O'Leary, Taylor, Gauthier, & Gossard, 1987; Crombez, Eccleston, De Vlieger, Van Damme, & De Clercq, 2008; Litt, 1988; Wiech et al., 2006). Yet, allowing participants to act on pain anticipation may provide interesting new

insights with respect to attention to pain. For instance, it has been shown that an attentional bias towards visual pain cues was enhanced when participants engaged in pain control behavior (Notebaert et al., 2011). More recently, it was found that the expectation of pain directed attention towards a currently threatened location

n, but the inclusion of pain control attempts generalize this prioritization to circumstances devoid of threat (Durnez & Van Damme, 2015). These results underpin the value of modeling active goal pursuit in experimental settings.

In the current study, we incorporated the aforementioned findings in order to expand on current literature. In a ternary SJ paradigm, participants judged the order in which two somatosensory stimuli were presented – one on the right hand and one on the left hand. Apart from the response options 'left first' and 'right first', a third 'simultaneous' response could be given. In half of all trials one location was threatened with a painful electrocutaneous stimulus. This was signaled by means of an auditory cue: one predictive of possible pain, the other foretelling a pain-free trial. Our first aim was to replicate the finding that the threat of pain can prioritize attention towards the threatened body site (Durnez & Van Damme, 2015; Van Hulle, Durnez, Crombez, & Van Damme, 2015; Vanden Bulcke et al., 2014, 2013) (hypothesis 1). In addition, we sought to expand the experiment's design by encouraging active pain control behavior in half of all participants. This pain control group was told they could avoid the potential administration of an electrocutaneous stimulus by executing a quick button press. The comparison group, on the other hand, was given a similar assignment that was not related to

pain avoidance. In line with Durnez & Van Damme (2015), we expected pain control attempts to enhance spatial prioritization (hypothesis 2a), to generalize this prioritization to neutral trials (hypothesis 2b), or a combination of both.

Method

Participants

Forty students of Ghent University (9 male and 31 female; M_{age} 22 SD_{age} 2.86) participated in this study, either to earn required course credits or in exchange for a small financial compensation. Five of them were left-handed. All participants had normal or corrected-to-normal vision and normal hearing. The study protocol was approved by the Ethics Committee of the Faculty of Psychology and Educational Sciences of Ghent University. The experiment took approximately 1 hour and 10 minutes. All participants signed an informed consent form.

Apparatus and stimulus material

The experiment was conducted in a darkened, sound isolated room. Participants sat on a chair in front a desk. Their hands were placed palm-down on marked positions. The tactile stimuli used in the experiment were vibrations, presented by means of two 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. Their functioning was controlled and amplified through a custom-built device. The tactors were attached directly to the skin in the center of the back of either hand using

double-sided tape rings. The frequency of tactile stimulation was 200 Hz. The stimulus duration was set to 20 ms. In between both hands, a red fixation LED (light-emitting diode) was placed, serving as a fixation point throughout the different trials of the experiment. Painful stimuli were generated electrically through means of constant current stimulators (Digitimer DS5, 2000). They were delivered via 2 lubricated Fukuda standard Ag/AgCl electrodes (1 cm diameter), placed in close proximity to the tactors and the superficial branch of the radial nerve. These sinusoid electrocutaneous stimuli had a frequency of 200 Hz and a duration of 200 ms. Amplitudes for both the tactile and electrocutaneous stimulation were set using adaptive procedures, as described in the procedure section. Auditory cues were administered using a set of headphones (Sennheiser HD 202 II). These cues consisted of either a high tone (1000 Hz) or a low tone (250 Hz). As part of the goal manipulation, participants were asked to press a foot pedal at specific moments in a portion of the trials. This foot pedal (M-Audio SP-1 sustain pedal) was attached to the floor at a distance that was comfortable for each participant, so that they could easily and quickly press down on it with their dominant foot. The pedal was connected to a Cedrus response box (RB-530 model) to optimize response time registration.

SJ paradigm

The task was programmed in the programming language C using the Tscope 5 library package, an upgraded version of the original Tscope (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006). It ran on a laptop (Dell latitude E5520).

Participants were instructed to keep their hands on the marked positions, and keep their gaze fixed on the fixation LED.

The experiment was divided into 4 blocks of 105 trials each, resulting in a total number of 420 trials. There were 2 blocks where the left hand was threatened by electrocutaneous stimulation, and 2 blocks where the right hand was threatened. Blocks were counterbalanced in this regard. Participants were informed by the experimenter prior to each block which hand was subject to possible painful stimulation. Additionally, they were given at least one electrocutaneous stimulus in the first ten trials, in order to re-establish contingency perception.

Each trial began with an illumination of the fixation LED for 1000 ms. Next, a 1000 ms auditory cue was presented, indicating whether or not an electrocutaneous stimulus could follow (within-subjects variable of THREAT). One tone frequency predicted the possible advent of such a stimulus (threat trial), while the other signaled that this would not be the case (neutral trial). The frequency of the threatening tone (high versus low) was counterbalanced. The tone was followed by a blank interval of 500 ms. Depending on the between-subject variable *Group*, the auditory cue was at times followed by a feedback message ("TOO SLOW") that was shown on screen for 2 s. The Procedure section provides more information concerning the purpose of this message. Next, a blank interval of 500 ms occurred.

Threat trials were marked by a chance of 1 out of 11 that there would be actual electrocutaneous stimulation. These trials are referred to in the remainder of the manuscript as 'pain trials'.

Participants were not informed of this proportion. In case of a pain trial, no other stimuli were presented but the electrocutaneous stimulus. In the remaining 10 threat trials, as well as in all neutral trials (10 in number), the auditory cue was followed by the administration of the SJ stimuli by the tactors on both hands. The stimuli were separated in time by 1 of 10 possible stimulus onset asynchronies (SOAs; -120, -60, -30, -15, -5, +5, +15, +30, +60 or +120 ms. These SOAs have also been used in multiple TOJ experiments (e.g. Moseley, Gallace, & Spence, 2009; Vanden Bulcke et al., 2013) . In SJ experiments, it is customary to code SOAs so that negative values indicate that the test stimulus was presented first. In this study, we will regard stimuli at the threatened side as test stimuli, while stimuli at the opposite side will be labeled as reference stimuli. In the remainder of the manuscript, negative SOAs thus refer to trials in which the stimulus at the pain location preceded the stimulus at the pain-irrelevant location. Every SOA occurred an equal number of times during the course of the experiment (5 times per block, per condition).

Participants were asked to report aloud on which hand they felt the first tactile stimulus, by saying 'left' or 'right'. If they did not sense a difference, they were asked to report this by saying 'simultaneous'. When a painful stimulus replaced an SJ trial, participants were asked to report the hand on which this stimulus was felt. They had up to 5000 ms to respond before their response was coded as a blank. All responses were coded by the experimenter using the laptop keyboard.

Procedure

Participants were given a brief description of the experiment and asked to fill in the informed consent form. They then completed a custom-made pre-test questionnaire, which is described in the self-report measures section below. Tactors and electrodes were then attached to the locations described above. Because it has been shown that somatosensory sensitivity can vary depending on which location of the body is stimulated (Weinstein, 1968), we first obtained appropriate tactile stimulation amplitudes for each hand. Our goal was to ensure that participants perceived tactile stimulation equally intense on both hands hand, so as not to give an advantage to either side. Our custom-made adaptive procedure, based on the double random staircase procedure, was designed as follows.

Participants were first given an orientation stimulus at 60 percent of the maximum capacity (and thus with a power of 0.612 watts) on the left hand. One second after that, a tactile stimulus was administered to the right hand. The amplitude of this second stimulus was taken from one of two staircases, which were alternated randomly for an equal number of times in total. The starting value for the first staircase was a random integer between 55 and 59, while the starting value of the second staircase was a random integer between 61 and 65. This way we ensured that participants would encounter both a stimulus that was higher in actual amplitude, and one that was lower in amplitude. After each pair of stimuli, participants were asked whether they perceived the second stimulus as “a lot stronger”, “stronger”, “equally strong”, “weaker” or “a lot weaker”. Their response determined the next value in the staircase

(respectively 5 units down, 1 unit down, no change, 1 unit up or 5 units up). This procedure ran for 16 repetitions. The continuous coupling of orientation stimuli and to-be-rated stimuli was intended to ensure participants could adequately compare both sensations, making sure there was no gradual shift in memory of how the stimulus was perceived. It also served to prevent divergent sensitization effects on both hands. An average was made of all amplitudes that participants had reported to perceive as being equally strong. This value was used in the main experiment (table 1).

In the following preparatory phase, we determined amplitudes for the electrocutaneous stimulation. We did this for each hand separately, using a double random staircase procedure of 14 steps. In this procedure, one staircase started with a value chosen between 15 and 19 (respectively 1.5 mA and 1.9 mA), whereas the other staircases started with a value between 20 and 24 (respectively 2.0 mA and 2.4 mA). Participants were asked to rate each stimulus on an 11-point scale (0 = "no pain", 10 = "unbearable pain"). Responses determined the next value in the corresponding staircase: a rating over 7 meant 1 unit down, a rating of 7 meant no change, and a rating under 7 meant 1 unit up. We took the average of all values to which participants gave a pain intensity rating of 7. This way we obtained pain intensities for both hands (table 1), which we then used in the further course of the experiment.

We proceeded by introducing the participants to the SJ paradigm and explained the nature of the task. We presented them with 22 practice trials. Every SOA was presented twice, with two additional pain trials intermixed. We only proceeded when participants achieved 100% accuracy on the trials with the largest

SOA (+/- 120 ms). Next, we informed participants about the meaning of the auditory cues. Dependent on which group they were placed in (between-subjects variable of GROUP), participants received additional instructions with regard to the use of the foot pedal. In the **pain control group** (20 participants), participants were instructed that they could significantly reduce the chance of receiving painful stimuli throughout the experiment, by pressing down on the pedal as soon as they heard the threat-signaling cue. In reality, the timing and occurrence of painful stimuli were predetermined, ensuring that participants in the pain control group received an equal amount of pain stimuli as those in the comparison group. In other words, our goal manipulation depended on subjective control, rather than actual control. In this group, the feedback message was shown only during pain trials. This was done in an effort to reinforce participants' perception of contingency between their (failed) pain control behavior and the occurrence of electrocutaneous stimuli.

Table 1

Overview of intensity levels per subject for experimental stimuli.

Participants	Tactile intensity *left* (W)	Tactile intensity *right* (W)	Electrocuta-neous intensity *left* (mA)	Electrocuta-neous intensity *right* (mA)
1	0.61	0.53	1.40	1.50
2	0.61	0.51	1.70	2.50
3	0.61	0.50	1.50	1.50
4	0.61	0.56	1.40	1.50
5	0.61	0.65	1.70	2.10
6	0.61	0.60	2.50	2.40
7	0.61	0.57	2.40	2.00

8	0.61	0.63	3.30	3.90
9	0.61	0.42	2.80	2.70
10	0.61	0.54	3.00	3.00
11	0.61	0.40	3.00	3.00
12	0.61	0.52	2.50	2.80
13	0.61	0.44	2.60	2.50
14	0.61	0.74	3.50	4.00
15	0.61	0.70	3.40	3.70
16	0.61	0.36	2.70	2.40
17	0.61	0.44	2.70	3.10
18	0.61	0.60	2.10	2.10
19	0.61	0.58	3.50	4.30
20	0.61	0.41	3.50	3.80
21	0.61	0.52	3.50	3.90
22	0.61	0.81	2.40	3.50
23	0.61	0.64	2.40	2.30
24	0.61	0.63	3.80	3.80
25	0.61	0.59	3.20	3.50
26	0.61	0.66	3.70	3.50
27	0.61	0.57	3.60	2.90
28	0.61	0.64	2.90	2.70
29	0.61	0.50	3.90	3.00
30	0.61	0.57	3.40	3.70
31	0.61	0.53	2.70	2.40
32	0.61	0.61	3.80	3.60
33	0.61	0.66	4.00	3.20
34	0.61	0.56	4.40	4.70
35	0.61	0.46	3.80	3.40
36	0.61	0.65	4.40	5.00
37	0.61	0.44	3.20	3.60
38	0.61	0.70	3.60	3.60
39	0.61	0.79	4.20	4.90
40	0.61	0.44	3.30	3.40
M	0.61	0.57	3.04	3.14
SD	0.00	0.11	0.81	0.88

In the **comparison group** (20 participants), participants were also instructed to press down on the pedal upon hearing the threat-signaling cue. These participants, however, were told this served to

obtain additional measures of attention and concentration. No instructions related to pain control were given whatsoever. These participants were shown the feedback message at random times throughout the experiment. As such, they were not contingent with the presentation of painful stimulation. Still, the message strictly followed threat cues, as this was the only trial type in which these participants were requested to execute the timed button press. Four SJ blocks were then presented, as described above. The presentation order was counterbalanced with regard to modality and threat location.

Self-report measures.

Prior to the experiment, participants filled in a custom-made questionnaire, for gauging pre-existing pain-related conditions and episodes. All ratings (e.g., "To what degree were you unable to conduct daily activities during the past six months because of your pain?") were indicated on an 11-point Likert scale. In addition, each experimental block was followed by a quick questionnaire, measuring effort ("To what extent did you put effort into the task?"), concentration ("How well could you concentrate on the task?"), attention ("How much attention did you pay to the somatosensory stimuli?"; "How much attention did you pay to the electrocutaneous stimuli?"), fear related to either cue ("To what extent did you fear that a high/low tone would be followed by an electrocutaneous stimulus?"), pain expectancy related to either cue ("To what extent did you expect an electrocutaneous stimulus to follow the high/low tone?"), pain perception ("How painful did you find the electrocutaneous stimulus?"), anxiety ("How anxious did you feel

during this block?") and fatigue ("How tiresome did you find this block?"). All questions were answered on an appropriately anchored 11-point Likert scale. Answers were averaged over blocks per participants, prior to analysis. Finally, upon completion of all experimental blocks, participants completed the Pain Catastrophizing Scale (PCS) (Sullivan, Bishop, & Pivik, 1995; Van Damme, Crombez, Bijttebier, Goubert, & Van Houdenhove, 2002).

Statistical analyses.

Participants not reaching a mean accuracy of 80% on trials with the largest SOAs (+/- 120) were excluded from further analyses (De Paepe, Crombez, Spence, & Legrain, 2014; Vanden Bulcke et al., 2013). We then analyzed performance on the SJ-task by fitting these data to functions based on an independent channels model, as described in (Alcalá-Quintana & García-Pérez, 2013). In this instance, three-curves were fit to the data of each condition, for every participant. The proportions of responses per SOA that indicate that a participant first perceived the stimulus at the pain location (TF: test stimulus first) were approximated with a first curve. Those indicating that the stimulus presented on the opposite hand was perceived first (RF: reference stimulus first) were approximated by a second curve. Finally, simultaneous (S) responses were fitted with a third curve. There are two possible ways to define the PSS in an SJ experiment. It can either be calculated as the SOA that is associated with the maximal chance of receiving a 'simultaneous' response (the **peak** of the S-curve), or as the **midpoint** between two boundaries (the point in between the intersections of the S-curve with either the TF-curve, or the RF-curve). If judgments are perfectly symmetrical,

these points should coincide. Empirically speaking, this is rarely the case (García-Pérez & Alcalá-Quintana, 2012; Van Eijk, Kohlrausch, Juola, & Van De Par, 2008). In this study, both measurements will therefore be examined.

Using these fits, we obtained PSS measures for each condition. Our coding scheme is such that the sign of our PSS measurements indicates the direction of potential attentional shifts. Positive values indicate that stimuli stemming from the threatened location should be presented *after* stimuli originating on the opposing hand for both to be perceived as simultaneously occurring. Negative values refer to the opposite. Correspondingly, positive PSS measurements indicate an attentional shift towards the pain location, whereas negative values suggest the contrary.

Participants with PSS-values greater than the largest SOA were removed from the dataset (Spence, Shore, & Klein, 2001). PSS values were analyzed using a mixed-effects model with a Gaussian link function, as implemented in the R package 'lme4'.

The statistical modeling procedure was as follows. First, all relevant factors and their interactions were entered in the model as fixed factors. These included *Threat* (threat trials vs. neutral trials) and *Group* (pain control group versus comparison group). By default, a random effect was added introducing adjustments to the intercept conditional on each subject separately. Next, we determined whether the addition of random effects was necessary for the within-subject fixed factor of *Threat*. If a random effect increased the model's goodness of fit, we included it in the final model. In a second step, we sought out the most parsimonious model that fit the

data by restricting the full model systematically, starting with higher-order terms. All model comparisons were made using likelihood-ratio tests. In a third and final step, we inspected the ANOVA table of the final model and tested specific hypotheses about possible main effects or interactions (see De Ruddere et al. 2013; Durnez and Van Damme 2015; Verbruggen and Aron 2010, for a similar approach). All contrast analyses were corrected for multiple testing according to the corrections of Holm-Bonferroni (Holm, 1979).

As discussed in the introduction, we hypothesized that the anticipation of a painful stimulus would induce attentional prioritization of the threatened location (hypothesis 1). In addition, we expected that this prioritization would depend on the *Group* factor. More specifically, we expected to see either more pronounced effects in the pain control group (hypothesis 2a: *Threat* x *Group* interaction), generalized effects across threat and neutral trials (hypothesis 2b: *Group* main effect), or a combination of both.

Results

Self-report data and manipulation check

Participants assessed their own health as 'very good', on average. One participant reported to be recovering from a serious injury, but did not report any pain at the time of testing. One participant reported having heart disease. There was no reason to suspect this influenced our data. No other participants reported any serious medical conditions, nor did anyone report mental illness of any sort.

Twenty-four participants had experienced some form of pain during the past 6 months (M = 25.94 days, SD = 36.92 days). This pain had an average intensity rating of 4.63 (SD = 1.53) and an average disability rating of 2.92 (SD = 2.38). One such participant reported to have suffered from her pain complaint for 180 days (intensity rating: 7; disability rating: 7). We found no evidence that these participants significantly distorted the data. One participant reported having taken an analgesic earlier during the day. However, this participant underwent the same pain calibration procedure, and reported perceiving the electrocutaneous stimulation as painful over the course of the experiment. Twelve participants reported feeling pain at the moment of testing, on a Likert-scale ranging from "no pain" to "worst possible pain". Their average pain intensity ratings were low (M = 1.69, SD = 0.95.

PCS scores were not significantly different between groups (comparison group: M = 10.75, SD = 8.95; pain control group: M = 11.05, SD = 8.59) (χ^2 = 0.01, p = .91). Over the course of the experiment, the electrocutaneous stimulus was rated moderately painful in both groups (comparison: M = 4.73, SD = 1.68; pain control: M = 3.83, SD = 2.42) with no significant difference between them (χ^2 = 1.86, p = .17). To verify the effect of the threat manipulation, we applied an ANOVA with the factors CUE (threatening versus neutral) and GROUP (comparison versus pain control) on fear and pain expectancy ratings.

Table 2

Self-report questionnaires per group (com = comparison group, pc = pain control group). Univariate ANOVA statistics are given.

	M com	SD com	M pc	SD pc	χ^2	*p*
Pain experience	4.73	1.68	3.83	2.42	1.86	.17
Anxiety	3.84	2.19	3.10	2.59	0.95	.33
Attention to painful stimuli	4.56	2.17	3.88	2.14	1.02	.31
Attention to tactile stimuli	7.40	2.24	6.38	2.33	2.01	.16
Concentration	7.38	1.67	7.29	0.93	0.04	.84
Effort	7.85	1.51	7.64	0.95	0.28	.59
Fatigue	5.29	2.34	5.11	1.89	0.07	.79
Fear (neutral cue)	1.00	1.73	1.21	1.61	0.06	.81
Fear (threat cue)	4.96	2.12	4.80	2.13	0.16	.69
Pain expectancy (neutral cue)	1.05	1.70	1.13	1.54	< 0.01	.93
Pain expectancy (threat cue)	4.43	2.12	4.36	2.52	0.02	.88
PCS	10.75	8.95	11.05	8.59	0.01	.91

With regard to fear ratings, we found a main effect of the CUE variable (χ^2 = 78.26, p < .001), indicating that participants felt more fearful upon hearing the threat cue (M = 4.88, SD = 2.10) compared to the neutral cue (M = 1.11, SD = 1.65) (d = 2.00, 95% CI = 1.45-2.56). This confirmed that the threat manipulation was successful. A comparable pattern was found with respect to pain expectancy ratings, again showing a significant main effect of CUE (χ^2 = 54.24, p < .001). Similarly, hearing the threatening cue led to more pain expectancy (M = 4.39, SD = 2.30) compared to hearing the neutral cue (M = 1.09, SD = 1.60) (d = 1.67, 95% CI = 1.14-2.19). No other group differences were found (table 2).

SJ data

We excluded 4 participants (all of which in the comparison group) whose accuracy on trials with the largest SOA (± 120 ms) fell under the cut-off level of 80 percent. None of the remaining participants showed PSS values outside of the SOA range. One participant's data did not yield a model suitable to obtain a midpoint PSS measurement, due to a noticeable lack of S-responses. This participant was omitted from further analyses.

We first fitted a model containing all fixed factors and interactions and a random subject-based intercept to both the PSS peak data and the PSS midpoint data (see fig. 1 and fig. 2 for an overview). No additional random effects were necessary in either model. The final models yielded no significance for any of the included factors (*Threat* and *Group*) or their interaction. Removing the interaction term from these models did not lift any of the fixed factors above significance level.

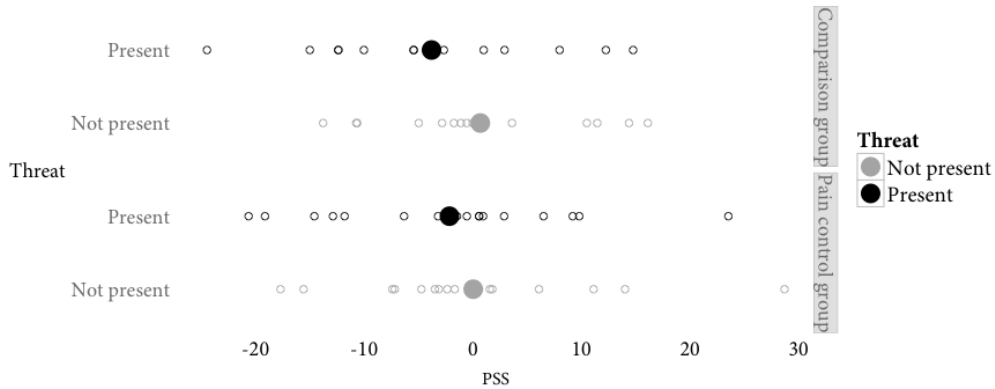


***Figure 1*: We compared individual Point of Subjective Simultaneity measurements across conditions, using *peak* measures. For every participant in both the comparison group and the pain control group, we calculated the Point of Subjective Simultaneity (PSS) in both threat trials and neutral trials (smaller, hollow circles). Mean PSS values are indicated as well (larger, solid circles).**

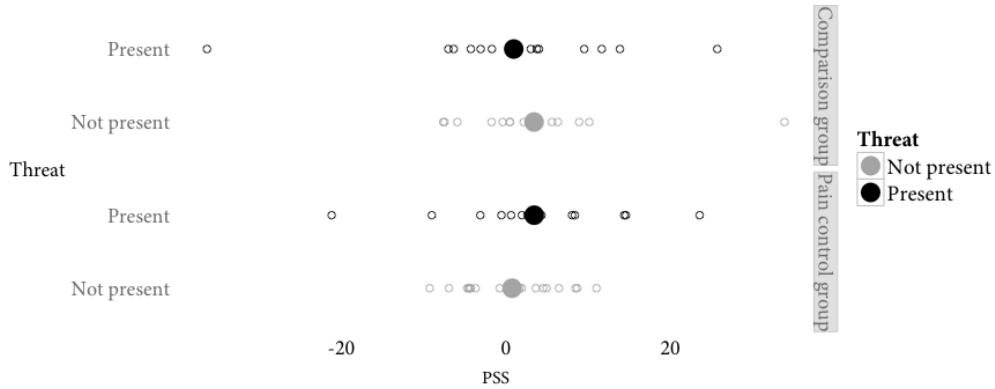


***Figure 2*: Second, we compared individual Point of Subjective Simultaneity measurements across conditions, using *midpoint* measures. Graphical parameters are identical to the ones as used in figure 1.**

Discussion

When an individual is under threat of pain, he or she tends to direct more attention towards the threatened location of the body (Vanden Bulcke et al., 2013). In addition, attempts to avoid this pain have been shown to lead to more generalized effects, expanding this

prioritization to neutral trials (Durnez & Van Damme, 2015). In the present study, we sought to provide additional support for these findings using a SJ3 paradigm. Our data failed to support the existence of the hypothesized prioritization effects. We found no evidence that the threat of pain led to faster processing of stimuli at the endangered body site, nor were we able to show that such effects could be modulated by pain control attempts.

There are several possible explanations for this lack of significant results. First, it is possible that the effects documented in previous judgment paradigms (Vanden Bulcke et al., 2014, 2013) are caused by mechanisms different to the proposed attentional shift explanation. For instance, TOJ paradigms have been suggested to be particularly susceptible to response bias. Applied to these studies, this could mean that participants are likely to name the threatened location when they are unsure of the order in which they perceived the experimental stimuli. In other words, the effect of anticipated pain could manifest itself in the decision making process, rather than the actual sensory processing (Schneider & Bavelier, 2003).

In this regard, SJ experiments are thought to hold the advantage, as the tertiary response option can eliminate response bias (García-Pérez & Alcalá-Quintana, 2012). Our inability to reproduce results could then be seen as an indication that such response bias was a crucial – or even, sole – determinant of earlier results. Still, there are arguments against this notion. Recent studies demonstrated spatial prioritization of a threatened location by means of a tactile change detection (TCD) paradigm (Durnez & Van Damme, 2015; Van Hulle, Van Damme, Spence, Crombez, & Gallace, 2013). In a TCD experiment, participants are requested to

judge whether or not they sensed a change in subsequent patterns of tactile stimulation. The derived data can then be analyzed to see if change detection is dependent on the crucial involvement of particular locations, such as a body location where pain is expected to occur. It is evident that the response format in TCD ("change" or "no change") is orthogonal to the variable indicating the involvement of 'special' locations. Consequently, their design leaves no room for response bias – of which aforementioned TOJ experiments are suspect – to take place. In spite of this, these TCD studies have all shown evidence of threat-induced spatial prioritization, using an arguably more complex paradigm. As such, these results suggest that the findings from TOJ experiments can be interpreted as support for the manifestation of spatial prioritization, as opposed to a mere reflection of response bias.

A second explanation for our underwhelming results is implied in the distribution of the obtained data. Closer inspection of the amount of TF-, S- and RF-responses reveals that subjects greatly differ with regard to the standard they use to decide which response option they should choose. For example, some participants report that they perceived the stimuli to occur simultaneously less than 8 times out of an approximate total of 400 trials (not withholding trials where the response time limit was exceeded), while others resort to such S-responses over 190 times throughout the experiment. These differences make extraction of useful measures of perception a difficult task. This problem has been documented before, particularly with regard to the ternary SJ-format (Spence & Parise, 2010). It has no clear-cut remedy, other than returning to a TOJ format and making adjustments where appropriate.

Third, it may be important to note that the use of feedback messages – pertaining to the effectiveness of pain avoidance attempts – could have had an inadvertent effect. In the pain control group, specifically, this message was contingent with the administration of an electrocutaneous stimulus. When a participant went through a pain trial – that is, a threat trial resulting in actual pain – this message was intended to further encourage control attempts and to reaffirm their necessity. However, due to the design, participants could have been aware that they were 'safe' when they did not see a visual feedback message but felt the tactile stimuli instead. If somatosensory monitoring is at the core of spatial prioritization towards a threatened location, this could have interfered with the attentional effects we aimed to investigate. Indeed, the feedback message– or lack thereof – in our experiment may have prematurely indicated that the pain location was in fact no longer threatened, eliminating the need to dedicate a surplus of attentional resources towards it. This rationale only applies to the pain control group, given that feedback in the comparison group was not contingent on the actual manifestation of pain. Moreover, we feel that this explanatory avenue would be more likely if we had implemented positive feedback when pain was 'successfully avoided'. Still, investigating the potential role of prioritization as a monitoring mechanism may be an interesting direction for future research.

Disclosures

This study was supported by a research grant (BOF11/STA/004) by the Special Research Foundation of Ghent University (BOF) awarded to S. Van Damme. There are no conflicts of interest that may arise as a result of this research.

References

Alcalá-Quintana, R., & García-Pérez, M. a. (2013). Fitting model-based psychometric functions to simultaneity and temporal-order judgment data: MATLAB and R routines. *Behavior Research Methods*, *45*, 972–98. doi:10.3758/s13428-013-0325-2

Bandura, a, O'Leary, a, Taylor, C. B., Gauthier, J., & Gossard, D. (1987). Perceived self-efficacy and pain control: opioid and nonopioid mechanisms. *Journal of Personality and Social Psychology*, *53*(3), 563–71. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2821217

Crombez, G., Eccleston, C., De Vlieger, P., Van Damme, S., & De Clercq, A. (2008). Is it better to have controlled and lost than never to have controlled at all? An experimental investigation of control over pain. *Pain*, *137*(3), 631–9. doi:10.1016/j.pain.2007.10.028

De Paepe, A. L., Crombez, G., Spence, C., & Legrain, V. (2014). Mapping nociceptive stimuli in a peripersonal frame of reference: evidence from a temporal order judgment task. *Neuropsychologia*, *56*, 219–28. doi:10.1016/j.neuropsychologia.2014.01.016

De Ruddere, L., Goubert, L., Stevens, M., Williams, A. C. de C., & Crombez, G. (2013). Discounting pain in the absence of medical evidence is explained by negative evaluation of the patient. *Pain*, *154*(5), 669–76. doi:10.1016/j.pain.2012.12.018

Durnez, W., & Van Damme, S. (2015). Trying to Fix a Painful Problem: The Impact of Pain Control Attempts on the Attentional Prioritization of a Threatened Body Location. *The Journal of Pain*, *16*(2), 135–143.

García-Pérez, M. a, & Alcalá-Quintana, R. (2012). On the discrepant results in synchrony judgment and temporal-order judgment tasks: a quantitative model. *Psychonomic Bulletin & Review*, *19*(5), 820–46. doi:10.3758/s13423-012-0278-y

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*(2), 65–70. Retrieved from http://www.jstor.org/stable/10.2307/4615733

Legrain, V., Damme, S. Van, Eccleston, C., Davis, K. D., Seminowicz, D. a, & Crombez, G. (2009). A neurocognitive model of attention to pain: behavioral and neuroimaging evidence. *Pain*, *144*(3), 230–2. doi:10.1016/j.pain.2009.03.020

Litt, M. D. (1988). Self-efficacy and perceived control: cognitive mediators of pain tolerance. *Journal of Personality and Social Psychology*, *54*(1), 149–60. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3346804

Moseley, G. L., Gallace, A., & Spence, C. (2009). Space-based, but not arm-based, shift in tactile processing in complex regional pain syndrome and its relationship to cooling of the affected limb. *Brain : A Journal of Neurology*, *132*(Pt 11), 3142–51. doi:10.1093/brain/awp224

Notebaert, L., Crombez, G., Vogt, J., De Houwer, J., Van Damme, S., & Theeuwes, J. (2011). Attempts to control pain prioritize attention towards signals of pain: an experimental study. *Pain*, *152*(5), 1068–1073. doi:10.1016/j.pain.2011.01.020

Schneider, K. a., & Bavelier, D. (2003). Components of visual prior entry. *Cognitive Psychology*, *47*(4), 333–366. doi:10.1016/S0010-0285(03)00035-5

Schrooten, M. G. S., Vlaeyen, J. W. S., & Morley, S. (2012). Psychological interventions for chronic pain: Reviewed within the context of goal pursuit. *Pain Management*, *2*(2), 141–150.

Spence, C., Baddeley, R., Zampini, M., James, R., & Shore, D. I. (2003). Multisensory temporal order judgments: When two locations are better than one. *Perception & Psychophysics*, *65*(2), 318–328. doi:10.3758/BF03194803

Spence, C., & Parise, C. (2010). Prior-entry: a review. *Consciousness and Cognition*, *19*(1), 364–79. doi:10.1016/j.concog.2009.12.001

Spence, C., Shore, D. I., & Klein, R. M. (2001). Multisensory prior entry. *Journal of Experimental Psychology: General*, *130*(4), 799–832.

Stevens, M., Lammertyn, J., Verbruggen, F., & Vandierendonck, A. (2006). Tscope: A C library for programming cognitive experiments on the MS windows platform. *Behavior Research Methods*, *38*(2), 280–286. doi:10.3758/BF03192779

Sullivan, M. J. L., Bishop, S., & Pivik, J. (1995). The pain catastrophizing scale: Development and validation. *Psychological Assessment*, *7*, 524–535.

Van Damme, S., Crombez, G., Bijttebier, P., Goubert, L., & Van Houdenhove, B. (2002). A confirmatory factor analysis of the Pain Catastrophizing Scale: invariant factor structure across clinical and non-clinical populations. *Pain*, *96*, 319–324. Retrieved from http://www.sciencedirect.com/science/article/pii/S0304395901004638

Van Damme, S., Legrain, V., Vogt, J., & Crombez, G. (2010). Keeping pain in mind: a motivational account of attention to pain. *Neuroscience and Biobehavioral Reviews*, *34*(2), 204–13. doi:10.1016/j.neubiorev.2009.01.005

Van Eijk, R. L. J., Kohlrausch, a., Juola, J. F., & Van De Par, S. (2008). Audiovisual synchrony and temporal order judgments: Effects of experimental method and stimulus type. *Perception & Psychophysics*, *70*(6), 955–968. doi:10.3758/PP.70.6.955

Van Hulle, L., Durnez, W., Crombez, G., & Van Damme, S. (2015). Detection of tactile change on a bodily location where pain is expected. *Perceptual & Motor Skills: Perception*, *120*(1), 219–231.

Van Hulle, L., Van Damme, S., Spence, C., Crombez, G., & Gallace, A. (2013). Spatial attention modulates tactile change detection. *Experimental Brain Research*, *224*(2), 295–302. doi:10.1007/s00221-012-3311-5

Vanden Bulcke, C., Crombez, G., Spence, C., & Van Damme, S. (2014). Are the spatial features of bodily threat limited to the exact location where pain is expected ? *Acta Psychologica*, *153*, 113–119. doi:10.1016/j.actpsy.2014.09.014

Vanden Bulcke, C., Van Damme, S., Durnez, W., & Crombez, G. (2013). The anticipation of pain at a specific location of the body prioritizes tactile stimuli at that location. *Pain*, *154*(8), 1464–8. doi:10.1016/j.pain.2013.05.009

Verbruggen, F., & Aron, A. (2010). Theta burst stimulation dissociates attention and action updating in human inferior frontal cortex. *Proceedings of the National Academy of Sciences*, *107*(31), 13966–13971. doi:10.1073/pnas.1001957107/-/DCSupplemental.www.pnas.org/cgi/doi/10.1073/pnas.1001957107

Wiech, K., Kalisch, R., Weiskopf, N., Pleger, B., Stephan, K. E., & Dolan, R. J. (2006). Anterolateral prefrontal cortex mediates the analgesic effect of expected and perceived control over pain. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *26*(44), 11501–9. doi:10.1523/JNEUROSCI.2568-06.2006

Wiech, K., & Tracey, I. (2013). Pain, decisions, and actions: A motivational perspective. *Frontiers in Neuroscience*, *7*(7 APR), 1–12. doi:10.3389/fnins.2013.00046

Zampini, M., Shore, D. I., & Spence, C. (2005). Audiovisual prior entry. *Neuroscience Letters*, *381*(3), 217–22. doi:10.1016/j.neulet.2005.01.085

On attention, pain control and monitoring strategies: a set of follow-up experiments

4

Abstract According to the neurocognitive model of attention to pain, top-down goals may determine which stimulus features are preferably selected by attention. In line with this idea, recent studies have shown that anticipating pain – and crucially, attempting to control its manifestation – gives way to prioritization of the body site that is under threat. However, due to the design of these studies, it can be argued that this prioritization effect is the result of a monitoring mechanism. More specifically, participants may have directed their attention to the threatened location to verify whether their actions were consequential to the occurrence of pain. To investigate this hypothesis, we reprised a tactile change detection (TCD) task, as this paradigm has been successfully used to evidence the aforementioned threat-induced spatial bias. In this paradigm, participants judge whether two subsequent patters of tactile stimulation were identical. Half of all trials were associated with the possibility of receiving a painful stimulus, by means of a visual cue. Critically, participants were divided into three groups. The pain control group was encouraged to attempt to avoid the pain by means of a quick button press. The feedback group was told the same, with the added instruction that this attempt would be followed by a feedback message that informed them of their success in avoiding the painful stimulus – prior to its possible administration. The comparison group was given a filler reaction time task, not related to pain control. We hypothesized that the feedback group would not exhibit prioritization, as the need to monitor the threatened location was abolished by the verbal feedback. Results failed to corroborate this. Instead, they hinted towards a threat-induced spatial prioritization pattern, albeit independent of the group variable. This replication failure prompted us to repeat the initial design of the TCD study, in an attempt to replicate the original findings. In this second experiment, we again found evidence for the attentional prioritization of threatened body site, irrespective of ongoing pain control attempts.

Introduction

In essence, attention is a functional dichotomy. (Allport, 1989) On the one hand, our ability to focus on current goals needs to be sufficiently strong, so that our objectives can be attained. On the other hand, this focus cannot be absolute. When our safety is compromised, it is vital that we are able to redirect attention to potential sources of threat. As a biologically evolved threat indicator, pain has the intrinsic capability to interrupt ongoing activities and grab our attention in a bottom-up manner. (Eccleston & Crombez, 1999; Sarter, Givens, & Bruno, 2001) This impromptu demand for attention is automatic and independent of our *a priori* goals.

Pain can also be subject to another mode of attentional selection. Once physical harm is considered a genuine possibility, it often trumps all other concurrent concerns. The goal to avoid, escape or control pain becomes predominant. (Eccleston & Crombez, 1999) This is commonly paired with a top-down modulation of attentional selection. (Sarter et al., 2001) Our attentional set – the cognitive checklist by which sensory input is assessed in order to determine its priority for attention selection – then adopts features of the anticipated noxious stimulus. (Legrain et al., 2009) This enables us to detect pain-related input – and as such, information relevant to the goal to control pain – more swiftly and efficiently. For instance, it has been shown on several occasions that anticipating pain on a specified part of the body can lead to the prioritization of – innocuous – somatosensory input at that location. (Van Hulle, Durnez, Crombez, & Van Damme, 2015; Vanden Bulcke, Van Damme, Durnez, & Crombez, 2013) This suggests that, when pain is imminent, more attentional resources are turned towards the jeopardized body site in question.

In a recent study, we sought to expand on this line of research by introducing a condition in which participants could actively seek to avoid the delivery of pain. (Durnez & Van Damme, 2015) Our aim in doing this was to experimentally model how pain control attempts – despite the ambiguity of their effectiveness – can further strengthen the prioritization of pain-related sensory input. Using a tactile change detection (TCD) task (Gallace, Tan, & Spence, 2006), we found that changes in tactile stimuli combinations were detected more easily when these changes critically involved the pain location. This confirmed previous findings that the fearful anticipation of pain redirects attention towards the threatened location. Crucially, though, our results suggested that when participants were simultaneously engaging in pain control behavior, this spatial prioritization effect generalized to neutral trials. In other words, there was evidence that participants who tried to avoid pain generally devoted more attention to the threatened location, regardless of the immediate presence of threat. Noteworthy in this regard is that these control attempts were of no consequence to the delivery of painful stimuli, rendering them futile by design.

An interesting analogon for such fruitless attempts at pain management can be found in theoretical models on chronic pain. The misdirect problem solving model (Eccleston & Crombez, 2007), for example, suggests that a dysfunctional perseverance loop influences attentional processes. When someone is confronted with enduring pain, worry emerges. This, in turn, spurs the individual to seek a solution for his or her painful problem. Failure to find such a solution further fans the flame of worry. In the model, this cycle of fruitless pain management is hypothesized to evoke excessive attention – also labeled as hypervigilance – to pain-related information. In a similar vein, the fear-avoidance model

(Lethem, Slade, Troup, & Bentley, 1983; Vlaeyen & Linton, 2000) proposes that avoidance behavior may instate a vicious cycle of disuse, disability and even depression. Maladaptive cognitions – such as catastrophic thoughts – then increase the fear of pain and physical harm, ultimately promoting stronger efforts to avoid the pain. Again, it is this negativity loop that is suggested to underlie hypervigilance to pain. Note that our experiment (Durnez & Van Damme, 2015) did not intend to unravel the cognitive mechanisms involved in dealing with futile pain control efforts, but rather investigated the attentional impact that comes with such behavior.

Importantly, due to the design of our previous experiment (Durnez & Van Damme, 2015), the presumed result of the pain control attempts was only apparent when all experimental tactile stimuli had already been administered. This is a critical observation, both from an experimental perspective as well as in light of the aforementioned clinical models. The problem – that is, the uncertainty whether pain has been successfully avoided or not – is not solved until the trial is over. In other words, it is possible that attention is redirected to the anticipated locus of pain as a strategy to monitor the efficacy of pain control attempts. If the subject feels pain at that location, this can easily be interpreted as evidence that the attempt to control pain was unsuccessful. As such, prioritization of the threat location could be seen as an adaptive strategy in the experimental setting.

This raises the question, "what would happen if this uncertainty were resolved prior to the presentation of tactile task stimuli, for instance by introducing immediate feedback that confirms if the pain has been successfully avoided or not?" This would remove the necessity to monitor the body for evidence of the efficacy of pain control behavior, and in turn, may result in an overall absence of attentional prioritization effects. Indeed,

if attention is primarily prioritized towards the threatened location in order to verify the efficacy of control attempts, then it is reasonable to assume that – once the need for verification has been filled in by prior feedback – the cause for prioritization is dissolved as well. If this is the case, a case could be made that feedback monitoring is at the core of increased attention – or hypervigilance – to pain-related information.

In a first experiment, we sought to test this idea. To this purpose, we reprised our TCD paradigm as described in (Durnez & Van Damme, 2015). In this paradigm, participants were presented with two subsequent patterns of tactile stimuli. Their task was to detect whether or not they perceived a change in these patterns. Half of all trials were associated with the threat of pain through means of a color cue. One cue predicted the possibility of receiving a painful stimulus along with either the first or the second tactile pattern, whereas the other cue represented a guaranteed pain-free trial. In addition to this threat manipulation, participants were divided into three groups. The first two groups – that is, the **comparison group** and the **pain control** group – were parallel to those in our former TCD study. The latter group was given instructions to try and avoid the experimental pain stimuli, whereas the former was simply given a comparable reaction time task. Crucially, we introduced a third group to the experiment. These participants were given the same pain control instructions as those in the pain control group. In this **feedback group**, however, their pain control behavior was immediately followed by a feedback message stating whether they succeeded at avoiding the painful stimulus or not ("avoided" versus "not avoided"). In other words, negative feedback informed participants when an electrocutaneous stimulus was in the offing, while positive feedback reassured them when it was not. Given that pain trials are not included in

the data, this also means that all remaining trials in this group would feature the positive feedback. This effectively removes the need to monitor the body for adverse stimulation, even in threat trials.

We expected results from the comparison and pain control groups to mimic those found in the previous study. (Durnez & Van Damme, 2015) Thus, we predicted prioritization of the pain location in the overall results. We hypothesized that this spatial prioritization would be threat-dependent in the comparison group (hypothesis 1), whereas it would be generalized to safe cues in the pain control groups (hypothesis 2). In the feedback group, we hypothesized spatial prioritization to be diminished – or abolished altogether – as attention no longer required redirection (hypothesis 3).

Experiment 1

Method

Participants

Sixty-one Ghent University students participated in this study, in exchange for course credits. Twenty-six of them were female. Twelve of the participants were left-handed. All of the participants had normal or corrected-to-normal vision and normal hearing. The study protocol was approved by the Ethics Committee of the Faculty of Psychology and Educational Sciences of Ghent University. Each participant signed a document confirming their informed consent. The experiment took approximately 1 hour and 15 minutes.

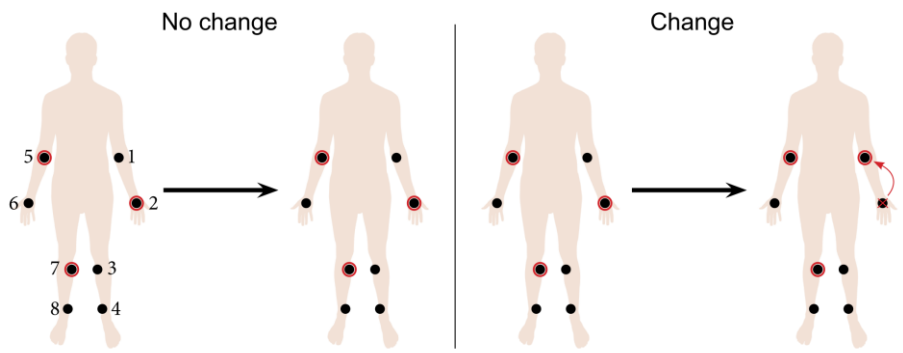


***Figure 1*: Example of typical trial without change in the tactile pattern (left hand side) and trial with change (right hand side). Tactor locations are numbered (see table 1 for mean intensities).**

Apparatus and stimulus material

This study was set up in the same manner as described in Durnez and Van Damme, (2015). It was conducted in a normally illuminated room, with participants sitting on a chair in front of a laptop screen (HP Compaq nc6120 – Notebook, 15" TFT display). Tactile stimuli consisted of vibrations, 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 could be administered on eight different body locations, four of which were situated on each side of the body: the back of the hand, close to the elbow joint on the inner arm, above the knee, and above the inner side of the ankle (fig. 1). Tactors were attached directly to the skin surface by means of double-sided tape rings and were amplified by a custom-built device. Tactor frequency was set to 200 Hz, while the stimulus duration was set to 200 ms. Two electrodes were also taped to one of the tactor locations. The selection of this location was counterbalanced across participants. Similar to the tactor settings, the electrostimulator (DS5, Digitimer, 2000) was set to a 200 Hz frequency and a duration of 200 ms. Amplitude for each of the

devices was determined by means of adaptive procedures, as described in the procedure section. Participants wore noise-cancelling headphones (Sennheiser HD 202), which played white noise at a moderate volume (58 dB) to prevent any interference from outside distractors.

Tactile Change Detection paradigm

Experiment timing, design and parameters were largely analogous to its predecessor TCD study (Durnez & Van Damme, 2015), save for the addition of the feedback condition (third level of Group variable, after **comparison** and **pain control**). The experiment was programmed in the programming language C, using the Tscope library package. (Stevens, Lammertyn, Verbruggen, & Vandierendonck, 2006) Participants were instructed to keep their eye on the black screen for the duration of the experiment. Ahead of each trial, a fixation cross was presented in the center of the screen for 500 ms. After that, one of two possible cues was presented (500 ms) in the form of a colored circle (turquoise or orange, matched in luminance). This was followed by a blank interval of 750 ms. In the feedback condition, this blank interval was followed by a centrally placed feedback message, lasting a total 1000 ms. This message was either the green word 'Vermeden' (Avoided) or the red words 'Niet vermeden' (Not avoided). It was associated with either a pain free TCD trial, or a pain trial. Additionally, the feedback message was trailed by an extra blank interval of 500 ms, after which the first tactile stimulation pattern was presented.

The TCD task consisted of two tactile stimulus patterns, separated by a 110 ms interval. A pattern consists of the simultaneous activation of three tactor locations for 200 ms. The first pattern was a random selection of a possible combination of locations, in such a way that every pattern was presented once per block. For each of these patterns, a possible change was

randomly selected. This means that one of the stimulated locations in the first pattern was no longer stimulated in the second pattern, whereas another location was stimulated instead. Change occurred in half of the trials. In the other half of the trials, the second pattern was identical to the first one. Participants were instructed to detect whether or not they thought the patterns were the same. They then responded 'yes' or 'no' by pressing the corresponding response keys ('f' and 'j' on the AZERTY keyboard) with both index fingers.

Procedure

Participants were given a brief description of the experiment and asked to fill in an informed consent form. Then, they answered a custom-made pre-test questionnaire, which gauged for pre-existing pain-related conditions are episodes. Tactors were attached to their body on the above-described locations (see fig. 1). 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) This was accomplished by means of a custom-made adaptive procedure, as described in Durnez and Van Damme (2015). This procedure gave us a participant-tailored set of tactor intensities, of which means and standard deviations are displayed in table 1.

Table 1

Tactor intensities per location (as indicated in fig. 1).

Location	M	SD
1	0.21	0.00
2	0.31	0.01
3	0.41	0.02
4	0.45	0.02
5	0.11	< 0.01
6	0.25	0.01
7	0.48	0.03
8	0.49	0.03

In a next step, electrodes were attached to one of eight possible locations, corresponding to the tactor positions. The choice of location for the electrodes to be attached to was balanced over participants. As our equipment did not allow us to give both electrocutaneous and tactile stimuli on exactly the same place, we placed the electrodes as close to the relevant tactor as possible. We continued under the assumption that the distance between the tactor and electrodes was negligible in the context of attentional prioritization (see also (Durnez & Van Damme, 2015; Van Hulle et al., 2015; Vanden Bulcke, Crombez, Spence, & Van Damme, 2014; Vanden Bulcke et al., 2013)). Using a similar procedure as the one used for the tactor locations, we determined the intensity of the electrocutaneous stimulus for each individual experiment session. In a double random staircase procedure of 26 steps, we individually selected an intensity that was scored by the

participants as 7 on a 10-point scale, with 10 denoting unbearable pain. We obtained a mean intensity value of 1.90 mA (SD 1.05 mA).

In the last step of the procedure, the TCD paradigm was introduced. TCD trials were modified with a threat component, which was tied to the color cue. Participants were instructed that these cues signified either a threatening situation or a safe situation (within variable, balanced). The threat condition implied the possible administration of a painful stimulus, concurrent with one of the patterns of the TCD trial. In the safe condition the cue was never followed by a painful stimulus. The threat value of both cues was balanced across participants. A threat cue was followed by an electrocutaneous stimulus (200ms) at a chance level of 10%. This stimulus was administered at the same time as one of the patterns. The pattern with which the stimulus co-occurred (i.e., either the first or the second pattern) was randomly selected, to keep the participants from feeling safe before the trial ended.

Additionally, participants were divided into three groups (between subjects variable). In the **pain control group** (21 subjects), we aimed to induce the presence of a pain control goal. The participants were told that pressing the spacebar in the event of a threatening cue served to avoid a more intense painful stimulus. Instructions were in Dutch. Translated to English, they were as follows:

"You can STRONGLY REDUCE THE CHANCE of receiving a painful stimulus. To avoid the pain, you must press the space bar as soon as you see this color (picture of a circle, colored according to experiment parameters for that participant)."

A second group – the **feedback group** – was given similar instructions. For these participants, an additional note followed the avoidance instruction:

"You will see feedback following each cue that will inform you whether you succeeded in avoiding the painful stimulus, or not."

Pressing the button, however, did not have an actual effect on the occurrence of the painful stimuli in either of these groups. Finally, in the **comparison condition** (20 subjects), participants were also instructed to press a button in the event of a threatening cue. However, these participants were told this served to measure ongoing attentional processes. At no point were they told to hold any control over the painful stimuli in the experiment.

Self-report measures

After each test phase, participants had to answer several questions on their experience of pain ("How painful did you find the electrocutaneous stimuli?"), anxiety ("How anxious were you during this block?"), attention to painful/tactile stimuli ("To what extent did you pay attention to the painful/tactile stimuli?"), effort ("To what extent did you put effort into this task?"), concentration ("To what extent did you concentrate on this task?"), and fatigue ("To what extent did you find this task tiresome?") on 11-point numerical rating scales (anchored 0 = not at all and 10 = very strongly). As a manipulation check, we were especially interested in the ratings of fear ("To what extent were you afraid that the blue/yellow cue would be followed by a painful stimulus?"), expectations ("To what extent did you expect that the blue/yellow cue would be followed by a painful stimulus?"), and control attempts ("To what extent did you try to avoid the painful stimulus?"). Before starting the main portion of the experiment, a few more

questionnaires were presented to the participant. Multiple somatic complaints were checked with the Patient Health Questionnaire (PHQ) (Kroenke, Spitzer, & Williams, 2002). Additionally, pain catastrophizing was assessed with the Pain Catastrophizing Scale (PCS) (Sullivan, Bishop, & Pivik, 1995; Van Damme, Crombez, Bijttebier, Goubert, & Van Houdenhove, 2002).

Statistical analyses

Analyses were conducted on the binary variable of response accuracy (correct vs. incorrect). In these analyses, we only used change trials, for the same reasons as described in (Durnez & Van Damme, 2015). That is, we were primarily concerned with participants' ability to detect changes on different parts of the body. In particular, we set out to compare those being threatened with electrocutaneous pain with other, neutral body sites. We defined change trials critically involving the pain location as trials where either the first pattern included a stimulus on the pain location and the second pattern did not, or vice versa. In other words, this means that any trial where something changed on the threatened location was categorized as a 'threat-location involved' trial, whereas the others were labeled 'threat-location not involved'. This trial quality was designated by the *Location* variable.

To begin, we eliminated all trials in which a painful stimulus was given, as the possible impact on task performance rendered these trials useless. Next, we ascertained that the data showed no significant outliers in terms of response accuracy. To this effect, we defined outliers as participants with an average response accuracy that fell outside of the interquartile range. As a result, 5 participants were excluded from the dataset (fig. 2).

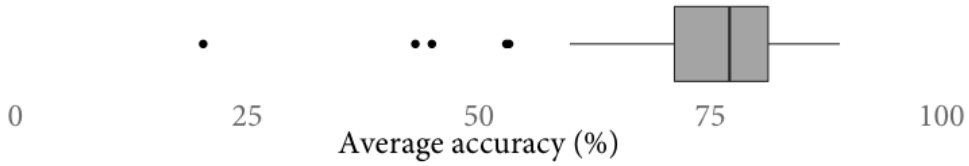


***Figure 2*: Boxplot showing distribution of mean response accuracy in Experiment 1, including outliers (black dots) according to interquartile range criterion.**

We analyzed response accuracy using a linear mixed-effects model with a logit link function, as implemented in the R package 'lme4' (Bates, Maechler, Bolker, & Walker, 2014). Steps in statistical modeling were similar to those reported in Durnez and Van Damme (2015). In step one, we fitted the model with all relevant factors and their interactions. These included *Threat* (threat trials vs. safe trials), *Location* (threatened location involved vs. not involved in pattern change) and *Group* (pain control vs. feedback vs. comparison). In addition, a standard random effect was added introducing adjustments to the intercept conditional on the *Subject* variable. We then assessed whether adding a random effect for each of the fixed within subject factors – ergo for the variables *Threat* and *Location* – improved the model's goodness of fit. In step two, we sought out the most parsimonious model. To achieve this, we systematically restricted the full model, comparing the goodness of fit using likelihood-ratio tests. In a third step, we inspected the ANOVA table of the final model and tested specific hypotheses about possible main effects or interactions (see (De Ruddere, Goubert, Stevens, Williams, & Crombez, 2013; Verbruggen & Aron, 2010) for experiments that adopted a similar statistical approach). Significant interactions were investigated using post-hoc contrast analyses. We corrected for multiple testing according to the Holm-Bonferroni corrections (Holm, 1979).

As discussed in the introduction, we predict that spatial prioritization would differ depending on which experimental group a participant was assigned to. Statistically, this requires a three-way interaction between the *Threat*, *Location* and *Group* variables. If this effect reaches significance, we can examine prioritization effects in each separate group.

Our **first** hypothesis states that, for participants in the comparison group, somatosensory change detection will be more accurate when a body site is involved that is simultaneously being threatened by pain. This implies that comparison group data will exhibit a *Threat* x *Location* interaction. Our **second** hypothesis predicts that the previous effect will be generalized across all trial types in participants who are attempting to control the painful stimulation. We thus expect the prioritization of the threatened location to depend less on the *Threat* variable, possibly only leaving a *Location* main effect. Our **third** hypothesis is that these spatial prioritization effects will be diminished or disappear entirely in the feedback condition. In other words, we expect the earlier mentioned factors (the *Threat* x *Location* interaction effect or possibly *Location* main effect) to be less significant compared to the comparison or pain control group.

Results

Self-report data and manipulation check

On average, participants described their general health to be "very good". None of the participants reported having a relevant ongoing medical or mental disorder. Thirty-two participants reported having experienced some form of pain during the previous 6 months (M 29.29 days, SD 34,09 days). This pain had an average intensity rating of 4.08 (SD 1.47), and an average disability rating of 2.78 (SD 2.17), both of which they indicated on a

10-point scale. One participant reported having taken a pain killer earlier that day. This was controlled for in the subsequent analyses and proved to be of some statistical importance. Therefore, we elected to remove this participant from the final data analysis. Sixteen participants reported feeling pain at the moment of testing, but the average rating of the intensity of the pain for these participants was low (M 0.97, SD 1.15) on a Likert scale where 0 indicated "no pain" and 10 indicated "worst possible pain". None of the participants had pain of a severity that warranted exclusion from further steps. Additionally, none of the participants reported pain at the location of any of the tactors/electrodes. There was no significant difference between groups for PCS scores (comparison: M 14.40, SD 7.84; pain control: M 13.38, SD 7.46; feedback: M 11.85, SD 5.91) (χ^2 = 1.30, p = .52). Similarly, the PHQ showed no significant group differences (comparison: M 6.55, SD 3.79; pain control: M 6.52, SD 4.58; feedback: M 6.85, SD 3.28) (χ^2 = 0.09, p = .96).

Over the course of the experiment, participants rated the electrocutaneous stimulus as moderately painful (M 5.09, SD 2.12). To determine whether the threat manipulation was successful, we performed an analysis of variance with the factors *Cue* (safe vs. threat) and *Group* (comparison vs. pain control vs. feedback) on fear and pain expectancy ratings. We found that, across groups, threat cues led to significantly larger fear ratings compared to safe cues (resp. M 5.87, SD 2.19 and M 0.72, SD 2.19) (χ^2 = 273.60, p < .001) (d = 3.02 [95% CI 2.50-3.56]). Similarly, pain expectancy was significantly higher following threat cues (M 6.33, SD 1.93) than after safe cues (M 0.86, SD 1.18) (χ^2 = 343.94, p < .001) (d = 3.41 [95% CI 2.84-3.98]). These results indicate that our threat manipulation was successful. There were neither main effects of nor interactions with *Group*,

suggesting that the threat manipulation had comparable effects in all conditions.

There was a significant group difference in attempted control, showing higher ratings for participants in the pain control group (M 6.34, SD 1.57) and feedback group (M 6.96, SD 2.08) compared to the comparison group (M 4.33, SD 2.65) ($\chi^2 = 16.63$, $p < .001$) ($d = 2.74$. [95% CI 2.23-3.24]) (see fig 3). Attempted control ratings did not differ between the pain control group and the feedback group ($\chi^2 = 0.85$, $p = .36$). None of the other self-report ratings were statistically different between groups. See table 2 for a complete overview.

Table 2

Experiment 1 – Self-report questionnaires per group (com = comparison group, pc = pain control group, fb = feedback group). Univariate ANOVA statistics are given.

	M com	SD com	M pc	SD pc	M fb	SD fb	χ^2	*p*
Pain experience	5.29	2.00	4.98	1.79	5.01	1.62	0.25	.62
Anxiety	3.63	2.65	3.83	2.38	3.67	2.05	<0.01	.96
Attention to painful stimuli	5.61	1.97	5.95	1.69	5.49	2.15	0.04	.85
Attention to tactile stimuli	6.10	1.72	6.11	1.63	6.94	1.45	2.75	.10
Concentration	6.38	1.40	5.93	1.64	6.28	1.22	0.04	.84
Effort	6.81	1.22	6.85	1.67	6.98	1.14	0.15	.70
Fatigue	5.51	1.60	5.01	2.39	5.43	1.90	0.01	.91
Fear (neutral cue)	0.74	1.04	0.81	1.13	0.61	0.83	0.18	.67
Fear (threat cue)	5.57	2.73	6.16	2.01	5.87	1.81	0.19	.67
Pain expectancy (neutral cue)	0.81	1.25	0.97	1.10	1.01	1.41	<0.01	.96
Pain expectancy (threat cue)	6.38	2.09	6.22	1.71	6.35	1.88	0.26	.61
Control attempts	4.33	2.65	6.34	1.57	6.96	2.08	16.63	<.001
PCS	14.40	7.84	13.38	7.46	11.85	5.91	1.30	.52
PHQ	6.55	3.79	6.52	4.58	6.85	3.28	0.09	.95

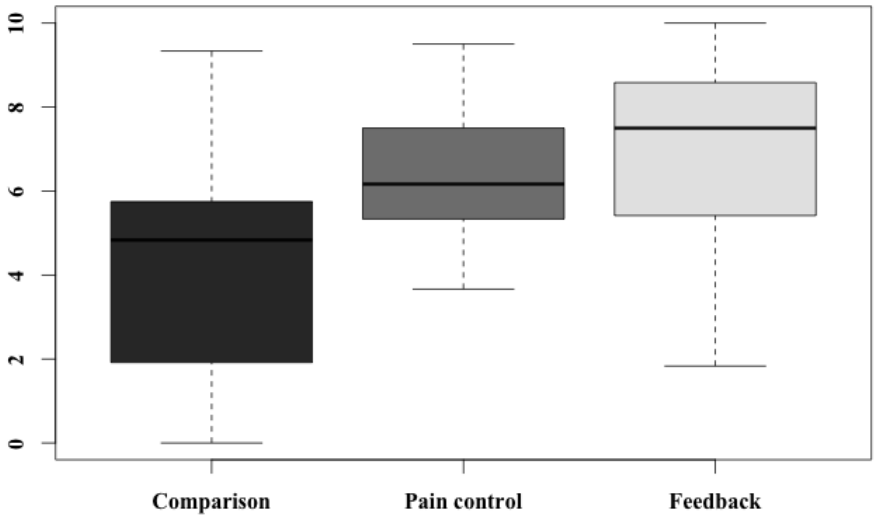


***Figure 3*: Boxplot illustration of pain control effort ratings per group, for Experiment 1.**

TCD data

The model that demonstrated the best fit included a random subject-based intercept, and one random effect (*Location*) (step 1: table 3). The final model, that is, the model that combined parsimony with an optimal goodness of fit, contained all fixed factors and two interactions (*Threat* x *Group* and *Threat* x *Location*) (step 2: table 4). The three-way interaction was not significant, nor did the *Group* x *Location* interaction reach significance.

Table 3

Experiment 1: Step 1 – Determine random structure.

Model	Test	Random	Log L	df	χ^2	p
1	Initial fit	1	-4491.2	13		
2	Random Location (1 vs 2)	1 + Location	-4464.5	15	53.24	< .001
3	Random Threat (1 vs 3)	1 + Threat	-4490.4	15	1.50	.47
4	Random Location and Threat (2 vs 4)	1 + Location + Threat	-4463.7	18	1.66	.65

Decision test model 2: add random Location; decision test model 3: retain current model; decision test model 4: retain current model

Inspection of the final ANOVA table (table 3) showed a significant main effect of *Location* (χ^2 = 10.91, p < .001), suggesting that changes at the threatened location generally were detected with greater accuracy. The *Location* and *Threat* variables showed a marginally significant interaction effect (χ^2 = 2.83, p = .09). We conducted additional contrast analyses to further explore this finding. The data indicated that the presentation of threat had a negative impact on change detection performance (χ^2 = 11.01, p < .001), unless change occurred at the threatened location. In this case, accuracy remained unaffected (χ^2 = 0.02, p = .88). This is suggestive of a threat-dependent spatial prioritization effect. This was predicted for the comparison group (hypothesis 1). However, as this interaction was not different across groups, we found no evidence for our hypotheses relating to either the pain control group of the feedback group.

Finally, the interaction between *Threat* and *Group* was found to be significant (χ^2 = 15.48, p < .001) (fig. 4). We further investigated this interaction by testing three additional contrasts. For each group, we compared accuracy on threat trials with accuracy on neutral trials, effectively examining the effect of threat in each condition. We found that threat worsened change detection significantly in the pain control group (χ^2 = 10.75, p < .01), whereas it did not have a significant effect in both the comparison group and the feedback group (resp. χ^2 = 2.83, p = .09 and χ^2 = 3.66, p = .06) – particularly considering the adjustment of the significance level due to multiple testing. Somewhat informative, a trend could be observed in the comparison and the feedback group where threat decreased and enhanced accuracy, respectively.

Table 4

Experiment 1: Step 3 – Evaluate final model.

Factor	$\widehat{ß}$	$SE(\widehat{ß})$	χ^2	p
Intercept	1.23	0.10	148.74	< .001
Threat	-0.05	0.03	1.99	.16
Location	0.20	0.07	10.91	< .001
Group (level 1 – pain control)	0.07	0.11	2.93	.23
Group (level 2 – feedback)	0.11	0.07		
Threat x *Location*	0.05	0.03	2.83	.09
Threat x *Group (level 1)*	-0.04	0.03	15.48	< .001
Threat x *Group (level 2)*	0.07	0.02		

Note: For variables with over two levels, regression coefficients are given for each level with the first level as reference. All χ^2-statistics and p-values are derived from a type III sum of squares ANOVA.

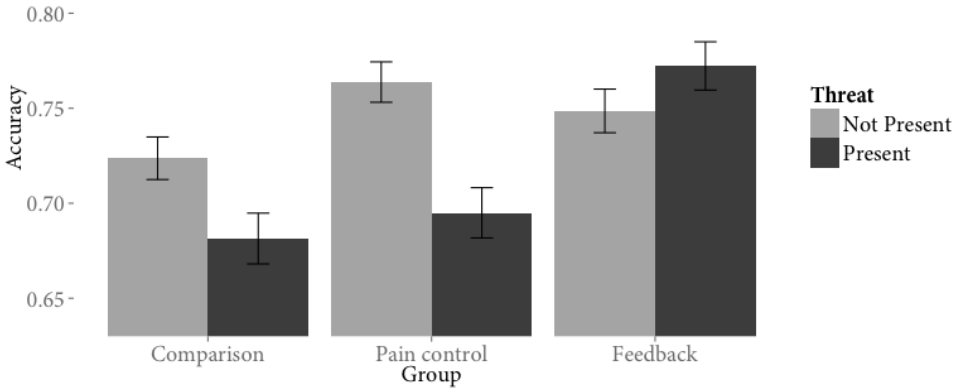


***Figure 4*: Illustration of interaction effect between Group and Threat variables in Experiment 1, including two-sided standard error bars.**

Interim discussion

In this study, we set out to test whether attentional prioritization effects that are induced by the anticipation of pain are strictly related to monitoring strategies. That is, we hypothesized that previously discovered spatial prioritization could be due to participants' continuous screening of their body – and in particular, the threatened body part – for the occurrence of the feared adverse sensation they attempted to avoid. In fact, this constant monitoring of bodily sensations was the only way in which participants could be sure whether or not they had passed the threatening trial unharmed – a mechanism that is reminiscent of theorized hypervigilance in chronic pain. (Crombez, Van Damme, & Eccleston, 2005) In addition, this experiment was intended to validate results obtained in earlier research efforts. (Durnez & Van Damme, 2015)

Results deviated from our expectations. We did not find a three-way interaction effect between the presence of threat, the involvement of the

pain location in tactile change, and the group variable. Our failure to do so effectively undermined the exact validation of all our hypotheses. The data, however, were not completely uninformative. The significant main effect of the *Location* variable indicated that attention was prioritized to the pain location over all group and all conditions. Such a contextual prioritization effect is not unthinkable, as the pain location played an important role in our experiment. However, we primarily expected such generalization to only occur in the pain control group (hypothesis 2), whereas we predicted spatial prioritization to be dependent on threat in the comparison group (hypothesis 1).

Interestingly, the interaction between *Threat* and *Location* approached the significance level – but across the full dataset. Contrast analyses tentatively indicated the existence of a spatial prioritization effect across all experimental groups. Still, as this interaction did not depend on the *Group* variable, we were largely unable to confirm our group-specific hypotheses. In sum, the data showed a rather general prioritization of the threatened location in every group, and suggested that this prioritization may be more pronounced when threat is immediately present, regardless of control attempts or feedback.

The absence of a three-way interaction did not bode well for our feedback group hypothesis (hypothesis 3) either. We expected spatial prioritization effects to disappear or be significantly decreased when feedback, confirming or refuting the success of control behavior, was presented prior to the TCD task. However, we only found a significant interaction between the presence of *Threat* and the *Group* variable, independent of the involvement of the pain location in the trial. This interaction suggested that anticipating pain impaired change detection in

both the comparison and the pain control group – although only significantly so in the latter condition. However, no such detrimental effect was found in the feedback group. Instead, these participants showed higher mean accuracy for threat trials. Taken together, these results tentatively suggest that the introduction of reassuring feedback may have countered the negative impact of threat.

It is evident that, despite some emerging parallels, the current results deviate from our earlier findings. (Durnez & Van Damme, 2015) Similar to our previous study, the current experiment indicated that changes on a threatened body location are generally detected more easily throughout the experiment. It is easy to imagine that the experimental setting was considered intimidating to certain participants, given the fact that they were confronted with an experiment revolving around painful stimulation – a less than trivial situation. Our findings thus imply that general context may play an important role in attention. Another provisional parallel with our previous TCD study lies in the interaction between the experimental *Threat* and *Location* variables, which are suggestive of a spatial prioritization effect. However, statistical testing shows that these results currently lack clarity. More importantly, in the present experiment, no three-way interaction of *Threat, Location* and *Group* was uncovered. Therefore, it was not possible to draw conclusions concerning either the effects of goal pursuit or the role of feedback monitoring on the spatial prioritization of a threatened location.

In order to address the inconsistencies between the present experiment and (Durnez & Van Damme, 2015), we conducted an attempt at replication. In the following experiment, we again included a comparison group and a pain control group. To simplify the data, we omitted the feedback group from Experiment 1. The hypotheses we set out were taken

from Experiment 1, save the third hypothesis, which pertained to the feedback group.

Experiment 2

Method

Participants

Forty-one Ghent University students participated in this study, in exchange for course credits. Twenty-seven of them were female. Five of the participants were left-handed. All of the participants had normal or corrected-to-normal vision and normal hearing. The study protocol was approved by the Ethics Committee of the Faculty of Psychology and Educational Sciences of Ghent University. Each participant signed a document confirming their informed consent. The experiment took approximately 1 hour and 15 minutes.

Apparatus and stimuli

Experiment 2 was a replication of Experiment 1, with the exception that no feedback condition was included. As such, we also intended to replicate findings from our previous study (Durnez & Van Damme, 2015).

Tactile Change Detection paradigm

The same paradigm was used as in Experiment 1 and in Durnez & Van Damme (2015).

Procedure

Procedurally, Experiment 1 and 2 were analogous, excepting the exclusion of the feedback group and feedback-related instructions.

Tactile Change Detection paradigm

The same paradigm was used as in Experiment 1, with the exception of the implementation of a feedback condition.

Statistical analyses

Four participants were excluded on the basis of their overall performance, as they fell outside of the interquartile range criterion (see fig. 5). Statistical analyses were performed as reported in Experiment 1 and in (Durnez & Van Damme, 2015). Hypotheses were identical to Experiment 1, with the exception of the now irrelevant feedback-related hypothesis.

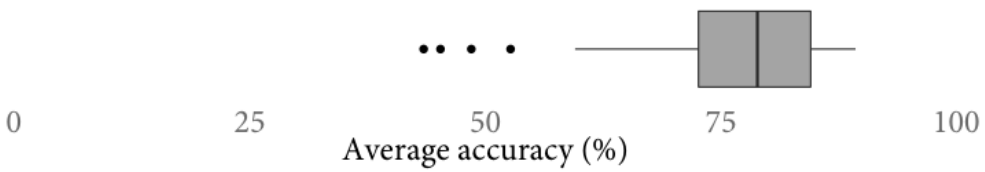


***Figure 5*: Boxplot showing distribution of mean response accuracy in Experiment 2, including outliers (black dots) according to interquartile range criterion.**

Results

Self-report data and manipulation check

On average, participants described their general health to be "very good". None of the participants reported having a relevant ongoing medical or mental disorder. Sixteen participants reported having experienced some form of pain during the previous 6 months (M 28.53 days, SD 26.62 days). This pain had an average intensity rating of 4.38 (SD 1.71), and an average disability rating of 2.50 (SD 2.42), both of which they indicated on a 10-point scale. None of the participants had taken any form of pain medication

prior to the experiment. Ten participants reported feeling pain at the moment of testing, but the average rating of the intensity of the pain for these participants was low (M 1.00, SD 1.10) on a Likert scale where 0 indicated "no pain" and 10 indicated "worst possible pain". None of the participants had pain of a severity that warranted exclusion from further steps. One of the participants reported pain close to the location of the tactors/electrodes at the right ankle. Removing this participant did not alter statistical results. There was no significant difference between groups for PCS scores (comparison: M 14.75, SD 8.09; pain control: M 15.00, SD 8.39) (χ^2 = 0.01, p = .92). Similarly, the PHQ showed no significant group differences (comparison: M 8.05, SD 4.20; pain control: M 7.05, SD 3.11) (χ^2 = 0.76, p = .38).

Over the course of the experiment, participants rated the electrocutaneous stimulus as moderately painful (M 5.92, SD 2.24). Analogous to Experiment 1, we verified the effectiveness of the threat manipulation by an analysis of variance with the factors *Cue* (safe vs. threat) and *Group* (comparison vs. pain control) on fear and pain expectancy ratings. Again, we found that threat cues led to significantly larger fear ratings compared to safe cues (resp. M 6.17, SD 2.15 and M 0.79, SD 1.44) (χ^2 = 175.75, p < .001) (d = 2.94 [95% CI 2.29-3.58]) in both groups. Similarly, pain expectancy was significantly higher following threat cues (M 6.43, SD 1.95) than after safe cues (M 0.81, SD 1.37) (χ^2 = 225.61, p < .001) (d = 3.33 [95% CI 2.64-4.02]). These results once again confirmed the successful implementation of our threat manipulation. There were neither main effects of nor interactions with *Group*, suggesting that the threat manipulation had comparable effects across conditions.

There was a significant group difference in attempted control, showing higher ratings for participants in the pain control group (M 6.79, SD 2.68) compared to the comparison group (M 5.35, SD 1.63) ($\chi^2 = 4.28$, $p = .04$) ($d = 3.32$ [95% CI 2.63-4.01]) (see fig. 6). None of the other self-report ratings were statistically different between groups.

Table 5

Experiment 2 – Self-report questionnaires per group (com = comparison group, pc = pain control group). Univariate ANOVA statistics are given.

	M com	SD com	M pc	SD pc	χ^2	*p*
Pain experience	5.88	1.97	5.95	1.93	0.01	.91
Anxiety	4.61	2.49	4.09	2.63	0.42	.52
Attention to painful stimuli	6.10	1.84	6.17	2.20	0.01	.91
Attention to tactile stimuli	6.55	1.65	6.48	1.95	0.02	.90
Concentration	6.34	1.31	6.56	1.21	0.32	.57
Effort	7.18	1.01	7.07	1.72	0.06	.80
Fatigue	6.36	1.96	5.79	2.07	0.80	.37
Fear (neutral cue)	0.47	0.94	1.10	1.77	1.98	.16
Fear (threat cue)	6.27	2.43	6.08	1.91	0.08	.77
Pain expectancy (neutral cue)	0.57	1.03	1.05	1.63	1.26	.26
Pain expectancy (threat cue)	6.22	2.22	6.63	1.69	0.46	.50
Control attempts	5.35	1.63	6.79	2.68	4.28	.04
PCS	14.75	8.09	15.00	8.39	0.01	.92
PHQ	8.05	4.20	7.05	3.11	0.76	.38

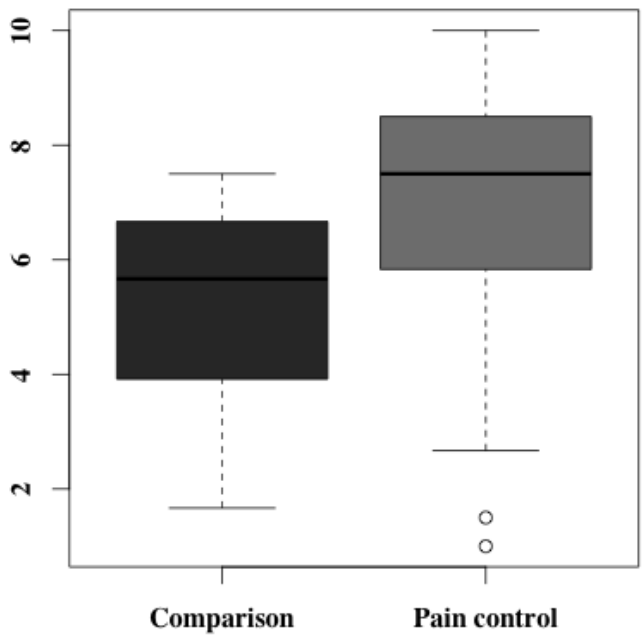


***Figure 6*: Boxplot illustration of pain control effort ratings per group, for Experiment 2.**

TCD data

The model that demonstrated the best fit included a random subject-based intercept, and one random effect (*Location*) (step 1: table 6). This is analogous to Experiment 1. The final model contained all fixed factors and one interaction (*Threat* x *Location*) (step 2). The three-way interaction was not significant, nor were any of the other interactions.

Inspection of the final ANOVA table (step 3: table 7) showed a significant main effect of *Location* (χ^2 = 12.27, p < .001), suggesting that changes at the threatened location are detected with greater accuracy. Similar to Experiment 1, we found that this effect interacted with *Threat* (χ^2 = 11.03, p < .001) (fig. 7). Further contrast analyses showed that the presence of threat generally diminished change detection accuracy when change did not occur on the threatened location (χ^2 = 16.61, p < .001). On the other hand, accuracy remained unaffected by threat when the threatened

location was involved in the pattern change ($\chi^2 = 0.09$, $p = .77$). This can be seen as an attentional advantage for the pain location in case of immediate threat. We hypothesized such a pattern to be present in data from the comparison condition (hypothesis 1). However, we also predicted that this spatial prioritization effect would be more generalized in the pain control group (hypothesis 2). Our results failed to support this assertion, showing no significant difference in attentional prioritization effects across groups.

Table 6

Experiment 2: Step 1 – Determine random structure.

Model	Test	Random	Log L	df	χ^2	p
1	Initial fit	1	-2888.8	9		
2	Random *Location* (1 vs 2)	1 + Location	-2869.2	11	39.23	< .001
3	Random *Threat* (1 vs 3)	1 + Threat	-2886.1	11	5.32	.07
4	Random *Location* and *Threat* (2 vs 4)	1 + Location + Threat	-4463.7	14	5.58	.13

Decision test model 2: add random *Location*; decision test model 3: retain current model; decision test model 4: retain current model

Table 7

Experiment 2: Step 3 – Evaluate final model.

Factor	$\widehat{ß}$	$SE(\widehat{ß})$	χ^2	p
Intercept	1.36	0.14	92.48	< .001
Threat	-0.01	0.04	0.09	.77
Location	0.28	0.08	12.27	< .001
Group	-0.06	0.11	0.32	.57
Threat x *Location*	0.14	0.04	11.03	< .001

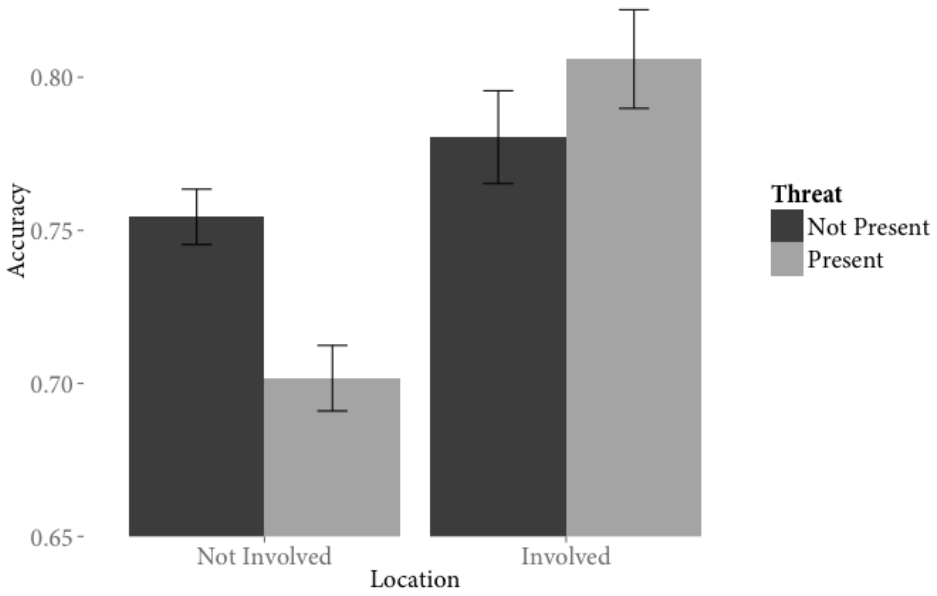


***Figure 5*: Illustration of interaction effect between Location and Threat variables in Experiment 2, including two-sided standard error bars.**

Discussion

The aim of Experiment 2 was, in essence, to gain more clarity with regard to previously found spatial prioritization effects, as well as their modulation by goal pursuit. To achieve this, we conducted a straightforward attempt to replicate earlier results (Durnez & Van Damme, 2015) using the same experimental task, threat manipulation and design. More explicitly, we again included a comparison group and a pain control group, but this time, omitted the feedback condition.

Regrettably, we failed to reproduce these former results. We did find evidence of a spatial prioritization effect caused by the anticipation of pain, as was demonstrated by the interaction between the presence of threat and the critical involvement of the threatened location in tactile change. To be precise, results showed that threat had an overall negative effect on change detection performance, except in trials where change occurred on the threatened location. In this case participants' performance did not deteriorate, but remained stable instead. This indicates that, in the event of threat, attention was directed more towards the pain location than to other body sites.

This spatial prioritization effect has already been demonstrated in past experiments. In our predecessor study (Durnez & Van Damme, 2015), a similar interaction between the anticipation of pain and attention to the threatened location was found. Unlike the presently discussed results, however, this interaction was significantly modulated by the goal pursuit manipulation. Still, prioritization of a location where pain is expected has been shown before, using temporal order judgment task. (Vanden Bulcke et al., 2013) In this paradigm, participants are asked to judge the order in which stimuli occurred. When the location of one of these stimuli is subject

to the threat of pain, it appears that stimuli on that location are processed more quickly, indicating attentional prioritization of that particular site. In sum, our results provide further evidence for the spatial redirection of attention to a body site that is threatened with pain. Somewhat surprisingly, we did not find additional support for the role of motivational factors (Van Damme, Legrain, Vogt, & Crombez, 2010), such as the active pursuit of the goal to control pain.

When comparing results for both Experiment 1 and Experiment 2 with those obtained in our previous TCD study (Durnez & Van Damme, 2015), we can remark on a handful of discrepancies. For one, it may be worthwhile to note that the actual instruction to avoid the painful stimulation was slightly different. In our foregoing study (Durnez & Van Damme, 2015), participants in both the pain control group and the feedback group were encouraged to press the spacebar to try and *avoid the occurrence of a more intense painful stimulus*, whereas the current experiment instructed them to try and *lower the chance of receiving a painful stimulus.* Still, we consider it unlikely that this difference had a significant impact on attentional processes, as participants reported even stronger pain control attempts in the current study (Experiment 1: pain control group M 6.34, SD 1.57, feedback group M 6.96, SD 2.08; Experiment 2: pain control group M 6.79, SD 2.68) than in the previous study (pain control group M = 4.33, SD = 2.51).

Closer inspection of these ratings, however, revealed an interesting particularity. In the current study, participants in the comparison condition – who did not receive any instructions pertaining to pain control – still reported substantial attempts to avoid the painful stimulus (Experiment 1: M 4.33, SD 2.65; Experiment 2: M 5.35, SD 1.63). This was different in the

previous study, where control attempt ratings were low (M 1.68, SD 2.51). It should be mentioned that self-reports are seldom fully accurate representations of underlying cognition. For instance, it has been discussed in literature that subjects tend to adapt their responses to what they believe are expectations of the experimenter. (Cook & Campbell, 1979) Still, it is possible that this observation – the reporting of significant attempts to control pain in a condition where this behavior was not promoted – is a contributing factor in our failure to uncover group differences in attentional allocation. A possible explanation of this finding may be found in the manner in which self-reports were included in the design of the experiment. Participants in all groups were requested to rate control attempts, along with a number of different parameters such as anxiety and concentration, after each experimental block. It is quite possible that the very posing of a question related to pain control may have prompted participants in the comparison condition to deduce that this was a possibility. In other words, it is conceivable that an inherent suggestiveness to this question may have given cause to the idea that pain control was a part of the experiment, despite the absence of explicit information to this effect. A possible recommendation for future studies, then, would be to omit this particular question from self-reports in comparison participants.

Finally, it is worthwhile noting that recent studies have further examined the spatial quality of attention prioritization effects. In a temporal order judgment study, a differentiation was made between trials where threat was presented on the same location as one of the experimental tactile stimuli, and trials where threat was presented elsewhere, but on the same limb. It was demonstrated that this prioritization was not limited to the exact locus of the pain, but rather generalized to the whole body part. (Vanden Bulcke et al., 2014) This was confirmed by Van Hulle and

colleagues (Van Hulle et al., 2015), who conducted a comparable TCD study, albeit with threat presented throughout the experiment rather than contingent on specific cues. In this study, a comparison was made between trials where change occurred on the threat location (e.g., the left hand), trials where changes occurred on the same limb as the threat location (e.g. the left upper arm), and trials where changes occurred elsewhere. Results again suggested that the presence of threat led to attentional prioritization of the threatened limb rather being limited to the exact location where pain was anticipated. Future studies that investigate topographical effects on attention to expected pain stand to benefit by taking this factor into consideration.

Conclusion

In this study, we first investigated whether feedback monitoring was at the basis of spatial prioritization of a location threatened with pain. We found tentative evidence that, overall, threat redirected attention to the locus of anticipated pain. However, we found no evidence that such prioritization effects were different when participants tried to control the pain, nor when they were immediately informed if these control attempts were successful, from the effects found in a comparison group. In addition, results suggested that threat negatively impacted participants' ability to detect somatosensory changes on the body when they were actively trying to avoid the painful stimulus. This negative impact was not found in either the comparison group or the feedback group. Instead, analyses seemingly indicated that the presentation of feedback reversed this threat-induced interference with somatosensory attention, although these results were not statistically conclusive.

In a follow-up experiment, we attempted to replicate previously uncovered divergent spatial prioritization effects related to the active pursuit of pain control goals. Results confirmed the existence of threat-induced spatial prioritization. Still, no differences were apparent between comparisons and pain controllers. Interestingly, self-report data pointed out that pain control attempts were also present in the former group – albeit to a lesser extent – regardless of the fact that these participants were never given instructions to do so. This suggest that future goal manipulations should be handled with care, so that attentional effects relating to goal pursuit are clearly distinguishable across experimental groups.

Disclosures

This study was supported by a research grant (BOF11/STA/004) by the Special Research Foundation of Ghent University (BOF) awarded to S. Van Damme. There are no conflicts of interest that may arise as a result of this research.

References

Allport, A. (1989). Visual Attention. In M. I. Posner (Ed.), *Foundation of Cognitive Science* (pp. 631–682). Hillsdale, NJ: Erlbaum.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using S4 classes. R package version 1.1-6. *R*. Retrieved from http://cran.r-project.org/package=lme4

Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation: Design and analysis issues*. Boston, MA: Houghton Mifflin Company.

Crombez, G., Van Damme, S., & Eccleston, C. (2005). Hypervigilance to pain: an experimental and clinical analysis. *Pain*, *116*(1-2), 4–7. doi:10.1016/j.pain.2005.03.035

De Ruddere, L., Goubert, L., Stevens, M., Williams, A. C. de C., & Crombez, G. (2013). Discounting pain in the absence of medical evidence is explained by negative evaluation of the patient. *Pain*, *154*(5), 669–76. doi:10.1016/j.pain.2012.12.018

Durnez, W., & Van Damme, S. (2015). Trying to fix a painful problem: The impact of pain control attempts on the attentional prioritization of a threatened body location. *The Journal of Pain*, *16*(2), 135–143.

Eccleston, C., & Crombez, G. (1999). Pain demands attention. *Psychological Bulletin*, *125*(3), 356–366.

Eccleston, C., & Crombez, G. (2007). Worry and chronic pain: a misdirected problem solving model. *Pain*, *132*(3), 233–236. doi:10.1016/j.pain.2007.09.014

Gallace, A., Tan, H. Z., & Spence, C. (2006). The failure to detect tactile change: a tactile analogue of visual change blindness. *Psychonomic Bulletin & Review*, *13*(2), 300–303.

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*(2), 65–70.

Kroenke, K., Spitzer, R. L., & Williams, J. B. W. (2002). The PHQ-15: validity of a new measure for evaluating the severity of somatic symptoms. *Psychosomatic Medicine*, *64*(2), 258–266.

Legrain, V., Van Damme, S., Eccleston, C., Davis, K. D., Seminowicz, D. A., & Crombez, G. (2009). A neurocognitive model of attention to pain: behavioral and neuroimaging evidence. *Pain*, *144*(3), 230–2. doi:10.1016/j.pain.2009.03.020

Lethem, J., Slade, P. D., Troup, J. D. G., & Bentley, G. (1983). Outline of a fear-avoidance model of exaggerated pain perception. *Behaviour Research and Therapy*, *21*(4), 401–408. doi:10.1016/0005-7967(83)90009-8

Sarter, M., Givens, B., & Bruno, J. P. (2001). The cognitive neuroscience of sustained attention: Where top-down meets bottom-up. *Brain Research Reviews*, *35*(2), 146–160. doi:10.1016/S0165-0173(01)00044-3

Stevens, M., Lammertyn, J., Verbruggen, F., & Vandierendonck, A. (2006). Tscope: A C library for programming cognitive experiments on the MS windows platform. *Behavior Research Methods*, *38*(2), 280–286. doi:10.3758/BF03192779

Sullivan, M. J. L., Bishop, S., & Pivik, J. (1995). The pain catastrophizing scale: Development and validation. *Psychological Assessment*, *7*, 524–535.

Van Damme, S., Crombez, G., Bijttebier, P., Goubert, L., & Van Houdenhove, B. (2002). A confirmatory factor analysis of the Pain Catastrophizing Scale: invariant factor

structure across clinical and non-clinical populations. *Pain*, *96*, 319–324. Retrieved from http://www.sciencedirect.com/science/article/pii/S0304395901004638

Van Damme, S., Legrain, V., Vogt, J., & Crombez, G. (2010). Keeping pain in mind: a motivational account of attention to pain. *Neuroscience and Biobehavioral Reviews*, *34*(2), 204–213. doi:10.1016/j.neubiorev.2009.01.005

Van Hulle, L., Durnez, W., Crombez, G., & Van Damme, S. (2015). Detection of tactile change on a bodily location where pain is expected. *Perceptual & Motor Skills: Perception*, *120*(1), 219–231.

Vanden Bulcke, C., Crombez, G., Spence, C., & Van Damme, S. (2014). Are the spatial features of bodily threat limited to the exact location where pain is expected ? *Acta Psychologica*, *153*, 113–119. doi:10.1016/j.actpsy.2014.09.014

Vanden Bulcke, C., Van Damme, S., Durnez, W., & Crombez, G. (2013). The anticipation of pain at a specific location of the body prioritizes tactile stimuli at that location. *Pain*, *154*(8), 1464–8. doi:10.1016/j.pain.2013.05.009

Verbruggen, F., & Aron, A. R. (2010). Theta burst stimulation dissociates attention and action updating in human inferior frontal cortex. *Proceedings of the National Academy of Sciences*, *107*(31), 13966–13971. doi:10.1073/pnas.1001957107/-/DCSupplemental.www.pnas.org/cgi/doi/10.1073/pnas.1001957107

Vlaeyen, J. W. S., & Linton, S. J. (2000). Fear-avoidance and its consequences in chronic musculoskeletal pain: A state of the art. *Pain*, *85*(3), 317–332. doi:10.1016/S0304-3959(99)00242-0

Weinstein, S. (1968). Intensive and extensive aspects of tactile sensitivity as a function of body part, sex and laterality. In D. R. Kenshalo (Ed.), *The Skin Senses* (pp. 195–200). IL: Thomas Springfield.

Getting out of a bad spot: Pain control pursuit modulates attentional prioritization of a stimuli at a threatened location

5

Abstract Recent studies have shown that the anticipation of pain is capable of redirecting attention towards tactile stimuli at the endangered body location. However, it is not clear whether this spatial bias is restricted to the somatosensory modality. Also, despite its prominence in contemporary theories, pain control motivation is not extensively discussed in the literature. We asked participants to judge the order of either two visual stimuli or two tactile stimuli, one on each hand. In half of the trials, one of the hands was threatened with pain. Half of our sample was encouraged to attempt to avoid the painful stimuli, whereas the other half executed a timed reaction task that was unrelated to pain. Results indicated that threat significantly shifted attention towards the pain location for *tactile* stimuli in the *pain control* group. These results suggest that a special role is played by the somatosensory modality when dealing with the threat of pain. They also highlight the importance of motivational factors.

Introduction

Imagine stepping on a thumbnail barefoot. Naturally, the accompanying experience of pain will draw immediate attention towards the hurt extremity, ensuring that the culprit can be extracted and the damage curtailed (Eccleston & Crombez, 1999). As such, this so-called bottom-up demand for attention serves the primal goal of self-preservation (Chapman et al., 2008). Now imagine having shattered a vase in a carpeted room. Despite your best efforts, you are not convinced that you have removed every last shard of glass. Dreading the idea of having your skin pierced, you are extra careful of your feet when walking there over the subsequent period of time. How you manage your attentional resources is now dictated, in part, by top-down concerns – the aim to exert control over a threatening setting in order to avoid physical harm (Van Damme et al., 2010).

Anticipating pain to be delivered to a particular body part has been proven to redirect attention towards the endangered site on multiple occasions, through use of different experimental paradigms (Durnez & Van Damme, 2015; Van Hulle et al. 2015; Vanden Bulcke et al., 2013, 2014). However, all of these studies investigated effects on attention for somatosensory events. One may wonder if this prioritization effect – the preferential allocation of attention towards stimuli located at the threatened body part – is confined to the somatosensory modality.

One perspective suggests that the top-down goal of pain control leads to prioritization of stimuli sharing features with the pain that is expected (Folk & Remington, 2008). This is referred to as the attentional set hypothesis, which states that input that is perceptually similar to a goal-relevant target stimulus is given priority during attentional selection

(Legrain et al., 2009). Following this view, all stimuli occurring at the pain location should conceivably benefit from a degree of attentional prioritization, as all of these stimuli share their spatial feature with pain. Hence, one would expect not only somatosensory, but also visual and auditory stimuli at the pain location to be prioritized. Revisiting the broken vase, we can imagine being on the lookout for the glimmer of light reflected from glass, the crackling sound of triturating glass splinters, or the sensation of sharp edges pressing up against your feet.

There is some support for this assertion. For instance, it has already been shown that the presence of pain on one hand leads to faster detection of visual stimuli close to that hand compared to visual targets close to the other hand (Van Damme et al., 2007). In addition, it has recently been argued that a multimodal neurophysiological network governs the detection of physical threat (Legrain et al., 2011; Mouraux et al., 2011). Such a network is believed to integrate input from different modalities into multimodal representations, enabling us to quickly detect threat-indicative changes on and immediately around our body, i.e., in our peripersonal space (De Paepe et al., 2014). Therefore, if threat detection is indeed governed by a multisensory integrative mechanism, one might expect these spatial prioritization effects to be present across different modalities.

And yet, despite the aforementioned arguments for a crossmodal viewpoint, there is evidence that hints at a special role for the somatosensory modality. A study by Van Damme and colleagues (Van Damme et al., 2009) found that the presentation of an image of physical threat (such as a knife) in front of one hand shortly before a pair of either tactile or auditory stimuli, resulted in quicker awareness of tactile stimuli at the 'threatened' hand than at the other hand. The same spatial prioritization was not found in the auditory modality, implying a modality-specific effect. However, as this

study only used visual representations of physical threat, effects of the actual anticipation of pain remain open to investigation.

When reviewing laboratory pain studies, it is apparent that in most cases experiments are predominantly designed with little or no room to act on the natural urge to avoid, escape or minimize the pain itself (Van Damme et al., 2010). Hence, most studies on attention to pain do not allow any conclusion about the presumed role of active pain control goals in attentional prioritization of a threatened location. While studies that specifically investigate the role of these pain control goals are currently scant, there is evidence that pursuing such goals codetermines how attentional resources are allocated (Notebaert et al., 2011). A case in point are the results of a recent tactile change detection experiment (Durnez & Van Damme, 2015). Here, half of all participants were encouraged to avoid administration of pain by means of a specified behavioral response. While all participants exhibited significant attentional prioritization of the location where the pain was anticipated, those attempting to avoid the pain showed a generalization of this effect, even to safe, pain-free trials. Still, the sensory scope of that study was – again – limited to somatosensory stimuli. It did not allow conclusions to be drawn with regard to the possible role and importance of the modality of pain.

Our aim in conducting the present study was to address two main research questions. First, we aimed to further clarify whether the attentional prioritization of a threatened location was indeed dependent on the modality of incoming stimuli (research question 1). Second, we aimed to explore the role of pain control motivation in these prioritization effects (research question 2). We designed a TOJ study featuring stimuli from two distinct sensory modalities. Participants were required to judge the order in which (unimodal) pairs of stimuli were presented to both hands. These

stimuli were visual in half of the trials and tactile in the other half. In both modalities, half of the trials were made threatening through a simple pain conditioning procedure. To induce a sense of threat, we used auditory cues (high frequency versus low frequency) that indicated either the possibility of receiving a painful stimulus on one of the hands (threat trial), or the guarantee that no such stimulus would follow (neutral trial). Additionally, we divided participants into a pain control group and a comparison group. The former group was actively encouraged to attempt to avoid pain by quickly pressing down on a foot pedal as soon as they heard the pain-indicative cue, whereas the latter group was simply asked to press the foot pedal as an additional timed reaction task. In reality, both groups were given an equal amount of painful stimuli. If prioritization of the threatened location is modality-independent, we should expect all stimuli applied to the pain location to benefit from comparable prioritization effects, relative to stimuli at the competing location. If, on the other hand, prioritization of a threatened location *is* dependent on the modality of the stimuli that are being processed, we particularly expected to see prioritization effects in somatosensory trials. Crucially, we predicted all prioritization effects to be significantly enhanced when participants actively pursued a pain control goal, as this goal-directed behavior was hypothesized to reinforce the attentional set.

Method

Participants

Forty-one students of Ghent University (20 male and 21 female; M_{age} 20.85 SD_{age} 4.08) participated in this study, either to earn required course

credits or in exchange for a small financial compensation. Nine of them were left-handed. All participants had normal or corrected-to-normal vision and normal hearing. Informed consent was obtained from all individual participants included in the study. The study protocol was approved by the Ethics Committee of the Faculty of Psychology and Educational Sciences of Ghent University. The experiment took approximately 1 hour and 10 minutes.

Apparatus and stimulus material

The experiment was conducted in a darkened, sound isolated room. Participants sat on a chair in front of a desk, with their hands palm-down on marked positions (see fig. 1). The tactile stimuli used in the experiment were vibrations, presented by means of two 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. Their functioning was controlled and amplified through a custom-built device. The tactors were attached directly to the skin in the center of the back of either hand using double-sided tape rings. The frequency of tactile stimulation was 200 Hz. The stimulus duration was set to 20 ms. Visual stimuli were presented by means of two green light-emitting diodes (LEDs). These LEDs were placed directly on top of the tactors. During the experiment, they were illuminated for a duration of 20 ms, causing them to be perceived by participants as briefly flashing green light. An additional, centrally placed red LED served as a fixation point throughout the different trials of the experiment. Painful stimuli were generated electrically through means of constant current stimulators (Digitimer DS5, 2000). They were delivered via 2 lubricated Fukuda standard Ag/AgCl electrodes (1 cm diameter), placed in close proximity to the tactors and the superficial branch

of the radial nerve. These sinusoid electrocutaneous stimuli had a frequency of 200 Hz and a duration of 200 ms. Amplitudes for both the tactile and electrocutaneous stimulation were set using adaptive procedures, as described in the procedure section. Auditory cues were administered using a set of headphones (Sennheiser HD 202 II). These cues consisted of either a high tone (1000 Hz) or a low tone (250 Hz). As part of the goal manipulation, participants were asked to press a foot pedal at specific moments in a portion of the trials. This foot pedal (Bespeco NT-13 sustain pedal) was attached to the floor at a distance that was comfortable for each participant, so that they could easily and quickly press down on it with their dominant foot. The pedal was connected to a Cedrus response box (RB-530 model) to optimize response time registration.

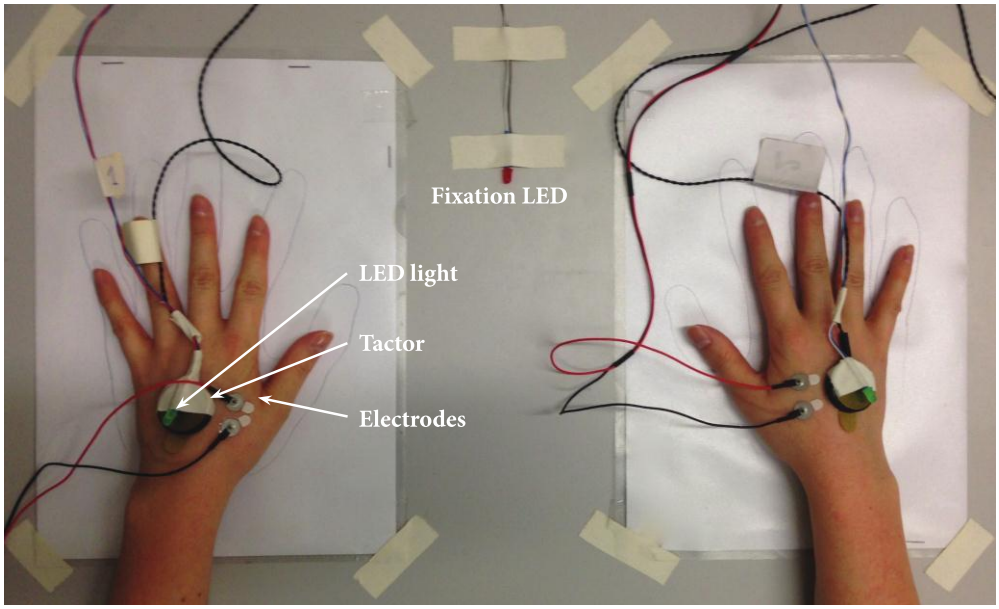


***Figure 1*: Illustration of placement of stimulus apparatus**

TOJ paradigm

The task was programmed in the programming language C using the Tscope 5 library package, an upgraded version of the original Tscope (Stevens et al., 2006). It ran on a laptop (Dell latitude E5520). Participants were instructed to keep their hands on the marked positions, and keep their gaze fixed on the fixation LED.

The experiment was divided into 2 visual and 2 somatosensory blocks (within-subjects variable of MODALITY) of 105 trials each, resulting in a total number of 420 trials. Both modalities had 1 block where the left hand was threatened by electrocutaneous stimulation, and 1 block where the right hand was threatened. Participants were informed by the experimenter prior to each block about the modality of the TOJ stimuli, as well as which hand was subject to possible painful stimulation. Additionally, they were given at least one electrocutaneous stimulus in the first ten trials, in order to re-establish contingency perception.

Each trial began with an illumination of the fixation LED for 1000 ms. Next, a 1000 ms auditory cue was presented, indicating whether or not an electrocutaneous stimulus could follow (within-subjects variable of THREAT). One tone frequency predicted the possible advent of such a stimulus (threat trial), while the other signaled that this would not be the case (neutral trial). The frequency of the threatening tone (high versus low) was counterbalanced. The tone was followed by an interval of 500 ms. Threat trials were marked by a chance of 1 out of 11 that there would be actual electrocutaneous stimulation. Participants were not informed of this proportion. In this case, no other stimuli were presented. In the remaining 10 threat trials, as well as in all neutral trials (10 in number), the auditory cue was instead followed by the administration of the TOJ stimuli. In visual blocks, the green LEDs on both hands were used. In somatosensory blocks

the stimulation was tactile, using the tactors on both hands. The stimuli were separated in time by 1 of 10 possible stimulus onset asynchronies (SOAs; -120, -60, -30, -15, -5, +5, +15, +30, +60 or +120 ms; see also Moseley, Gallace, & Spence, 2009; Vanden Bulcke et al., 2013) . In TOJ experiments, it is customary to code SOAs so that negative values indicate that the test stimulus was presented first. In this study, we regard stimuli at the threatened side as test stimuli, while stimuli at the opposite side are labeled as reference stimuli. In the remainder of the manuscript, negative SOAs thus refer to trials in which the stimulus at the pain location preceded the stimulus at the pain-irrelevant location. Every SOA occurred an equal number of times during the course of the experiment (5 times per condition, per block).

Participants were asked to report aloud on which hand they noticed stimulation first. In visual case, they thus indicated on which hand they first saw an illuminated LED. In the somatosensory case, they reported on which hand they felt the first tactile stimulus. When a painful stimulus replaced a TOJ trial, participants were asked to report the hand on which this stimulus was felt. They had up to 5000 ms to respond before their response was coded as a blank. All responses were coded by the experimenter using a keyboard. An overview of possible trial courses is given in figure 2.

Procedure

Participants were given a brief description of the experiment and asked to fill in an informed consent form. They then completed a custom-made pre-test questionnaire, which is described in the self-report measures section below. Tactors, electrodes and LEDs were then attached to the locations described above (fig. 1). Because it has been shown that somatosensory sensitivity can vary depending on which location of the body

is stimulated (Weinstein, 1968), we first obtained appropriate tactile stimulation amplitudes for each hand. Our goal was to ensure that participants perceived tactile stimulation to be of equal intensity on both hands hand, so as not to give an advantage to either side. Our custom-made adaptive procedure, based on the double random staircase procedure, was designed as follows.

Participants were first given a reference stimulus at 25 percent of the maximum capacity (and thus with a power of 0.10625 watts) on the left hand. One second after that, a tactile stimulus was administered to the right hand. The amplitude of this second stimulus was taken from one of two staircases, which were alternated randomly for an equal number of times in total. The starting value for the first staircase was a random integer between 20 and 24, while the starting value of the second staircase was a random integer between 26 and 30. This way we ensured that participants would encounter both a stimulus that was higher in actual amplitude, and one that was lower in amplitude. After each pair of stimuli, participants were asked whether they perceived the second stimulus as being "a lot stronger", "stronger", "equally strong", "weaker" or "a lot weaker". Their response determined the next value in the staircase (respectively 5 units down, 1 unit down, no change, 1 unit up or 5 units up). This procedure ran for 16 repetitions. The continuous coupling of reference stimuli and to-be-rated stimuli was intended to ensure participants could adequately compare both sensations, making sure there was no gradual shift in memory of how the stimulus was perceived. It also served to prevent divergent sensitization effects on both hands. An average was computed from all amplitude values which participants had reported to perceive as being equally strong (table 1). This value was used in the main experiment.

Table 1

Overview of intensity levels per subject for experimental stimuli.

Participants	Tactile intensity *left* (W)	Tactile intensity *right* (W)	Electrocutaneous intensity *left* (mA)	Electrocutaneous intensity *right* (mA)
1	1.06	0.68	2	2
2	1.06	1.53	0.5	0.5
3	1.06	1.24	0.8	0.5
4	1.06	0.68	1.4	1.6
5	1.06	0.82	1.3	1.7
6	1.06	1.74	0.8	0.7
7	1.06	1.43	1.5	0.5
8	1.06	0.98	2	2
9	1.06	0.68	1.4	2
10	1.06	0.68	2	3
11	1.06	0.82	1.5	0.8
12	1.06	1.15	2.5	2.8
13	1.06	0.38	1	0.6
14	1.06	0.75	0.7	1.6
15	1.06	0.90	1.4	2.5
16	1.06	0.98	1.4	1
17	1.06	0.68	0.7	0.7
18	1.06	0.90	1.3	1.5
19	1.06	1.06	3	3
20	1.06	0.98	1.2	1.2
21	1.06	0.98	3	3
22	1.06	1.33	1	2
23	1.06	1.15	2	1.9
24	1.06	1.06	3	2.4
25	1.06	0.98	2.2	1.6
26	1.06	0.757	2	2.5
27	1.06	1.85	2.8	3.5
28	1.06	0.98	2	1.7
29	1.06	0.90	2	2.1
30	1.06	1.15	2.4	3.1
31	1.06	1.15	1.9	1.8
32	1.06	1.15	1.4	1.2
33	1.06	0.98	1.9	1.4

34	1.06	0.75	1.6	1.3
35	1.06	1.24	2.4	2.6
36	1.06	0.98	2.4	2.6
37	1.06	2.59	2.8	3
38	1.06	1.43	2	1.4
39	1.06	1.53	2.7	3.3
40	1.06	1.33	2.7	2.5
41	1.06	1.53	1.7	1.6

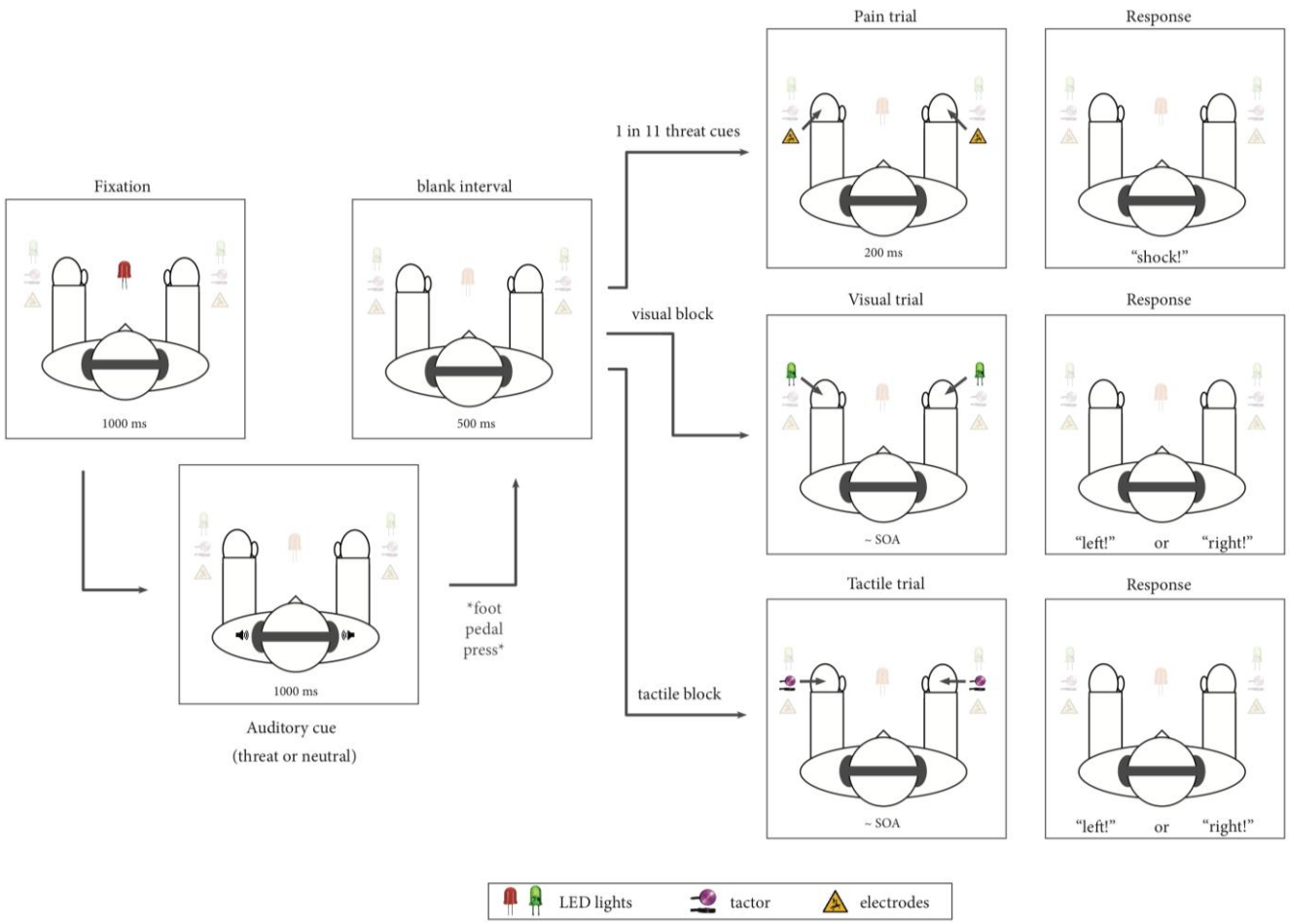


Figure 2: **Overview of possible trial courses. Fixation cross presentation is followed by an auditory cue. After a blank interval, one of three possibilities occurs. If the auditory cue indicated threat, there was a chance of 1 out of 11 that a painful stimulus would follow (pain trial). If not, then a TOJ trial was presented, in which two stimuli were presented, separated by an interstimulus interval (SOA). Dependent on the nature of the experimental block, these stimuli were either visual (visual trial) or tactile (tactile trial). Participants responded by stating the side they perceived first, or in case of a pain trial, by stating the word 'shock'.**

In the following preparatory phase, we determined amplitudes for the electrocutaneous stimulation. We did this for each hand separately, using a double random staircase procedure of 14 steps. In this procedure, starting values for both staircases were chosen randomly between 1 and 20 (respectively 0.1 and 2.0 mA). Participants were asked to rate each stimulus on an 11-point scale (0 = "no pain", 10 = "unbearable pain"). Reponses determined the next value in the corresponding staircase: a rating over 7 meant 1 unit down, a rating of 7 meant no change, and a rating under 7 meant 1 unit up. We took the average of all values to which participants gave a pain intensity rating of 7. This way we obtained pain intensities for both hands (table 1), which we then used in the further course of the experiment.

We proceeded by introducing the participants to the TOJ paradigm and explained the nature of the task. We presented them with 22 practice trials, divided into two sections. The first 11 trials were visual TOJ trials with one pain trial intermixed. The other 11 trials were somatosensory TOJ trials with one pain trial. In each modality, every SOA (10 in number) was presented once. We only proceeded when participants scored 100% accuracy on the trials with the largest SOA (+/- 120 ms).

Next, we informed participants about the meaning of the auditory cues. Dependent on which group they were placed in (between-subjects variable of GROUP), participants received additional instructions with regard to the use of the foot pedal. In the pain control group (20 participants), participants were instructed that they could significantly reduce the chance of receiving painful stimuli throughout the experiment, by pressing down on the pedal as soon as they heard the threat-signaling cue. In reality, the timing and

occurrence of painful stimuli were predetermined, ensuring that participants in the pain control group received an equal amount of pain stimuli as those in the comparison group. Differently put, our goal manipulation depended on subjective control, rather than actual control. In this comparison group (21 participants), participants were also instructed to press down on the pedal upon hearing the threat-signaling cue. These participants, however, were told this served to obtain additional measures of attention and concentration. No instructions related to pain control were given whatsoever. Four TOJ blocks were then presented, as described above. The presentation order was counterbalanced with regard to modality and threat location.

Self-report measures

Prior to the experiment, participants filled in a custom-made questionnaire, for measuring pre-existing pain-related conditions and episodes. All ratings (e.g., "To what degree were you unable to conduct daily activities during the past six months because of your pain?") were indicated on an 11-point Likert scale. In addition, each experimental block was followed by a quick questionnaire for gauging effort ("To what extent did you put effort into the task?"), concentration ("How well could you concentrate on the task?"), attention ("How much attention did you pay to the somatosensory/visual stimuli?"; "How much attention did you pay to the electrocutaneous stimuli?"), fear related to either cue ("To what extent did you fear that a high/low tone would be followed by an electrocutaneous stimulus?"), pain expectancy related to either cue ("To what extent did you expect an electrocutaneous stimulus to

follow the high/low tone?"), pain perception ("How painful did you find the electrocutaneous stimulus?"), anxiety ("How anxious did you feel during this block?") and fatigue ("How tiresome did you find this block?"). Participants in the pain control group were also asked to what degree they attempted to avoid the occurrence of painful stimuli. This question was not posed to the comparison group, so as not to evoke the illusion of underlying control mechanisms. All questions were answered on an appropriately anchored 11-point Likert scale. Answers were averaged over blocks per participants, prior to analysis. Finally, upon completion of all experimental blocks, participants completed the Pain Catastrophizing Scale (PCS; Sullivan, Bishop & Pivik, 1995).

Statistical analyses

Participants not reaching a mean accuracy of 80% on trials with the largest SOAs (+/- 120) were excluded from further analyses. We then analyzed performance on the TOJ-task by fitting these data to functions based on an independent channels model, as described in (Alcalá-Quintana & García-Pérez, 2013). Using these fits, we obtained PSS measures for each condition. A minimal accuracy of 80% on trials with the largest SOA was used as an exclusion criterion (see also De Paepe et al., 2014; Vanden Bulcke et al., 2013). Additionally, participants with PSS-values greater than the largest SOA were removed from the dataset (Spence et al., 2001). These were analyzed using a mixed-effects model with a Gaussian link function, as implemented in the R package 'lme4'. The statistical modeling procedure was as follows.

First, all relevant factors and their interactions were entered in the model as fixed factors. These included THREAT (threat trials vs. neutral trials), MODALITY (visual trials vs. somatosensory trials) and GROUP (pain control group versus comparison group). By default, a random effect was added introducing adjustments to the intercept conditional on each subject separately. Next, we determined whether the addition of random effects was necessary for any of the within-subject fixed factor. If a random effect increased the model's goodness of fit, we included it in the final model. In a second step, we sought out the most parsimonious model that fit the data by restricting the full model systematically, starting with higher-order terms. All model comparisons were made using likelihood-ratio tests. In a third and final step, we inspected the ANOVA table of the final model and tested specific hypotheses about possible main effects or interactions (see De Ruddere et al., 2013; Durnez & Van Damme, 2015; Verbruggen & Aron, 2010, for a similar approach). All contrast analyses were corrected for multiple testing according to the corrections of Holm-Bonferroni (Holm, 1979).

In order to visualize prioritization in different conditions, we then calculated baseline-adjusted PSS scores per participant. We did this by subtracting the PSS in neutral conditions from PSS values in corresponding threat conditions, i.e., respective MODALITY and GROUP variables. For example, to determine the strength of the attentional prioritization of the pain location in somatosensory trials for pain controllers, we calculated the value of the PSS in somatosensory threat trials for the pain control group *minus* the value of the PSS in somatosensory neutral trials for this group. This way, we

effectively applied a subject-based baseline correction to threat-induced prioritization measures.

As discussed in the introduction, we investigated whether the presence and strength of possible threat-induced attentional prioritization of the pain site was dependent on the modality of the experimental stimuli (research question 1). If so, this scenario should translate into a significant THREAT x MODALITY interaction effect. If, on the other hand, prioritization of the pain location is modality-independent, we should only find a main effect of THREAT and no such interaction. In addition, we expected that actively pursuing pain control would enhance prioritization effects (research question 2). In statistics, we would then expect the GROUP variable to significantly modulate either the interaction (resulting in the three-way THREAT x MODALITY x GROUP interaction effect), or to simply enhance the threat-induced location prioritization (resulting in a THREAT x GROUP interaction), respectively. Finally, when interpreting effects on the PSS measurement, it is important to keep in mind that – as a result of our coding scheme – positive values indicate stimuli stemming from the threatened location should be presented *after* stimuli originating on the opposing hand for both to be perceived as simultaneously occurring. Negative values indicate the opposite. Correspondingly, increased PSS measurements indicate an attentional shift towards the pain location, whereas lesser values suggest attention is being drawn away from it.

Results

Self-report data and manipulation check

Participants assessed their own health as 'very good', on average. Two participants reported suffering from scoliosis, but did not report any significant pain at the time of testing. Two participants had been previously diagnosed with ADHD. These data were kept in the dataset, as they met the accuracy criterion described in the next section. Twenty-seven participants had experienced some form of pain during the preceding 6 months (M = 31.52 days, SD = 40.93 days). This pain had an average intensity rating of 3.92 (SD = 1.32) and an average disability rating of 2.43 (SD = 2.19). Three of them reported to have suffered from their pain complaint for 90 days or more (intensity rating: M = 4, SD = 1; disability rating = 2, SD = 1.73). We found no evidence that these participants significantly distorted the data. One participant reported having taken an analgesic earlier during the day. However, this participant underwent the same pain calibration procedure, and reported perceiving the electrocutaneous stimulation as painful over the course of the experiment. Twelve participants reported feeling pain at the moment of testing, on a Likert-scale ranging from "no pain" to "worst possible pain". Their average pain intensity ratings were low (M = 2.5, SD = 1.44), apart from one participant who awarded his current pain intensity a rating of 7. Coincidentally, this participant did not meet the performance criterion described below, prompting his removal from the dataset.

PCS scores were not significantly different between groups (comparison group: M = 12.9, SD = 8.38; pain control group: M = 12.24, SD = 9.72) (t_{35} = 0.22, p = .82). Over the course of the

experiment, the electrocutaneous stimulus was rated moderately painful in both groups (comparison: M = 3.80, SD = 2.03; pain control: M = 4.15, SD = 1.90) with no significant difference between them (t_{35} = -0.53, p = .60). To verify the effect of the threat manipulation, we applied an ANOVA with the factors CUE (threatening versus neutral) and GROUP (comparison versus pain control) on fear and pain expectancy ratings. With regard to fear ratings, we found main effects of both the CUE and GROUP variable (resp. χ^2 = 174.92, p < .001 and χ^2 = 4.15, p < .05). These indicated that participants felt more fearful upon hearing the threat cue (M = 4.89, SD = 1.96) compared to the neutral cue (M = 0.5, SD = 0.72) (d = 2.97, 95% CI = 2.28-3.65), indicating that the threat manipulation was successful. Interestingly, we found that fear ratings were overall higher in the pain control group (M = 3.06, SD = 3.00) than in the comparison group (M = 2.38, SD = 2.30) (d = 0.26, 95% CI = -0.26-0.73). The interaction was marginally significant (χ^2 = 3.21, p = .07), showing a slightly stronger effect of the threat cue in the pain control group. A comparable pattern was found with respect to pain expectancy ratings, again showing significant main effects of CUE (χ^2 = 111.48, p < .001) and GROUP (χ^2 = 4.81, p < .05) and a marginal interaction effect (χ^2 = 3.67, p = .06). Similarly, hearing the threatening cue led to more pain expectancy (M = 4.30, SD = 2.32) compared to hearing the neutral cue (M = 0.31, SD = 0.62) (d = 2.35, 95% CI = 1.74-2.97). Additionally, pain expectancy ratings were significantly higher for participants in the pain control group (M = 2.76, SD = 3.10) than for those in the comparison group (M = 1.93, SD = 2.10) (d = 0.32, 95% CI = 0.15-0.79). Participants in the pain control group

reported paying more attention to the electrocutaneous stimulus (M = 5.62, SD = 2.28) than those in the comparison condition (M = 3.58, SD = 1.85) (t_{35} = -3.01, p < .01, d = 2.46, 95% CI = 1.83-3.08). We found no difference among groups for self-reported attention to visual or tactile stimuli (comparison group: M = 7.79, SD = 1.54; pain control group: M = 7.78, SD = 1.54) (t_{35} = 0.02, p = .99), effort (comparison group: M = 7.68, SD = 1.13; pain control group: M = 7.75, SD = 1.08) (t_{35} = -0.21, p = .84), concentration (comparison group: M = 7.08, SD = 1.25; pain control group: M = 7.46, SD = 1.01) (t_{35} = -0.97, p = .34), or fatigue (comparison group: M = 5.46, SD = 1.73; pain control group: M = 4.43, SD = 1.81) (t_{35} = 1.77, p = .08). Finally, participants in the pain control group reported substantial attempts to control the painful stimulus (M = 7.54, SD = 1.57).

TOJ data

We excluded 4 participants (1 in the comparison group, 3 in the pain control group) whose accuracy on trials with the largest SOA (± 120 ms) fell under the cut-off level of 80 percent. None of the remaining participants showed PSS values outside of the SOA range, prompting no further exclusions.

The best fitting statistical model included all fixed factors and interactions, and a random subject-based intercept. No other random effects were necessary (see table 2). The significance of the three-way interaction (χ^2 = 4.00, p < .05) kept us from further restricting the model. In this model, we also found a significant main effect of the THREAT variable (χ^2 = 8.43, p < .01), indicating higher PSS values when threat was presented. Larger, positive PSS values denote that input from the pain location is processed relatively quicker than input

from the neutral location, indicating that the threat of pain caused attention to shift towards the threatened hand. The main effect of GROUP, as well as the interaction between GROUP and THREAT, was marginally significant (resp. χ^2 = 3.28, p = .07 and χ^2 = 3.02, p = .08) (see table 3).

Table 2

Step 1 – Determine random structure.

Model	Test	Random	Log L	df	χ^2	p
1	Initial fit	1	-686.82 -671.22	10		
2	Random THREAT (1 vs 2)	1 + THREAT	-686.53 -670.20	12	.57 2.06	.75 .36
3	Random MODALITY (1 vs 3)	1 + MODALITY	-686.74 -671.14	12	.16 .17	.92 .91

Full data: Decision test model 2: retain current model; decision test model 3: retain current model

Trimmed data: *analogous*

Upon closer inspection of the PSS table, we noticed one value standing out remarkably. This value (PSS = -111.73) was identified as an outlier, both by the interquartile range criterion as by a Grubbs test ($p < .001$). While data restriction in TOJ experiments typically ends after the application of the aforementioned exclusion criteria, and in spite of having obtained a significant three-way interaction, we chose to rerun the analyses barring this outlier value. Model selection was

not affected by this data trimming (see table 2: values in italics). The main effect of THREAT remained highly significant (χ^2 = 12.20, p < .001), whereas the three-way interaction rose slightly above the level of significance (χ^2 = 3.14, p = .07) (see table 3: values in italics). The distribution of the remaining PSS values is shown per condition in figure 3.

Table 3

Step 3 – Evaluate final model.

Factor	$\widehat{ß}$	$SE(\widehat{ß})$	χ^2	p
Intercept	5.27	2.13	6.14	.01
	6.01	*1.98*	*9.22*	*<.01*
THREAT	6.17	2.13	8.43	<.01
	6.92	*1.98*	*12.20*	*<.001*
MODALITY	1.00	2.13	0.33	.64
	1.74	*1.98*	*.77*	*.37*
GROUP	3.85	2.13	3.28	.07
	3.11	*1.98*	*2.46*	*.11*
THREAT x MODALITY	2.61	2.13	1.51	.22
	3.36	*1.98*	*2.87*	*.09*
THREAT x GROUP	3.69	2.13	3.02	.08
	2.95	*1.98*	*2.22*	*.13*
MODALITY x GROUP	2.08	2.13	1.00	.33
	1.34	*1.98*	*0.46*	*.50*
THREAT x MODALITY x GROUP	4.25	2.13	4.00	<.05
	3.51	*1.98*	*3.14*	*.07*

In order to disentangle the three-way interaction, we examined the data for both groups separately, using the same statistical methodology and the trimmed dataset. In the comparison group, we found neither a significant interaction between MODALITY and THREAT nor main effects for these variables, even upon removing the interaction from the model. In the pain control group, on the other hand, both the interaction effect of MODALITY and THREAT and the main effect of THREAT reached significance (resp. $\chi^2 = 5.15$, $p = .02$ and $\chi^2 = 10.64$, $p < .01$) (see table 4). The latter showed higher PSS values for threat trials than for neutral trials – indicating an attentional shift towards the threatened location – while the former shows this effect to be dependent on the MODALITY of the trial. More explicitly, contrast analyses show that THREAT significantly enlarged PSS values in tactile TOJ trials ($\chi^2 = 15.29$, $p = < .001$), but not visual TOJ trials ($\chi^2 = 0.49$, $p = .48$). In sum, we found evidence that attention shifted towards the threatened location in the pain control group, but only when somatosensory information was presented (fig. 4).

Table 4

Step 3 – Evaluate final model (pain control group).

Factor	$\widehat{ß}$	$SE(\widehat{ß})$	χ^2	p
Intercept	9.12	3.64	6.28	.01
THREAT	9.87	3.03	10.64	<.01
MODALITY	3.08	3.03	1.03	.31
THREAT x MODALITY	6.86	2.13	5.15	.02

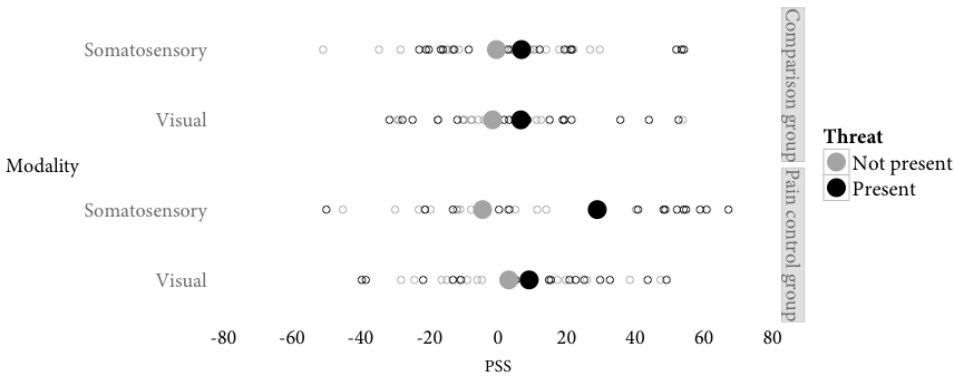


***Figure 3*: We compared individual Point of Subjective Simultaneity measurements across conditions. For every participant in both the comparison group and the pain control group, we calculated the Point of Subjective Simultaneity (PSS) in both threat trials and neutral trials (smaller, hollow circles), across block modality. Mean PSS values are indicated as well (larger, solid circles). More positive values mean that information presented on the threatened location is processed quicker relative to information on the other location. The illustrated pattern shows that threat prioritizes somatosensory information, particularly in the pain control group.**

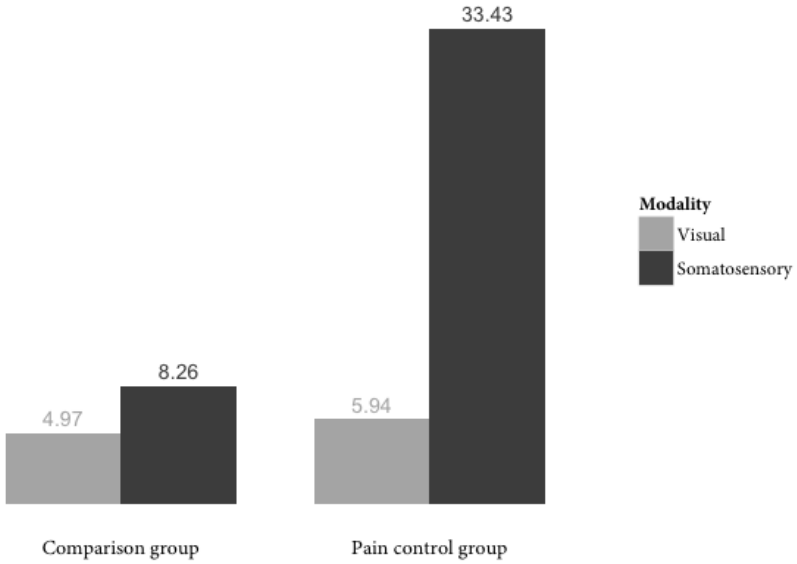


***Figure 4*: Baseline-corrected PSS values indicate prioritization of the pain location per condition. We applied an individual baseline correction to our calculations of the Point of Subjective Simultaneity (PSS) by subtracting values resulting from neutral trials from values resulting from threat trials in each corresponding condition. Positive values indicate a shift towards the threatened location, whereas negative values represent the opposite. Visualization of the resulting condition-wise averages shows that attentional prioritization of the threatened is strongest for tactile trials in the pain control group.**

Discussion

In conducting this study, we set out to tackle two main research questions. First, we investigated attentional prioritization of a body location threatened with pain. We specifically compared effects for somatosensory stimulation with effects for visual stimulation. The attentional set hypothesis proposes that stimuli sharing features with a motivationally salient target stimulus will be selected by attention

more readily (Folk & Remington, 2008). As such, it suggests that the prioritization of a body location threatened with pain should be observable for stimuli from different modalities, provided that these stimuli and the anticipated pain have a common location. Contrary to this idea, our findings presented a more nuanced picture – and one that was heavily related to our second research question. PSS values indicated that, in threat trials, stimulation administered to the threatened hand was processed more quickly than when it was administered to the neutral hand. However, while this appeared to be the case for tactile and visual trials in both the comparison group and the pain control group, the outcome only reached statistical significance for *tactile* trials in the *pain control* group (see fig. 3). In this group, analyses showed stronger attentional prioritization of the threatened location in tactile trials compared to visual trials. In contrasts, the comparison group revealed no prioritization effects.

Tactile trials in the pain control group were certainly candidate for particularly robust spatial prioritization effects. On the one hand, it has already been shown that the fearful anticipation of pain can redirect attention towards the threatened location (Durnez & Van Damme, 2015; Van Hulle et al., 2015; Vanden Bulcke et al., 2013, 2014). On the other hand, we hypothesized that emphasizing pain control as a focal goal would feasibly increase the motivational salience of information that shared features with pain, enhancing its demand for attention (Folk & Remington, 2008). Taking into account the fact that we found evidence for a significant attentional shift in but this one specific condition – tactile TOJ trials during which participants attempted to control the threat of pain – the present study provides

more evidence for the importance of motivation in the attentional selection of pain-related information (Van Damme et al., 2010).

In addition to underlining the value of a motivational perspective on attention to pain, our findings also imply that the somatosensory modality is of particular importance in attention to pain. Rather than uncovering modality-independent prioritization of a threatened location – and seemingly in disagreement with the attentional set hypothesis (Legrain et al., 2009) – we could only establish such attentional redirection towards somatosensory stimuli. The results are somewhat comparable to those reported by Van Damme and colleagues (Van Damme et al., 2009). In their study, physically threatening visual cues were demonstrated to elicit prioritization of tactile stimuli at a proximate location. Presenting physical threat had no such effect on the processing of auditory stimuli, implying a modality-specific effect.

Still, this does not necessarily mean that the attentional set hypothesis is unfounded. Rather, these findings suggest that – when drawing hypotheses concerning stimuli that share multiple features with a painful target – a more complex dynamic is at play. From a simple, mathematical viewpoint, one would indeed expect prioritization effects for both the visual and tactile trials. In the former case, the visual stimulus on the threatened hand shares one feature with the anticipated pain (its location) whereas the stimulus on the opposing hand shares none. In the latter, the tactile stimulus on the threatened hand shares two features with the anticipated pain (its location and modality) whereas the stimulus on the opposing hand shares only one (its modality). Given that both trial types lend a comparable net advantage to the stimulus on the pain location (one

feature), one might expect them to produce similar prioritization effects. However, our findings suggest that such a strict, cumulative interpretation of the attentional set hypothesis may be misguided. Rather, they hint towards an interplay between stimulus qualities that surpasses simple addition, perhaps leading to the modality-specific results exhibited in the current study. Considering that our knowledge of such attentional set dynamics is particularly constrained to studies of visual attention (e.g. Becker et al., 2013; Folk & Remington, 2008; Harris et al., 2013), and the fact that none of them seem to offer a clear-cut explanation of our findings, it may be worthwhile to further investigate differential effects of attention on stimuli sharing a number of features with a motivationally salient target. To this purpose, follow-up crossmodal experiments may be a particularly interesting future avenue.

Surprisingly, we failed to find any significant threat effects in the comparison group, in either modality. This contradicts previous research findings. The prioritization of tactile stimulation at a threatened location, in particular, has been found in several TOJ studies (Vanden Bulcke et al., 2013, 2014). Similarly, it has been shown that pain may prioritize visual information at its location (Van Damme et al., 2007). One explanation for this inconsistency with current literature could be sought in a possible lack of power in the present study. However, given that the previously reported PSS values in threat trials (e.g., 25.37 ms, 20 ms, respectively, in Vanden Bulcke et al., 2014, 2013) exceed those in our own study (none greater than 10 ms in the comparison condition), it is unlikely that this is the only factor at play. It is also conceivable that data-analytical differences are responsible for these divergent findings. Whereas previous TOJ

studies investigating threat effects typically used Gaussian fits to calculate perceptual measures (e.g., the PSS), the present study fitted functions based on independent-channels models (Alcalá-Quintana & García-Pérez, 2013; García-Pérez and Alcalá-Quintana, 2012). This strategy typically leads to better fits compared to the application of arbitrary psychometric functions. Moreover, its design can account for irregularities and asymmetries in the data of individual fits, and incorporates error parameters – such as those caused by mistaken button presses. To investigate whether such data-analytical differences were at the source of our lack of basal threat effects, particularly in the comparison condition, we also fit the data with Gaussian functions[2]. Still, we were unable to detect the hypothesized threat effects.

Another difference with earlier TOJ studies can be sought in methodology, as our study boasted a lower number of observations per SOA. Establishing modality as a within-subject variable necessarily halved the number of observations per cell. Were we to counter this by doubling the experiment's duration, it would severely strain participants' attention span. In turn, dividing the experiment into multiple sessions would make it difficult to keep experimental control over all relevant parameters (such as pain intensity, tactor placement, etc.). Sacrificing observations per SOA means that the estimates of the data-points used to fit the psychometric functions were coarser, which in turn implies a loss of precision. In reducing the number of between-subject variables, however, we also attempted to create a more robust design and increase the experiment's sensitivity for effects. Moreover,

[2] These analyses are not included in the present chapter, but are available with the authors.

we were not necessarily interested in pinpointing the perceptually exact value of the PSS, but rather wished to compare the effect of a number of experimental manipulations on these measurements. Still, it is possible that this design choice was – paradoxically so – at the expense of our experiment's measurement accuracy, hindering us in uncovering threat – and other – effects.

When interpreting the current results, it is noteworthy that participants in the pain control group never had any actual influence over the timing or quantity of the painful stimuli. This does not mean that our goal manipulation was without effect. Such manner of goal induction has been implemented successfully in a number of previous studies (Durnez & Van Damme, 2015; Notebaert et al., 2011). In addition, an obvious argument in favor of the efficacy of our goal induction strategy can be found in the divergent results between the comparison group and the pain control group. Indeed, only the pain control group showed any evidence of significant prioritization. Interestingly, we also found increased fear and pain expectancy ratings for threat trials in the pain control group, as compared to the comparison group – even though pain perception itself was stable across groups. It is possible that these threat-dependent differences contributed to the diverging pattern of attention biases we uncovered in the present experiment. However, fear and pain expectancy ratings were mainly included as a threat manipulation check, and not to test additional hypotheses.

Given the special role taken up by the somatosensory modality in the present findings, one might wonder whether somatosensory input would be prioritized over directly competing input from other modalities, regardless of their location of origin. This would be in line

with the attentional set perspective, as somatosensory stimuli are more perceptually similar to a motivationally salient pain target than either visual or auditory information. As such, they lay a stronger claim to the available attentional resources. Hinting towards the legitimacy of such a claim is a study by Jia and colleagues (2013), who showed that threatening imagery of near-body physical harm prioritized somatosensory stimuli over auditory stimuli. However, effects on attention following the anticipation of real pain remain open to investigation.

In conclusion, the present study suggests that the manifestation of physical threat inclines us to pay close attention to the occurrence of somatosensory stimuli at the locus of threat – particularly when we are trying our best to distance ourselves from the consequences feared. Reprising the broken vase analogy, as we concern ourselves with the integrity of our skin, it is not the sight of broken shards or the sound of crackling glass that seems to matter most, but the alarming sensation of irregularities beneath our soles.

Disclosures

This study was supported by a research grant (BOF11/STA/004) by the Special Research Foundation of Ghent University (BOF) awarded to S. Van Damme. There are no conflicts of interest that may arise as a result of this research.

References

Alcalá-Quintana, R., & García-Pérez, M. A. (2013). Fitting model-based psychometric functions to simultaneity and temporal-order judgment data: MATLAB and R routines. *Behavior Research Methods*, *45*, 972–98. doi:10.3758/s13428-013-0325-2

Becker, S. I., Folk, C. L., & Remington, R. W. (2013). Attentional capture does not depend on feature similarity, but on target-nontarget relations. *Psychological science*, *24*(5), 634–47. doi:10.1177/0956797612458528

Chapman, C. R., Tuckett, R. P., & Song, C. W. (2008). Pain and Stress in a Systems Perspective: Reciprocal Neural, Endocrine, and Immune Interactions. *Journal of Pain*, *9*(2), 122–145. doi:10.1016/j.jpain.2007.09.006

De Paepe, A. L., Crombez, G., Spence, C., & Legrain, V. (2014). Mapping nociceptive stimuli in a peripersonal frame of reference: evidence from a temporal order judgment task. *Neuropsychologia*, *56*, 219–28. doi:10.1016/j.neuropsychologia.2014.01.016

De Ruddere, L., Goubert, L., Stevens, M., Williams, A. C. de C., & Crombez, G. (2013). Discounting pain in the absence of medical evidence is explained by negative evaluation of the patient. *Pain*, *154*(5), 669–76. doi:10.1016/j.pain.2012.12.018

Durnez, W., & Van Damme, S. (2015). Trying to Fix a Painful Problem: The Impact of Pain Control Attempts on the Attentional Prioritization of a Threatened Body Location. *The Journal of Pain*, *16*(2), 135–143.

Eccleston, C., & Crombez, G. (1999). Pain demands attention. *Psychological Bulletin*, *125*(3), 356–366.

Folk, C. L., & Remington, R. W. (2008). Bottom-up priming of top-down attentional control settings. *Visual Cognition*, *16*(2-3), 215–231. doi:10.1080/13506280701458804

García-Pérez, M. a, & Alcalá-Quintana, R. (2012). On the discrepant results in synchrony judgment and temporal-order judgment tasks: a quantitative model. *Psychonomic bulletin & review*, *19*(5), 820–46. doi:10.3758/s13423-012-0278-y

Harris, A., Remington, R., & Becker, S. (2013). Feature specificity in attentional capture by size and color. *Journal of vision*, *13*, 1–15. doi:10.1167/13.3.12.doi

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*(2), 65–70. http://www.jstor.org/stable/10.2307/4615733

Jia, L., Shi, Z., Zang, X., & Müller, H. J. (2013). Concurrent emotional pictures modulate temporal order judgments of spatially separated audio-tactile stimuli. *Brain Research*, *1537*, 156–163. doi:10.1016/j.brainres.2013.09.008

Legrain, V., Damme, S. Van, Eccleston, C., Davis, K. D., Seminowicz, D. a, & Crombez, G. (2009). A neurocognitive model of attention to pain: behavioral and neuroimaging evidence. *Pain*, *144*(3), 230–2. doi:10.1016/j.pain.2009.03.020

Legrain, V., Iannetti, G. D., Plaghki, L., & Mouraux, A. (2011). The pain matrix reloaded: A salience detection system for the body. *Progress in Neurobiology*, *93*(1), 111–124. doi:10.1016/j.pneurobio.2010.10.005

Moseley, G. L., Gallace, A., & Spence, C. (2009). Space-based, but not arm-based, shift in tactile processing in complex regional pain syndrome and its relationship to cooling of the affected limb. *Brain : a journal of neurology*, *132*(Pt 11), 3142–51. doi:10.1093/brain/awp224

Mouraux, A., Diukova, A., Lee, M. C., Wise, R. G., & Iannetti, G. D. (2011). A multisensory investigation of the functional significance of the "pain matrix." *NeuroImage*, *54*(3), 2237–2249. doi:10.1016/j.neuroimage.2010.09.084

Notebaert, L., Crombez, G., Vogt, J., De Houwer, J., Van Damme, S., & Theeuwes, J. (2011). Attempts to control pain prioritize attention towards signals of pain: an experimental study. *Pain*, *152*(5), 1068–1073. doi:10.1016/j.pain.2011.01.020

Spence, C., Shore, D. I., & Klein, R. M. (2001). Multisensory prior entry. *Journal of Experimental Psychology: General*, *130*(4), 799–832.

Stevens, M., Lammertyn, J., Verbruggen, F., & Vandierendonck, A. (2006). Tscope: A C library for programming cognitive experiments on the MS windows platform. *Behavior research methods*, *38*(2), 280–286. doi:10.3758/BF03192779

Van Damme, S., Crombez, G., & Lorenz, J. (2007). Pain draws visual attention to its location: experimental evidence for a threat-related bias. *The journal of pain : official journal of the American Pain Society*, *8*(12), 976–82. doi:10.1016/j.jpain.2007.07.005

Van Damme, S., Gallace, A., Spence, C., Crombez, G., & Moseley, G. L. (2009). Does the sight of physical threat induce a tactile processing bias? Modality-specific attentional facilitation induced by viewing threatening pictures. *Brain research*, *1253*, 100–106. doi:10.1016/j.brainres.2008.11.072

Van Damme, S., Legrain, V., Vogt, J., & Crombez, G. (2010). Keeping pain in mind: a motivational account of attention to pain. *Neuroscience and biobehavioral reviews*, *34*(2), 204–13. doi:10.1016/j.neubiorev.2009.01.005

Van Hulle, L., Durnez, W., Crombez, G., & Van Damme, S. (2015). Detection of tactile change on a bodily location where pain is expected. *Perceptual & Motor Skills: Perception*, *120*(1), 219–231.

Vanden Bulcke, C., Crombez, G., Spence, C., & Van Damme, S. (2014). Are the spatial features of bodily threat limited to the exact location where pain is expected ? *Acta Psychologica*, *153*, 113–119. doi:10.1016/j.actpsy.2014.09.014

Vanden Bulcke, C., Van Damme, S., Durnez, W., & Crombez, G. (2013). The anticipation of pain at a specific location of the body prioritizes tactile stimuli at that location. *Pain*, *154*(8), 1464–8. doi:10.1016/j.pain.2013.05.009

Verbruggen, F., & Aron, A. (2010). Theta burst stimulation dissociates attention and action updating in human inferior frontal cortex. *Proceedings of the National Academy of Sciences*, *107*(31), 13966–13971. doi:10.1073/pnas.1001957107/-/DCSupplemental.www.pnas.org/cgi/doi/10.1073/pnas.1001957107

Let it be? Attention to somatosensory input is amplified by the threat of pain and pain control attempts

6

Abstract Recent studies have suggested that the threat of pain may redirect attention towards specific features of the pain stimulus via attentional control settings. For instance, it has been shown that anticipating pain results in attentional prioritization of the location where pain is expected. In contemporary theories on attention and pain it has been argued that pain control motivation – e.g., attempting to avoid pain – is capable of enhancing these effects. The present study investigated if the threat of pain prioritizes attention towards somatosensory input over other sensory information, and if pursuing a pain control goal augments this effect. In a Temporal Order Judgment experiment, 41 participants were presented with visuotactile stimulus pairs and asked to judge which stimulus they had perceived first. Half of all trials were associated with the threat of acute pain, while the other half was not. Furthermore, half of our sample was encouraged to avoid the administration of pain by means of a specified behavioral response, whereas the other half was not. In line with our hypotheses, we found the threat of pain to prioritize attention towards the somatosensory modality, i.e., participants tended to perceive the tactile stimulus as occurring earlier in time than the visual stimulus. Second, results showed that pain control attempts further enhanced this prioritization effect. Interestingly, our findings suggested generalization of somatosensory prioritization in pain controllers to safe trials. These findings support the idea that pain goals exert top-down attentional control prioritizing pain-relevant sensory information. Clinical relevance and future directions are discussed.

Introduction

As an evolutionary tactic, pain may at first glance seem at odds with its purpose. Yet, while it is in itself an unpleasant and unwelcome experience, the ability to feel pain is vital to the survival of later-stage organisms such as humans (Chapman et al., 2008). Pain alerts us of the possibility of impending physical harm, prompting us to shift our attention in order to effectively address the threat in question (Eccleston & Crombez, 1999).

While this attentional demand is most evident in a bottom-up sense, i.e., when the sudden onset of pain disrupts ongoing goal-directed behavior, it is also possible that one's goals are a priori directed at pain control (Van Damme et al., 2010). When faced with contexts that signal the likelihood of hurt, it is adaptive to devote attention to pain-related signals pre-emptively (Öhman et al., 1979). As such strategy permits us to deal with physical threat swiftly and efficiently, it is in effect a way of attempting to gain control over the threat. This is an example of a top-down, goal-driven mode of attentional selection (Legrain et al., 2009).

Goals, such as attempting to prevent or control imminent pain, have a way of adjusting our attentional control settings – a mental set of stimulus features that allows us to efficiently identify and act upon goal-relevant information (Folk & Remington, 2008). When pain becomes the focal point of one's motivation, it can thus be expected that stimuli sharing perceptual features with the anticipated pain will be selected by attention more easily (the so-called attentional set hypothesis) (Legrain et al., 2009). Prevalent stimulus features of pain include its location and the somatosensory modality. The former feature, i.e., the spatial characteristics of pain, has been the focus of recent research. In favor of the attentional set perspective, these experiments have demonstrated that the anticipation of pain directs

one's attention towards the location where this pain is expected to occur (Durnez & Van Damme, 2015; Vanden Bulcke et al., 2013, 2014).

The attentional set hypothesis further predicts that somatosensory stimuli, sharing their modality with pain, will be selected by attention more easily than stimuli from other sensory modalities. Evidence in support of this assertion is scarce yet. A number of cross-modal cueing studies have shown that attention can be selectively directed to the specific modalities using visual cues (Spence et al., 2002; Van Damme et al., 2004). For instance, there is evidence that cueing the word 'pain' or 'tone' can prioritize attention to the somatosensory and auditory modality, respectively. Also informative in this regard may be the study by Van Damme and colleagues (2009). Using an unspeeded temporal order judgment (TOJ) task, they found that the presentation of an image of physical threat (such as a knife) in front of one hand shortly before a pair of either tactile or auditory stimuli resulted in quicker awareness of tactile stimuli at the "threatened" hand than at the other hand. This prioritization effect was not found for auditory stimuli presented close to the threatened hand. In other words, threat only seemed to prioritize somatosensory information at the threat location, implying a modality-specific effect. However, the experiment did not place auditory and somatosensory information in direct competition for attention. Hence, it does *not* support any inference with regard to the prioritization of a specific modality, but rather suggests that the prioritization of threatened locations may depend on the modality of the input that requires processing.

In an attempt to address this shortcoming, Jia, Shi, Zang and Müller (2013) conducted a series of bimodal TOJ experiments, in which participants judged the order of audio-tactile stimulus pairs. Results showed that the prior presentation of affectively salient pictures – at a location

independent of the audio-tactile stimuli – was capable of shifting attention towards the somatosensory modality, resulting in the quicker perception of tactile stimuli compared to concomitant auditory stimuli. Notably, this effect was only found when stimuli from different modalities were also separated in space. Prioritization effects were found for both positive (e.g., an erotic couple) and negative (e.g., a spider) high-arousal imagery. When disentangling the effects of physically threatening contexts with regard to the locus of threat, prioritization of somatosensory stimuli only occurred when the visual cue represented a near-body threat (e.g., a snake), and not when it depicted remote threat (e.g., a car accident). A limitation of the aforementioned studies (Jia et al., 2013; Van Damme et al., 2009) is that only visual threat cues were used. Effects of the actual anticipation of pain thus remain open to investigation.

As is often the case with laboratory pain studies, the design of the vast majority of aforementioned studies left little or no room for the natural urge to avoid, escape or minimize the pain itself. Thus, these studies seldom allow any conclusion to be made about the presumed role of active pain control goals in attentional prioritization of a threatened location. Few studies on pain-related attention include a pain control option. One experiment demonstrated that attempts to avoid a painful stimulus are capable of prioritizing attention to visual cues predicting pain stimulation (Notebaert et al., 2011). However, this study does not permit any conclusions with regard to prioritization of pain-related stimulus features, specifically. More recently, in a tactile change detection task, researchers observed how attentional prioritization of a threatened location was more pronounced when participants were encouraged to avoid administration of pain by means of a specified behavioral response (Durnez & Van Damme, 2015). This study provides some evidence that pain-control goals may activate the

location feature of pain in the attentional control settings. However, as only tactile stimuli were used in this study, it cannot tell us anything about the hypothesized prioritization of the somatosensory modality over other modalities.

The present study has two main objectives. First, we examine whether the threat of acute pain prioritizes attention towards somatosensory input, at the cost of input from other modalities. In this study, specifically, a comparison will be made with visual information. In accordance with the attentional set hypothesis, we predict that stimuli more perceptually similar to pain, i.e., somatosensory input, will be processed more swiftly by attention (hypothesis 1). Second, we investigate the significance of pain control motivation by encouraging half of our sample to actively try to avoid the administering of pain stimuli. Extending the notion that goal pursuit shapes our attentional control settings (Folk & Remington, 2008), we propose that explicit activation of pain control goals will enhance attentional prioritization of the somatosensory modality (hypothesis 2). To test these ideas, we designed a TOJ study featuring stimuli from two distinct sensory modalities. Participants were required to judge the order in which pairs of stimuli were presented to both hands: one visual stimulus and one somatosensory stimulus. These stimuli were always presented on a different hand (visual left and somatosensory right or vice versa). Stimulus locations were counterbalanced over trials. Half of all trials were made threatening through a simple pain conditioning procedure. To achieve this, we used auditory cues (high frequency versus low frequency) that indicated either the possibility of receiving a painful stimulus on both hands, or the certainty that no such stimulus would follow. Additionally, we divided participants in a pain control group and a comparison group. The former group was actively encouraged to attempt to avoid pain by quickly pressing down on a

foot pedal as soon as they heard the pain-indicative cue, whereas the latter group was simply asked to press the foot pedal as an additional timed reaction task. In reality, both groups were given an equal amount of painful stimuli. We expected somatosensory stimuli to be prioritized over visual stimuli when the threat of impending pain was present. In addition, we predicted this prioritization effect to be significantly stronger when participants actively pursued a pain control goal, as this goal-directed behavior would significantly reinforce attentional control settings.

Method

Participants

Forty-two students of Ghent University (17 male and 25 female; M_{age} 22.76 SD_{age} 7.27) participated in this study, either to earn required course credits or in exchange for a small financial compensation. Three of them were left-handed. All participants had normal or corrected-to-normal vision and normal hearing. The study protocol was approved by the Ethics Committee of the Faculty of Psychology and Educational Sciences of Ghent University. The experiment took approximately 1 hour and 10 minutes. Informed consent was obtained by all individual participants included in the study.

Apparatus and stimulus material

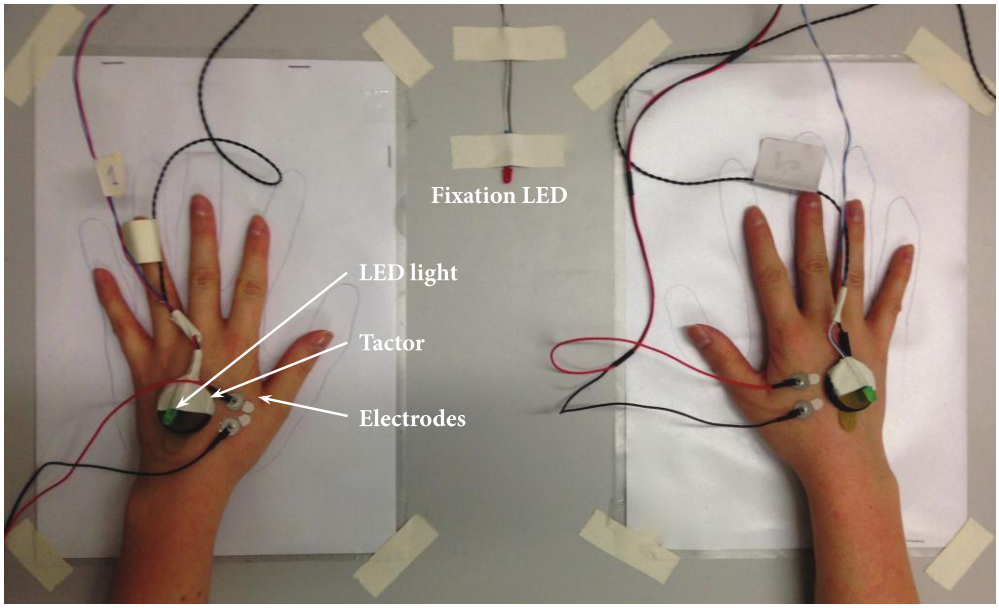


***Figure 1*: Illustration of placement of stimulus apparatus**

The experiment was conducted in a darkened, sound-isolated room. Participants sat on a chair in front of a desk, with their hands palm-down on marked positions (identical to chapter 4, fig. 1). The tactile stimuli used in the experiment were vibrations, presented by means of two 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. Their function was controlled and amplified through a custom-built device. The tactors were attached directly to the skin in the center of the back of either hand using double-sided tape rings. The frequency of tactile stimulation was 200 Hz. The stimulus duration was set to 20 ms. Visual stimuli were presented by means of two green light-emitting diodes (LEDs). These LEDs were placed directly on top of the tactors. During the experiment, they were illuminated for a duration of 20 ms, causing them to be perceived by participants as briefly flashing green light. An additional, centrally placed red LED served as a fixation point throughout the different

trials of the experiment. Painful stimuli were generated electrically through means of constant current stimulators (Digitimer DS5, 2000). They were delivered via 2 lubricated Fukuda standard Ag/AgCl electrodes (1 cm diameter), placed in close proximity to the tactors and the superficial branch of the radial nerve. These sinusoid electrocutaneous stimuli had a frequency of 200 Hz and a duration of 200 ms. Throughout the experiment, painful stimulation always occurred on both hands simultaneously. Amplitudes for both the tactile and electrocutaneous stimulation were set using adaptive procedures, as described in the procedure section. Auditory cues were administered using a set of headphones (Sennheiser HD 202 II). These cues consisted of either a high tone (1000 Hz) or a low tone (250 Hz) and had a duration of 1000 ms. As part of the goal manipulation, participants were asked to press a foot pedal at specific moments in a portion of the trials. This foot pedal (Bespeco NT-13 sustain pedal) was attached to the floor at a distance that was comfortable for each participant, so that they could easily and quickly press down on it with their dominant foot. The pedal was connected to a Cedrus response box (RB-530 model) to optimize response time registration.

TOJ paradigm

The task was programmed in the programming language C using the Tscope 5 library package, an upgraded version of the original Tscope. It was presented on a laptop (Dell latitude E5520). Participants were instructed to keep their hands on the marked positions, and keep their gaze fixed on the fixation LED.

The experiment was divided into 5 blocks of 84 trials each, resulting in a total of 420 trials. Electrocutaneous stimulation was presented at least once in the first ten trials of each block in order to maintain contingency

perception. Each trial began with an illumination of the fixation LED for 1000 ms. Next, a 1000 ms auditory cue was presented, indicating whether or not electrocutaneous stimulation could follow (within-subjects variable of THREAT). One tone frequency predicted the possible advent of such stimulation (threat trial), while the other signaled that this would not be the case (neutral trial). The frequency of the threatening tone (high versus low) was counterbalanced. The tone was followed by an interval of 500 ms. One out of eleven threat trials included actual electrocutaneous stimulation. Participants were not informed of this proportion. In this case, no other stimuli were presented. In the remaining 10 threat trials, as well as in all neutral trials (10 in number), the auditory cue was instead followed by the administration of the TOJ stimuli. In each trial, the stimulation on one hand was visual (LED light), while the other hand received a somatosensory stimulus (vibration). In half of the trials, the somatosensory stimulus was presented on the left side and the visual stimulus on the right side. In the other half, the opposite was true. The stimuli were separated in time by 1 of 10 possible stimulus onset asynchronies (SOAs; -200, -90, -55, -30, -10, +10, +30, +55, +90 or +200 ms; see also Spence et al., 2003). In TOJ experiments, it is customary to code SOAs so that negative values indicate that the test stimulus was presented first. In this study, we regard somatosensory stimuli as test stimuli, while visual stimuli are treated as reference stimuli. In the remainder of the manuscript, negative SOAs thus refer to trials in which the somatosensory stimulus preceded the visual stimulus. Every SOA occurred an equal number of times during the course of the experiment (8 per block, in which the modality location was counterbalanced).

Participants were asked to verbally report on which hand they noticed the stimulation first. They did this by either saying “light” or “vibration” aloud. When a painful stimulus replaced a TOJ trial, participants were asked

to report this by saying "shock". They had up to 5 seconds to respond before their response was coded as a blank. All responses were coded by the experimenter using a keyboard. Figure 2 depicts a typical trial course.

Procedure

Participants were given a brief description of the experiment and asked to fill in an informed consent form. They then completed a custom-made pre-test questionnaire, which is described in the self-report measures section below. Tactors, electrodes and LEDs were then attached to the locations described above (fig. 1). Because it has been shown that somatosensory sensitivity can vary depending on which location of the body is stimulated (Weinstein, 1968), we first obtained appropriate tactile and electrocutaneous stimulation amplitudes for each hand. Our aim was to ensure that participants perceived somatosensory stimulation of equal intensity on both hands hand, so as not to privilege either side.

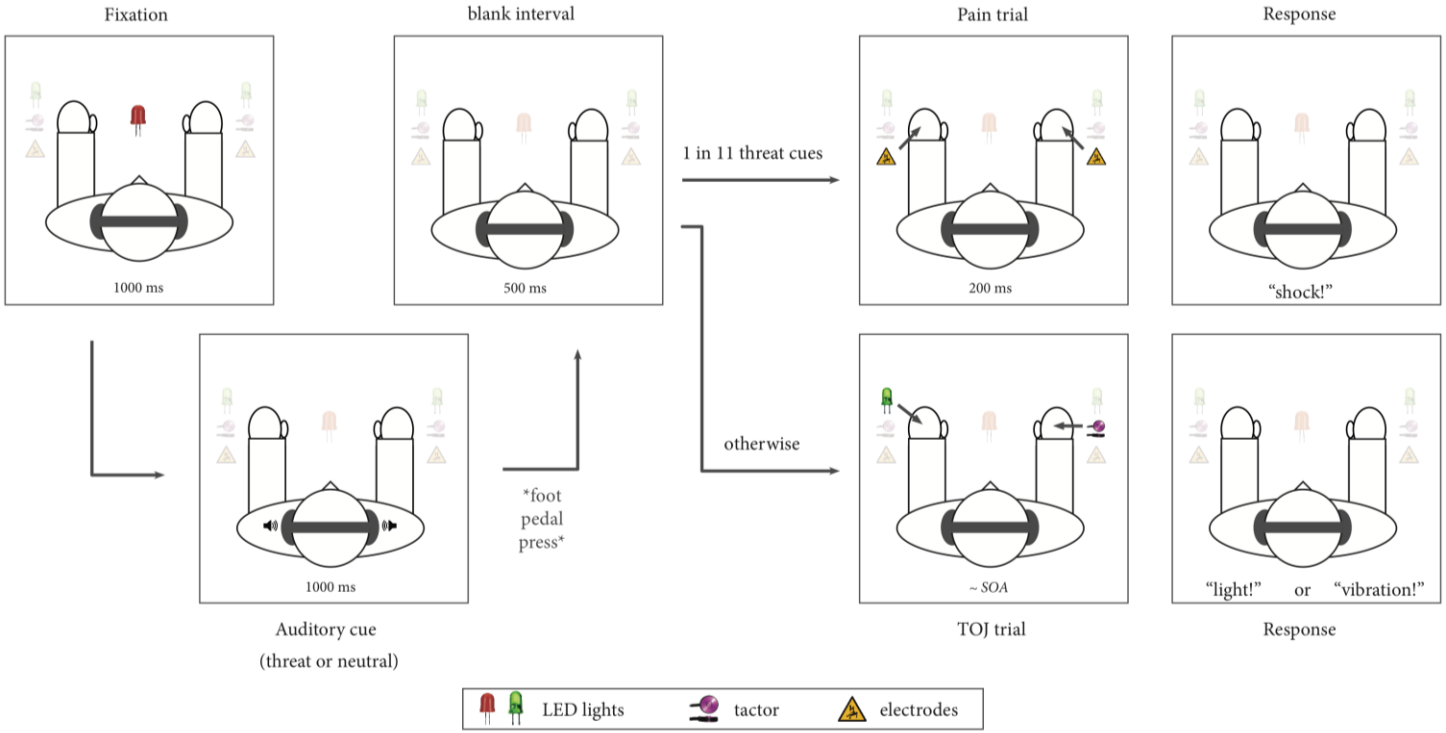


Figure 2: **Overview of possible trial courses. Fixation cross presentation is followed by an auditory cue. After a blank interval, one of two possibilities occurs. If the auditory cue indicated threat, there is a chance of 1 out of 11 that a painful stimulus would follow (pain trial). If not, then a TOJ trial is presented, in which two stimuli are presented, separated by an interstimulus interval (SOA). Participants responded by stating which they perceived first, the light or the vibration. In case of a pain trial, they are asked to report that as well.**

Determining intensity of tactile stimuli

Our custom-made adaptive procedure (see also: Durnez & Van Damme, 2015; Vanden Bulcke et al., 2014, 2013) based on the double random staircase procedure, was designed as follows. Participants were first given a reference stimulus at 50 percent of the maximum capacity (P = 0.425 watts) on the left hand. One second after that, a tactile stimulus was administered to the right hand. The amplitude of this second stimulus was taken from one of two staircases, which were alternated randomly for an equal number of times in total. The initial value for the first staircase was a random integer between 45 and 49, while it was a random integer between 51 and 55, for the second. This way we ensured that participants would encounter both a stimulus that was higher in actual amplitude, and one that was lower in amplitude. After each pair of stimuli, participants were asked whether they perceived the second stimulus as "a lot stronger", "stronger", "equally strong", "weaker" or "a lot weaker". Their response determined the next value in the staircase (5 units down, 1 unit down, no change, 1 unit up or 5 units up, respectively). This was repeated for 16 times. The continuous coupling of reference stimuli and to-be-rated stimuli was intended to ensure participants could adequately compare both sensations, making sure there was no gradual shift in memory of how the stimulus was perceived. It also served to prevent divergent sensitization effects on both hands. An average was made of all amplitude values which participants had reported to perceive equally strong (supplementary table 1). This value was used in the main experiment.

Determining intensity of electrocutaneous stimuli

In the following preparatory phase, we determined amplitudes for the electrocutaneous stimulation. We did this by obtaining an appropriate value for the left hand and then finding a matching value for the right hand, both times using a double random staircase procedure of 14 steps. In the first part of this procedure, starting values for both staircases were chosen randomly between 1 and 20 (respectively 0.1 and 2.0 mA). A series of 15 stimuli was administered on the left hand. Participants were asked to rate each of these on an 11-point scale (0 = "no pain", 10 = "unbearable pain"). Reponses determined the next value in the corresponding staircase: a rating over 7 meant 1 unit down, a rating of 7 meant no change, and a rating under 7 meant 1 unit up. We took the average of all values to which participants gave a pain intensity rating of 7. This way we obtained the pain intensity for the left hand (supplementary table 1). This was then used as a reference stimulus during the second part of the procedure. In this part, a stimulus on the right hand followed the reference stimulus on the left hand. Its functioning was similar to the former procedure for determining tactile intensities – and because of the same reasons. Participants were asked once more whether they perceived the second, right hand stimulus as "a lot stronger", "stronger", "equally strong", "weaker" or "a lot weaker". Their response pattern over the next fourteen trials determined the pain intensity for the right hand, which was calculated as the average of all right hand intensities which participants had judged to be "equally strong" to the reference stimulus on the left hand.

We proceeded by introducing the TOJ paradigm to the participants and explained the nature of the task. We presented them with 20 practice TOJ trials with two additional pain trials intermixed. We only proceeded

when participants scored 70% accuracy on the trials with the largest SOA (+/- 200 ms). Next, we informed participants about the meaning of the auditory cues. Dependent on which group they were placed in (between-subjects variable of GROUP), participants received additional instructions with regard to the use of the foot pedal. In the pain control group (21 participants), participants were instructed that they could significantly reduce the chance of receiving painful stimuli throughout the experiment, by pressing down on the pedal as soon as they heard the threat-signaling cue. In reality, the timing and occurrence of painful stimuli were predetermined, ensuring that participants in the pain control group received an equal amount of pain stimuli as those in the comparison group. This implies that our goal manipulation depended on subjective control, rather than actual control. In this comparison group (21 participants), participants were also instructed to press down on the pedal upon hearing the threat-signaling cue. These participants, however, were told this served to obtain additional measures of attention and concentration. No instructions related to pain control were given whatsoever. Five TOJ blocks were then presented, as described above.

Self-report measures

Prior to the experiment, participants filled in a custom-made questionnaire on pre-existing pain-related conditions and episodes. All ratings (e.g., "To what degree were you unable to conduct daily activities during the past six months because of your pain?") were indicated on a 11-point Likert scale. In addition, each experimental block was followed by a quick questionnaire on effort ("To what extent did you put effort into the task?"), concentration ("How well could you concentrate on the task?"), attention ("How much attention did you pay to the somatosensory/visual

stimuli?"; "How much attention did you pay to the electrocutaneous stimuli?"), fear related to either cue ("To what extent did you fear that a high/low tone would be followed by an electrocutaneous stimulus?"), pain expectancy related to either cue ("To what extent did you expect an electrocutaneous stimulus to follow the high/low tone?"), pain perception ("How painful did you find the electrocutaneous stimulus?"), anxiety ("How anxious did you feel during this block?") and fatigue ("How tiresome did you find this block?"). Participants in the pain control group were also asked to what degree they attempted to avoid the occurrence of painful stimuli. This question was not posed to the comparison group, so as not to evoke the illusion of underlying control mechanisms. All questions were answered on an appropriately anchored 11-point Likert scale. Answers were averaged over blocks per participants, prior to analysis. Finally, upon completion of all experimental blocks, participants completed the Pain Catastrophizing Scale (PCS; Sullivan, Bishop, & Pivik, 1995; Van Damme, Crombez, Bijttebier, Goubert, & Van Houdenhove, 2002).

Statistical analyses

Participants not reaching a mean accuracy of 70% on trials with the largest SOAs (+/- 200) were excluded from further analyses (Spence et al. 2003). We then analyzed performance on the TOJ-task by fitting these data to functions based on an independent channels model, as described in Alcalá-Quintana & García-Pérez (2013). Using these fits, we obtained Point of Subjective Simultaneity (PSS) measures for each condition. These measures represent the (fictitious) SOA at which observers can be expected to give either response ("vibration" or "light) with equal probability. Consequently, a shift in this point teaches us about the relative speed with which the competing information is processed. Participants with PSS-values

greater than the largest SOA were removed from the dataset (see also Spence, Shore, & Klein, 2001). The final PSS values were analyzed using a generalized linear mixed-effects model with a Gaussian link function, as implemented in the R package 'lme4' (Bates et al., 2014). The statistical modeling procedure was as follows.

First, all relevant factors and their interactions were entered in the model as fixed factors. These included THREAT (threat trials vs. neutral trials) and GROUP (pain control group versus comparison group). By default, a random effect was added introducing adjustments to the intercept conditional on each subject separately. This accounts for by-subject baseline differences. Next, we determined whether the addition of a random slope for the within-subject THREAT variable, conditional on each subject, was necessary. This random effect statistically represents the possibility that the effect of THREAT is different for different subjects. If this random effect increased the model's goodness of fit, we included it in the final model. In a second step, we sought out the most parsimonious model that fit the data by restricting the full model systematically, starting with higher-order terms. All model comparisons were made using likelihood-ratio tests. In a third and final step, we inspected the ANOVA table of the final model and tested specific hypotheses about possible main effects or interactions (see De Ruddere, Goubert, Stevens, Williams, & Crombez, 2013; Durnez & Damme, 2015; Verbruggen & Aron, 2010, for a similar approach). As we were interested in the interaction between THREAT and GROUP, type III sum of squares were calculated.

In order to further investigate the nature of the interaction effect, when present, 4 additional (planned) orthogonal contrasts were calculated. These analyses examined the effect of threat in both the comparison group and the pain control group, independently. Similarly, we investigated the

separate effect of pain control attempts in neutral trials and threat trials. These contrast analyses were corrected for multiple testing according to the corrections of Holm-Bonferroni (Holm, 1979).

As discussed in the introduction, we expected the threat of pain to prioritize attention towards somatosensory input (hypothesis 1: THREAT main effect). Additionally, we expected that the strength of such threat-induced attentional bias would be increased in the pain control group, relative to the comparison group (hypothesis 2: THREAT x GROUP interaction effect).

Results

Self-report data and manipulation check

Participants assessed their own health as 'very good', on average. Twenty-three participants had experienced some form of pain during the past 6 months (M = 19.37 days, SD = 26,76 days). This pain had an average intensity rating of 5,09 (SD = 1,20) and an average disability rating of 3,565 (SD 2,79). One of these participants reported to have suffered from his pain complaint for more than 90 days (intensity rating = 5, disability rating = 4). We found no evidence that including this participant significantly distorted the data. Eight participants reported feeling pain at the moment of testing, on a Likert-scale ranging from "no pain" to "worst possible pain". Their average pain intensity ratings were low (M = 2.13, SD = 1.25).

PCS scores were not significantly different between groups (comparison group: M = 18.80, SD = 8.94; pain control group: M = 22.41, SD = 8.16) (t_{35} = -1.27, p = .21). Over the course of the experiment, the electrocutaneous stimulus was rated as being moderately painful in both

groups (comparison: M = 4.34, SD = 2.01; pain control: M = 4.19, SD = 1.82) with no significant difference between them (t_{36} = 0.24, p = .81). To verify the effect of the threat manipulation, we applied an ANOVA with the factors CUE (threatening versus neutral) and GROUP (comparison versus pain control) on fear and pain expectancy ratings. With regard to fear ratings, we found main effects of both the CUE and GROUP variable (resp. χ^2 = 85.10, p < .001 and χ^2 = 6.27, p = .01). These indicated that participants felt more fearful upon hearing the threat cue (M = 4.97, SD = 2.15) compared to the neutral cue (M = 1.03, SD = 1.69) (d = 2.04, 95% CI = 1.47-2.62), indicating that the threat manipulation was successful. Interestingly, we found that fear ratings were overall higher in the pain control group (M = 3.57, SD = 3.04) than in the comparison group (M = 3.04, SD = 2.40) (d = 0.39, 95% CI = -0.08-0.86). The interaction was not significant. A comparable pattern was found with respect to pain expectancy ratings, showing a significant main effect of CUE (χ^2 = 51.66, p < .001) and a now marginally significant main effect of GROUP (χ^2 = 3.01, p = .08). Similarly, hearing the threatening cue led to more pain expectancy (M = 4.23, SD = 2.44) compared to hearing the neutral cue (M = 0.92, SD = 1.51) (d = 1.63, 95% CI = 1.09-2.17). Additionally, pain expectancy ratings were slightly higher for participants in the pain control group (M = 2.99, SD = 2.84) than for those in the comparison group (M = 2.20, SD = 2.36) (d = 0.32, 95% CI = 0.15-0.79).

The remainder of the self-report measures is summarized in table 1. Notably, participants in the pain control group reported paying more attention to the electrocutaneous stimulus (M = 6.63, SD = 1.58) than those in the comparison condition (M = 4.99, SD = 1.58) (t_{36} = -2.41, p = .02, d = 0.78, 95% CI = 0.08-1.49). Finally, participants in the pain control group

reported moderate attempts to control the painful stimulus (M = 4.27, SD = 2.60).

Table 1:

Self-report questionnaires.

	M com	SD com	M pc	SD pc	*t*	*p*
Pain experience	4.34	2.01	4.19	1.82	0.24	.81
Anxiety	2.81	2.64	3.28	2.46	-0.56	.58
Attention to painful stimuli	4.99	1.58	6.63	1.58	-2.41	.02
Attention to visual/tactile stimuli	7.78	1.32	7.74	1.08	0.85	.40
Concentration	7.28	1.58	7.73	1.40	-0.94	.36
Effort	8.12	1.13	7.72	1.08	0.85	.40
Fatigue	4.75	2.29	4.91	2.10	-0.22	.82
Control attempts	-	-	4.27	2.60	-	-
PCS	18.80	8.94	22.41	8.16	-1.27	.21

TOJ data

We eliminated 3 participants (1 in the comparison group, 2 in the pain control group) whose accuracy on trials with the largest SOA (± 200 ms) fell under the cut-off level of 70 percent. Of the remaining participants, one showed a PSS value outside of the SOA range (-210.84 ms), prompting this participant's exclusion. This left us with 20 participants in the comparison group, and 18 participants in the pain control group.

Upon closer inspection of the PSS table, we noticed one value standing out remarkably. This value (PSS = -184.34) was identified as an outlier by a Grubbs test (G = 4.75, U = 0.70, p < .001). While data restriction in TOJ experiments typically ends after the application of the aforementioned exclusion criteria, we chose to bar this participant from the analyses. The distribution of the PSS values is shown per condition in figure 3 and table 2.

Table 2

Point of Subjective Simultaneity per condition (in milliseconds).

	Neutral	Threat	Baseline corrected
Comparison group	13.41	77.69	64.28
	38.66	17.93	-20.74
	35.57	43.25	7.68
	39.31	79.34	40.03
	-44.10	-17.44	26.66
	35.50	48.37	12.87
	36.49	34.83	-1.66
	29.85	83.31	53.46
	47.43	66.26	18.83
	34.36	88.35	53.99
	70.64	37.57	-33.07
	47.48	44.02	-3.46
	97.40	91.81	-5.59
	83.88	88.83	4.95

	-19.59	53.47	73.07
	81.07	58.06	-23.02
	38.38	94.43	56.05
	15.86	22.65	6.79
	55.09	65.47	10.38
Pain control group	78.15	83.77	5.61
	17.61	10.06	-7.55
	51.89	93.87	41.98
	0.37	190.08	189.71
	29.93	148.62	118.69
	45.00	54.60	9.60
	42.37	84.32	41.95
	65.82	92.18	26.37
	92.42	169.48	77.06
	23.11	47.40	24.29
	-19.37	***-184.34***	-164.97
	94.25	96.98	2.73
	136.73	177.77	41.04
	41.30	59.39	18.09
	40.61	58.25	17.64
	51.62	87.63	36.01

Note: Outlier value is in bold italics.

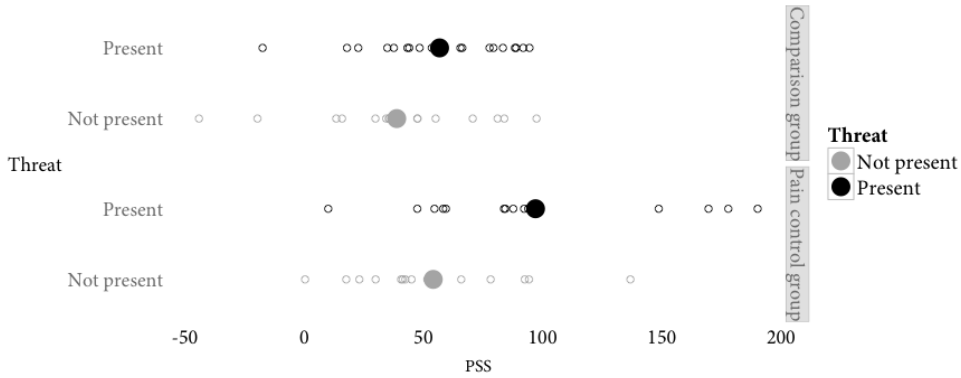


***Figure 3*: We compared individual Point of Subjective Simultaneity measurements across conditions. For every participant in both the comparison group and the pain control group, we calculated the Point of Subjective Simultaneity (PSS) in both threat trials and neutral trials (smaller, hollow circles). Mean PSS values are indicated as well (larger, solid circles). More positive values means somatosensory information is processed quicker relative to visual information. The illustrated pattern shows that threat prioritizes somatosensory information, particularly in the pain control group.**

Analysis of PSS measures.

The best fitting statistical model included all fixed factors and interactions, and a random subject-based intercept. No other random effects were necessary (see table 3). The interaction effect was marginally significant (χ^2 = 3.51, p = .06). We chose not to restrict the model any further. This model's intercept was strongly significant, indicating that tactile information was generally perceived quicker than visual information, regardless of our experimental manipulations. This result has been found before on several occasions (e.g., Spence et al. 2001, 2003). In addition, we found a significant main effect of the THREAT variable (χ^2 = 22.01, p < .001), indicating higher PSS values when threat was presented. In our coding scheme, higher PSS values indicate that somatosensory input was processed relatively quicker than visual input following a threatening cue. We also found a main effect of GROUP (χ^2 = 4.62, p = .03), showing generally higher

PSS values in the pain control group compared to the comparison group. The interaction suggested that the effect of THREAT was stronger in the pain control group than it was in the comparison group, although this was only a tentative result with borderline significance (see table 4).

Table 3

Step 1 – Determine random structure.

Model	Test	Random	Log L	df	χ^2	*p*
1	Initial fit	1	-366.85	6		
2	Random THREAT (1 vs 2)	1 + THREAT	-366.17	8	1.35	.51
Full data: Decision test model 2: retain current model						

In order to further dissect this near-significant interaction, 4 additional contrasts were calculated (α = .05/4 = .0125). The effect of threat was not significant in the comparison group (χ^2 = 3.61, p = .06). In the pain control group, however, threat significantly increased PSS measures (χ^2 = 16.21, p < .001) – and thus, facilitated the detection of somatosensory input compared to visual input. In addition, we found no evidence that PSS values for neutral trials differed between groups (χ^2 = 1.37, p = .24). In contrast, threat trials yielded significantly higher PSS measurements in the pain control group, compared to the comparison group (χ^2 = 9.48, p < .01). This suggests that pain control attempts prioritize somatosensory information over other input, but only when critical threat is presented.

Discussion

The aim of the present study was twofold. On the one hand, we set out to investigate if the anticipation of pain led participants to prioritize all somatosensory input over input from other modalities – in this case visual information. We thus directly compared processing speed for stimuli in both these modalities. Our predictions were derived from the attentional set hypothesis, which proposes that stimuli sharing features with a motivationally salient target stimulus will be selected by attention more readily. We thus expected all somatosensory input to be prioritized, as this input shares its modality with the anticipated pain (hypothesis 1). On the other hand, we were interested in verifying whether motivational factors – in this case the goal to control pain – have the capability to enhance this somatosensory prioritization (hypothesis 2) (Van Damme et al., 2010). We predicted such an increase in attention, as we estimated that inducing a pain control goal would increase the salience of the goal-relevant stimulus (the anticipated pain), thus further strengthening the prioritization of pain-related features through these participants' attentional set.

The results largely substantiated our hypotheses, showing larger (and positive) PSS values in the threat condition compared to the neutral condition. Given our coding scheme, a positive PSS means that visual information needs to be presented earlier than somatosensory information in order for both stimuli to be perceived as simultaneously occurring. In other words, positive PSS values show that somatosensory input is processed more quickly than visual input – the so-called prior-entry effect (Spence & Parise, 2010; Titchener, 1908). In turn, the finding that PSS values are on average larger in threat trials compared to neutral trials signifies that this difference in processing speed is enlarged through the anticipation of pain.

This confirms our first hypothesis, which predicted that the threat of pain would prioritize attention towards the somatosensory modality at the cost of competing information in other modalities.

With respect to the second hypothesis, the pattern of results appears to be a little more nuanced. We predicted that the addition of a pain control option would further enhance the prioritization of somatosensory information following the anticipation of pain. Indeed, analyses uncovered that the threat-induced shift of PSS values towards the somatosensory modality was more pronounced in this pain control group than in the comparison group. Still, this effect narrowly failed to reach the applied significance level, making it harder to draw strong inferences. An interesting finding in this regard, though, is the fact that PSS values overall were significantly higher in the pain control group than in the comparison group, as shown by the significant main effect of our grouping variable. In more explicit terms, results suggest that pain controllers exhibited stronger attentional prioritization of somatosensory information over the course of the whole experiment, and not only when threat was instantaneous. This is not the first instance where such generalized effect of pain control motivation has been found. It has previously been reported that the goal to control imminent pain prioritizes attention to the pain location in a broad, contextual fashion, whereas the mere anticipation of pain induces more moment-tied effects (Durnez & Van Damme, 2015). As such, it is not unthinkable that motivating participants to gain control over the experimental pain – however futile these attempts may prove to be in the long term – puts them in a different frame of mind than those participants who are led to simply undergo the stimulation. It is possible that, while threat induced instantaneous yet transient alterations of the attentional set

of comparison group participants, pain features were part of the attentional set of pain controllers in a more enduring, generalized manner.

In this regard, it may be worthwhile noting that we found both increased fear ratings and increased pain expectancy ratings, for threat trials, when comparing the pain control group to the comparison group – even though pain perception itself was stable across groups. It is possible that these differences contributed to the higher PSS values for pain controllers facing threat, when compared to threat trials in the comparison group. An earlier meta-analysis reported that anxiety is significantly related to attentional prioritization of threat-related information, albeit with a medium effect size (Bar-Haim et al., 2007). However, a meta-analytic study that investigated attentional bias to pain-related information, specifically, failed to confirm that individual differences – such as pain-related fear or catastrophizing – significantly affected the magnitude of such biases (Crombez et al., 2013). This avenue of interpretation is therefore not wholly unquestionable, and warrants further investigation. Note that the fear and pain expectancy ratings in our study were mainly included as a threat manipulation check. Adding these ratings to our analyses would force us beyond the (statistical) scope of this study.

Several additional points of discussion present themselves. First, it is important to note that while participants in the pain control group were encouraged to attempt to avoid the painful stimulus, they never exerted actual control during trials. This type of goal induction has been implemented in several earlier studies, showing that such a manipulation is in fact capable of altering attentional prioritization (Durnez & Van Damme, 2015; Notebaert et al., 2011). Even when participants deemed their pain control attempts fruitless after a period of time, this does not necessarily diminish the effect of our manipulation. In fact, the frustration of goal

pursuit can serve to activate the pertinent goal even more (Moskowitz, 2002).

Second, stimuli in the present experiment were always spatially separated. We made sure not to cue one specific location by always presenting electrocutaneous stimulation on both sites simultaneously, in the case of a pain trial. Additionally, stimulus modalities (i.e., visual or somatosensory) and stimulus locations (i.e., left or right hand) were fully counterbalanced, so that there could never be any confound between these features – thus safeguarding the validity of our results. However, in the study conducted by Jia and colleagues (2013) the spatial separation of stimuli appeared to be a prerequisite in the search for the emotional modulation of TOJs. When stimuli were presented at the same location no effects were found. The authors explained this through the idea of crossmodal integration, citing that multisensory stimuli stemming from the same location are more prone to be processed as a unitary object, rather than as multiple events in multiple modalities (Welch & Warren, 1980; Spence et al., 2003; Stein & Stanford, 2008). It might then be worthwhile to replicate the present study, limiting both visual, somatosensory and electrocutaneous stimuli to one fixed location instead. Assuming that the anticipation of pain – and more importantly, attempts to control said pain – indeed primarily impacts attention through modification of the attentional set, such a design would place modal prioritization effects in an interesting direct competition with the unity effect (Welch & Warren, 1980). If somatosensory prioritization would still be evident, and the unity effect thus overcome, an even more robust case would be made for the capability of pain to significantly impact attention.

Third, another obvious difference between the present study and its predecessor studies (Jia et al., 2013; Van Damme et al., 2009) can be found

in the stimulus material used. Whereas our experiment juxtaposed somatosensory stimuli against visual information, these latter studies used audiotactile stimulus pairs. This discrepancy holds no implications for the soundness of our current hypotheses and results. More so, it is likely that visual information is more functionally relevant in the context of pain. That said, it would be interesting to replicate the experiment with audiotactile stimulus material, as such replication could provide us with additional support for the attentional set perspective.

Finally, it is important to note the potential implications of this line of research. Experimental studies on pain-related attention, and particularly those that investigate psychometric effects of pain control motivation, serve to provide a scientific substrate and basis of credibility for contemporary models of chronic pain. Individuals suffering from this condition are characterized by unrelenting pain symptoms for which often no clear-cut medical explanation can be found. Current theoretical accounts, such as the misdirected problem solving model (Eccleston & Crombez, 2007), propose that when patients strongly adhere to a biomedical framework of their pain problem, problem solving is often directed at gaining control over a – largely uncontrollable – pain problem. In failing to do so, worry is magnified, which further motivates such "misdirected problem solving", resulting in more disability and distress. Along with the amplification of the worry process, attention to pain and pain-related information may increase considerably – often referred to as a hypervigilant state (Crombez et al., 2005). The precise manifestation of hypervigilance in chronic pain patients, particularly in terms of body location and sensory modality, is still under debate (Rollman, 2009; Van Damme et al., 2009). The present study can be construed as an attempt to recreate a rudimentary state of increased vigilance to pain by inducing – intrinsically dysfunctional – pursuit of the

goal to control pain. Its results at the very least suggest that such a context comes with heightened and generalized attention to pain-specific features, which may in turn influence pain perception. The reported findings thus – preliminarily – suggest that interventions, designed to directed patients' focus away from pain control and towards acceptance (e.g., Acceptance and Commitment Therapy: Hayes, Luoma, Bond, Masuda, & Lillis, 2006), are a step in the right direction.

Disclosures

This study was supported by a research grant (BOF11/STA/004) by the Special Research Foundation of Ghent University (BOF) awarded to S. Van Damme. There are no conflicts of interest that may arise as a result of this research.

References

Alcalá-Quintana, R., & García-Pérez, M. A. (2013). Fitting model-based psychometric functions to simultaneity and temporal-order judgment data: MATLAB and R routines. *Behavior Research Methods*, *45*, 972–98. doi:10.3758/s13428-013-0325-2

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: a meta-analytic study. *Psychological bulletin*, *133*(1), 1–24. doi:10.1037/0033-2909.133.1.1

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using S4 classes. R package version 1.1-6. *R*. http://cran.r-project.org/package=lme4

Chapman, C. R., Tuckett, R. P., & Song, C. W. (2008). Pain and Stress in a Systems Perspective: Reciprocal Neural, Endocrine, and Immune Interactions. *Journal of Pain*, *9*(2), 122–145. doi:10.1016/j.jpain.2007.09.006

Crombez, G., Van Damme, S., & Eccleston, C. (2005). Hypervigilance to pain: an experimental and clinical analysis. *Pain*, *116*(1-2), 4–7. doi:10.1016/j.pain.2005.03.035

Crombez, G., Van Ryckeghem, D. M. L., Eccleston, C., & Van Damme, S. (2013). Attentional bias to pain-related information: a meta-analysis. *Pain*, *154*(4), 497–510. doi:10.1016/j.pain.2012.11.013

De Ruddere, L., Goubert, L., Stevens, M., Williams, A. C. de C., & Crombez, G. (2013). Discounting pain in the absence of medical evidence is explained by negative evaluation of the patient. *Pain*, *154*(5), 669–76. doi:10.1016/j.pain.2012.12.018

Durnez, W., & Van Damme, S. (2015). Trying to Fix a Painful Problem: The Impact of Pain Control Attempts on the Attentional Prioritization of a Threatened Body Location. *The Journal of Pain*, *16*(2), 135–143.

Eccleston, C., & Crombez, G. (1999). Pain demands attention. *Psychological Bulletin*, *125*(3), 356–366.

Eccleston, C., & Crombez, G. (2007). Worry and chronic pain: a misdirected problem solving model. *Pain*, *132*(3), 233–236. doi:10.1016/j.pain.2007.09.014

Folk, C. L., & Remington, R. W. (2008). Bottom-up priming of top-down attentional control settings. *Visual Cognition*, *16*(2-3), 215–231. doi:10.1080/13506280701458804

Hayes, S. C., Luoma, J. B., Bond, F. W., Masuda, A., & Lillis, J. (2006). Acceptance and Commitment Therapy: Model, processes and outcomes, *44*, 1–25. doi:10.1016/j.brat.2005.06.006

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*(2), 65–70.

Jia, L., Shi, Z., Zang, X., & Müller, H. J. (2013). Concurrent emotional pictures modulate temporal order judgments of spatially separated audio-tactile stimuli. *Brain Research*, *1537*, 156–163. doi:10.1016/j.brainres.2013.09.008

Legrain, V., Van Damme, S., Eccleston, C., Davis, K. D., Seminowicz, D. A., & Crombez, G. (2009). A neurocognitive model of attention to pain: behavioral and neuroimaging evidence. *Pain*, *144*(3), 230–2. doi:10.1016/j.pain.2009.03.020

Moskowitz, G. B. (2002). Preconscious effects of temporary goals on attention. *Journal of Experimental Social Psychology*, *38*, 397–404. doi:10.1016/S0022-1031(02)00001-X

Notebaert, L., Crombez, G., Vogt, J., De Houwer, J., Van Damme, S., & Theeuwes, J. (2011). Attempts to control pain prioritize attention towards signals of pain: an experimental study. *Pain*, *152*(5), 1068–1073. doi:10.1016/j.pain.2011.01.020

Rollman, G. B. (2009). Perspectives on hypervigilance. *Pain*, *141*(3), 183–4. doi:10.1016/j.pain.2008.12.030

Spence, C., Baddeley, R., Zampini, M., James, R., & Shore, D. I. (2003). Multisensory temporal order judgments: When two locations are better than one. *Perception & Psychophysics*, *65*(2), 318–328. doi:10.3758/BF03194803

Spence, C., Bentley, D. E., Phillips, N., McGlone, F. P., & Jones, A. K. (2002). Selective attention to pain: A psychophysical investigation. *Experimental Brain Research*, *145*(3), 395–402. doi:10.1007/s00221-002-1133-6

Spence, C., & Parise, C. (2010). Prior-entry: a review. *Consciousness and cognition*, *19*(1), 364–79. doi:10.1016/j.concog.2009.12.001

Spence, C., Shore, D. I., & Klein, R. M. (2001). Multisensory prior entry. *Journal of Experimental Psychology: General*, *130*(4), 799–832.

Titchener, E. B. (1908). Lectures on the elementary psychology of feeling and attention. New York: Macmillan.

Van Damme, S., Crombez, G., Bijttebier, P., Goubert, L., & Van Houdenhove, B. (2002). A confirmatory factor analysis of the Pain Catastrophizing Scale: invariant factor structure across clinical and non-clinical populations. *Pain*, *96*, 319–324. http://www.sciencedirect.com/science/article/pii/S0304395901004638. Accessed 7 February 2014

Van Damme, S., Crombez, G., Eccleston, C., & Goubert, L. (2004). Impaired disengagement from threatening cues of impending pain in a crossmodal cueing paradigm. European Journal of Pain, 8(3), 227–236. doi:10.1016/j.ejpain.2003.08.005

Van Damme, S., Crombez, G., Wiech, K., Legrain, V., Peters, M. L., & Eccleston, C. (2009). Why become more general when we can be more specific? Comment on Hollins et al. "Perceived intensity and unpleasantness of cutaneous and auditory stimuli: an evaluation of the generalized hypervigilance hypothesis" [Pain 2009;141:215-221], and on Rollman . *Pain*, *144*(3), 342–3; author reply 343–4. doi:10.1016/j.pain.2009.04.035

Van Damme, S., Gallace, A., Spence, C., Crombez, G., & Moseley, G. L. (2009). Does the sight of physical threat induce a tactile processing bias? Modality-specific attentional facilitation induced by viewing threatening pictures. *Brain research*, *1253*, 100–106. doi:10.1016/j.brainres.2008.11.072

Van Damme, S., Legrain, V., Vogt, J., & Crombez, G. (2010). Keeping pain in mind: a motivational account of attention to pain. *Neuroscience and biobehavioral reviews*, *34*(2), 204–213. doi:10.1016/j.neubiorev.2009.01.005

Vanden Bulcke, C., Crombez, G., Spence, C., & Van Damme, S. (2014). Are the spatial features of bodily threat limited to the exact location where pain is expected ? *Acta Psychologica*, *153*, 113–119. doi:10.1016/j.actpsy.2014.09.014

Vanden Bulcke, C., Van Damme, S., Durnez, W., & Crombez, G. (2013). The anticipation of pain at a specific location of the body prioritizes tactile stimuli at that location. *Pain*, *154*(8), 1464–8. doi:10.1016/j.pain.2013.05.009

Verbruggen, F., & Aron, A. R. (2010). Theta burst stimulation dissociates attention and action updating in human inferior frontal cortex. *Proceedings of the National Academy of Sciences*, *107*(31), 13966–13971. doi:10.1073/pnas.1001957107/-/DCSupplemental.www.pnas.org/cgi/doi/10.1073/pnas.1001957107

Welch, R. B., & Warren, D. H. (1980). Immediate perceptual response to intersensory discrepancy. *Psychological bulletin*, *88*(3), 638–667. doi:10.1037/0033-2909.88.3.638

Mind over matter? Investigating the moderating potential of pain catastrophizing in attentional redirection due to the anticipation of pain and attempts to control its manifestation

7

Abstract In popular explanatory models of chronic pain, a significant role is attributed to cognitive-affective factors such as pain catastrophizing. This refers to the tendency to entertain persistent negative thoughts as a result of being confronted with pain. Crucially, current models do not merely construe this maladaptive mindset as a co-occurrence with pain, but rather an important factor that codetermines how goal pursuit, and consequent attentional allocation are affected. In the present study we revisited data from five earlier experiments with healthy volunteers, in which we investigated how pain anticipation and pain control goals may shape attention to pain-related features. In a new series of analyses, we investigated whether the outcomes from these experiments can be – in part – explained by dispositional pain catastrophizing tendencies. Evidence for such a relationship was inconsistent. In one study, we found evidence that a strong inclination towards pain catastrophizing was associated with stronger attentional prioritization of somatosensory stimuli at the location where the pain was anticipated. However, when participants were encouraged to engage in pain control attempts, this prioritization generalized to visual trials and became independent of the immediate presentation of threat. In the remainder of the studies that were considered, the moderating role of dispositional pain catastrophizing was not supported.

Introduction

The mind is a powerful tool. To most people, such an adage may conjure positive images of mental coaches, endurance athletes or success-oriented individuals in general. Yet, there is a flip side to the medal, as negative thoughts may be no less potent in shaping experiences and actions. This notion is particularly prevalent in contemporary pain theories (Janssen, 2002). For instance, the constructs of *worry* and *pain catastrophizing* can be considered a principal part of several established models of chronic pain (Aldrich, Eccleston, & Crombez, 2000; Eccleston & Crombez, 2007; Leeuw et al., 2007; Sullivan et al., 2001; Vlaeyen & Linton, 2000).

Worry has been defined as "a chain of thoughts and images, negative-affect laden and relatively uncontrollable" (Borkovec, Robinson, Pruzinsky, & DePree, 1983). Pain catastrophizing, in turn, has been described as "an exaggerated negative mental set brought to bear during actual or anticipated painful experiences" (Sullivan et al., 2001). There are some academic differences with regard to these constructs, primarily with regard to their scope, concreteness and chronicity. Worry pertains to a broad, abstract and recurrent state of mind, while pain catastrophizing is conceptualized as a concrete state of mind that rather affects the "here and now" (Lackner & Quigley, 2005). However, as is apparent from their definitions, both constructs tap into comparable content.

In the fear-avoidance model of chronic pain, catastrophizing is suggested to lead to heightened pain-related fear, which consequently fuels an excessive attentional focus towards pain-related features. There is some support for this proposition. For instance, it was shown that a stronger tendency to engage in

catastrophic thought made it significantly more difficult to disengage attention from signals of impending pain, even though this pain did not always actually occur (Van Damme, Crombez, & Eccleston, 2002). Moreover, a recent diary study found that chronic pain patients who entertained fearful thoughts about their pain were inclined to attend to it more (Crombez, Viane, Eccleston, Devulder, & Goubert, 2013).

Somewhat similar to the role of pain catastrophizing in the fear-avoidance model, worry is described in the misdirected problem solving model as a precursor of hypervigilance – that is, excessive attention to pain-related information. While there is evidence that pain-related worry can be associated with reported levels of pain (Davis, 2014), support for the critical involvement of attentional components is lacking. Interestingly, there has been evidence that pain catastrophizing may act as a significant mediator in the relationship between worry and pain experience (Lackner & Quigley, 2005). In a study involving patients with irritable bowel syndrome – an affliction characterized by chronic pain – it was demonstrated that those patients who worried excessively also engaged in more catastrophic thinking, which then augmented the suffering component of pain.

Both the fear-avoidance model and the misdirected problem solving model incorporate some form of dysfunctional goal pursuit in their explanatory mechanisms. The former suggests that chronic pain sufferers are principally preoccupied with the goal to avoid or escape their pain (Leeuw et al., 2007). This preoccupation further fuels their pain experience, eventually leading to an increase in catastrophic thinking and more pain-related fear. Similarly, the latter model proposes that these patients worry increasingly as they fail to find a

solution for the pain they are so often faced with (Eccleston & Crombez, 2007). In both these models, such negative affect is associated with increased attention to pain. Still, studies that empirically evidence these claims of causality are scarce. There is some evidence to suggest that the impact of negative affect on attention may be determined by the strength of its inherent motivational intensity (Gable & Harmon-Jones, 2010). For instance, it was demonstrated that 'sadness' – an exemplar of negative affect that is low in motivational intensity – broadened attention, whereas the motivationally intense affect of 'fear' narrowed attention. This may be particularly interesting in chronic pain contexts, where pain-related fear and dysfunctional goal pursuit are closely tied.

While the sum of the aforementioned studies are in favor of the chronic pain models mentioned earlier, they seldom provide direct evidence for the relationship between pain catastrophizing on the one hand, and attention to pain or pain-related features on the other. It would be worthwhile to investigate such connection, especially using paradigms that purposely gauge these particular attentional processes. In this study, we examine whether individual differences in increased attention to pain features – such as the location where it is expected to occur and the somatosensory modality (Legrain et al., 2009) – can be attributed to dispositional pain catastrophizing. In addition, we will explore whether a dispositional tendency to engage in catastrophic thought can moderate the effects of goal pursuit on attention to pain. We expect that those individuals who are prone to catastrophizing will exhibit stronger effects of pain control pursuit on attention to pain.

To this purpose, we will revisit data from chapters 1 (tactile change detection study 1; TCD1), 3 (TCD2 & TCD3), 4 (temporal order judgment

study 1; TOJ1) and 5 (TOJ2). In each of these studies, we will analyze to what extent scores of pain catastrophizing may moderate the link between threat of pain, pain control motivation and attention to pain-related information. We predict that participants who score higher on pain catastrophizing would react more strongly to anticipated pain. As such, we expect that these participants will be more likely to demonstrate hypervigilance to pain, thus showing more attentional prioritization of pain features – such as its location or modality. Finally, we hypothesize that pain catastrophizing can enhance the effect of engaging in (dysfunctional) pain control attempts on pain-related attention.

Method

Data selection criteria

All data from the previous chapters are included in the following analyses, conditional on their adherence to the respective studies' inclusion criteria, with the exception of one study. As the synchrony judgment study in chapter 2 failed to demonstrate any effects of threat and goal pursuit on attention, we do not inspect this study in more detail. An overview of the remaining studies is given in table 1.

Table 1

Study overview.

Chapter	Study	Participants (F)	Hypothesis	Dependent variable
1	TCD1	37 (27)	Location prioritization?	Binary
3	TCD2	61 (26)	Location prioritization Feedback mechanism?	Binary
3	TCD3	41 (27)	Location prioritization?	Binary
4	TOJ1	41 (21)	Spatial prioritization modality-specific?	Continuous
5	TOJ2	41 (25)	Modality prioritization?	Continuous

In the studies described in chapters 1 and 3 (TCD1-3), outliers were removed from the dataset using the interquartile range criterion. In an effort to synthesize these studies, we reapplied this inclusion criterion to the conjunction of all these datasets. An overview of all relevant variables in each study is given in table 2.

Table 2

Variable overview.

Study	Factor	Levels	Description
TCD1-3	Threat	Not present Present	Is the participant threatened with pain (location-specific)?
	Location	Involved Not involved	Does change occur on the threatened location?
	Group	Comparison Pain control	Is the participant encouraged to control the pain?
TOJ1	Threat	Not present Present	Is the participant threatened with pain (location-specific)?
	Modality	Visual Somatosensory	Are the stimuli visual or somatosensory?
	Group	Comparison Pain control	Is the participant encouraged to control the pain?
TOJ2	Threat	Not present Present	Is the participant threatened with pain (general)?
	Group	Comparison Pain control	Is the participant encouraged to control the pain?

In chapters 4 and 5, a TOJ paradigm was used. In this paradigm, participants are only included in the dataset if accuracy on the easiest trials – that is, those with the largest stimulus onset asynchrony – is sufficient. This criterion was adopted from earlier TOJ studies using a similar SOA range and

similar stimulus material. In the first TOJ task, trials only featured stimuli from the same modality. Here, the threshold was set at a minimum of 80 percent correct responses on trials with SOA (here: 120 ms) (De Paepe, Crombez, Spence, & Legrain, 2014; Vanden Bulcke, Crombez, Spence, & Van Damme, 2014; Vanden Bulcke, Van Damme, Durnez, & Crombez, 2013). The second TOJ experiment presented trials using TOJ stimuli from different modalities. For participants in the bimodal TOJ2, minimal accuracy on trials with the largest SOA (here: 200 ms) was set at 70 percent (Spence, Baddeley, Zampini, James, & Shore, 2003). Both TOJ studies were subject to a final inclusion criterion, which required all Point of Subjective Simultaneity (PSS) measurements Finally, on the final Point of Subjective Simultaneity (PSS) measurements that were derived from TOJ1 and TOJ2, we imposed the criterion that every value must fall within the range of SOAs used in that respective study (-120 to 120 ms, and -200 to 200 ms, respectively).

Statistical analyses

Given that not all of these studies are designed equivalently, each statistical analysis must be approached appropriately. Based on the paradigm used in the study and the definition of the variables involved, further data analysis is divided into three sections.

In *section 1*, we aggregate the data of all TCD studies into a single data frame (139 participants). To further the equivalence of the individual experiments, we omit the feedback group from TCD2 (20 participants) from the dataset. This leaves us with 119 participants. Our aim is to get a unitary model in which the effect of the pain catastrophizing score (PCS) can be tested across all TCD experiments. As an added advantage, this would simultaneously allow

us to see whether there are effects that are present across the board, that is, independent of the experiment number. Participants whose accuracy fell outside of the interquartile range criterion were excluded from further steps.

Our TOJ analyses were not equivalent in terms of design. The first study investigated attention redirection towards a threatened location in multiple modalities, while the second study examined whether the threat of pain can prioritize somatosensory information in general. Because of this, two separate analyses are necessary. In *section 2*, we analyze TOJ1, whereas *section 3* deals with TOJ2.

General model building

In each of the aforementioned sections, a separate model is built. The first model reflects a synthesis of all three TCD studies. Given that this model deals with a collection of multiple datasets from the same paradigm, it yields an opportunity to investigate which effects were most consistent across different experiments. The second and third model serve to examine TOJ1 and TOJ2, respectively, in more detail. These models were designed to provide an optimal fit with the data, mimicking the methodology used in the previous chapters. This process entailed several steps.

Step 1. We entered all relevant factors, and their interactions in the model as fixed factors, including a random effect that introduced adjustments to the intercept conditional on each subject. This includes the PCS covariate and its interactions with the study's independent variables. We determined whether the addition of random effects was necessary for any of the within-subject fixed

factors. If a random effect increased the model's goodness of fit, we included it in the final model.

Step 2. We sought out the most parsimonious model that fit the data by restricting the full model systematically, starting with higher-order terms. All model comparisons were made using likelihood-ratio tests.

Step 3. We inspected the ANOVA table of the final model. Additionally, specific hypotheses and follow-up questions were investigated using contrast analyses. All contrast analyses were corrected for multiple testing according to the corrections of Holm-Bonferroni (Holm, 1979).

Results

In order to verify that participants' individual measurements of dispositional pain catastrophizing were homogenous across different experiments (table 3), we conducted a univariate ANOVA. We found that PCS scores significantly depended on the experiment variable ($\chi^2 = 20.88$, $p < .001$). More specifically, we found that PCS scores were significantly higher in TOJ2 compared to the other experiments that were included ($t_{208} = -4.4$, $p < .001$). This should be taken into account in further interpretation of future results.

Table 3

Pain catastrophizing scores per study.

Study	*Mean*	*Standard deviation*
TCD1	13.59	10.06
TCD2	13.21	7.08
TCD3	14.88	8.14
TOJ1	13.11	8.99
TOJ2	20.56	8.67

Section 1: TCD1-3

We excluded 12 participants from further analyses (4 in TCD1, 5 in TCD2, 3 in TCD3), as the interquartile range criterion branded them outliers (see fig. 1). This left us with a total of 127 participants. To verify that there were no significant differences in participants' pain catastrophizing scores between all three TCD experiments, we again conducted a univariate ANOVA. No differences were found (see fig. 2).

First, the model's random structure was determined (table 4). This structure consisted of a random effect for the variable Location and a random intercept, conditional on each subject. Next, the most parsimonious model was sought (see table 5). This model contained a significant interaction between Location and Threat (see fig. 3), as well as main effects for both these variables (see table 6).

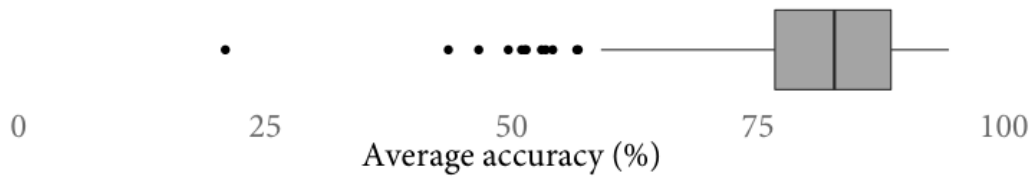


***Figure 1*: Boxplot showing distribution of mean response accuracy, including outlier (black dot) according to interquartile range criterion.**

In order to disentangle this interaction, we conducted follow-up contrast analyses. We found that, in general, change detection accuracy was significantly lowered when threat was presented ($\chi^2 = 60.89$, $p < .001$). When the threatened location was involved in the change, on the other hand, accuracy was not affected ($\chi^2 = 1.66$, $p = .20$). Overall, change detection was better for trials involving change on the threatened location, compared to trials where change was present on another location. This was the case for both threat trials ($\chi^2 = 56.70$, $p < .001$) and neutral trials ($\chi^2 = 10.65$, $p < .01$).

Importantly, pain catastrophizing did not significantly moderate any of the aforementioned effects. To further verify that this pattern of results was not dependent on the Experiment number, we added an additional variable. Upon going through all the steps of our analyses again, we could conclude that the aforementioned findings did not interact with this variable. This may serve as additional support for the robustness of the threat-induced spatial prioritization result.

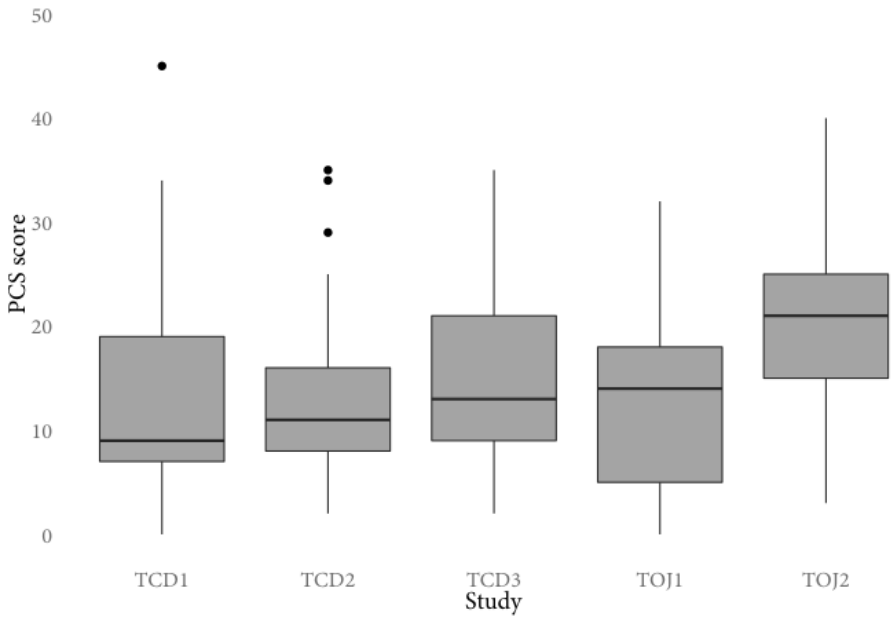


***Figure 2*: Boxplot showing distribution of pain catastrophizing scores per study, including outlier (black dot) according to interquartile range criterion. On average, scores were higher in the final TOJ study.**

Table 4

TCD experiments: Step 1 – Determine random structure.

Model	Test	Random term	Log L	df	χ^2	*p*
1	Initial fit	1	-8924.3	17		
2	Random *Location* (1 vs 2)	1 + *Location*	-8877.4	19	*93.82*	*< .001*
3	Random *Threat* (1 vs 3)	1 + *Threat*	-8922.0	19	*4.64*	*.10*
4	Random *Location* and *Threat* (2 vs 4)	1 + *Location* + *Threat*	-8923.3	22	*0*	*1*

Decision test model 2: add random *Location*; decision test model 3, 4: retain current model

Table 5

TCD experiments: Step 2 – Determine most parsimonious model

Model	Test	Fixed term	Log L	df	χ^2	*p*
2	Maximal model	(Threat + Location + Group + PCS)^4	-8877.4	19		
5	Test significance four-way interaction (5 vs 2)	*minus* Threat x Location x Group x PCS	-8877.7	18	*0.60*	*.44*
6	Test significance three-way interaction (6 vs 5)	*minus* Threat x Location x PCS	-8878.1	17	*0.70*	*.40*
7	Test significance three-way interaction (7 vs 6)	*minus* Threat x Group x PCS	-8878.9	16	*1.59*	*.21*
8	Test significance three-way interaction (8 vs 7)	*minus* Location x Group x PCS	-8880.2	15	*2.61*	*.11*
9	Test significance three-way interaction (9 vs 8)	*minus* Threat x Location x Group	-8881.5	14	*2.68*	*.10*
10	Test significance two-way interaction (10 vs 9)	*minus* Location x PCS	-8881.5	13	*< 0.01*	*.96*
11	Test significance two-way interaction (11 vs 10)	*minus* Location x Group	-8881.5	12	*< 0.01*	*.94*
12	Test significance two-way interaction (12 vs 11)	minus Group x PCS	-8881.5	11	0.05	.83
13	Test significance two-way interaction (13 vs 12)	*minus* Threat x Group	-8881.6	10	*0.06*	*.81*
14	Test significance two-way interaction (14 vs 13)	*minus* Threat x PCS	-8882.0	9	*0.89*	*.35*
Decision test model 5, 6, 7, 8, 9, 10, 11, 12, 13, 14: remove interaction term						

Table 6

TCD experiments: Step 3 – Evaluate final model

Factor	$\widehat{ß}$	$SE(\widehat{ß})$	χ^2	p
Intercept	1.21	0.15	63.66	< .001
Threat	-0.06	0.02	5.76	.02
Location	0.26	0.04	39.38	< .001
Group	0.18	0.13	2.01	.16
PCS	-0.003	< 0.01	0.21	.65
Threat x Location	0.11	0.02	22.02	< .001

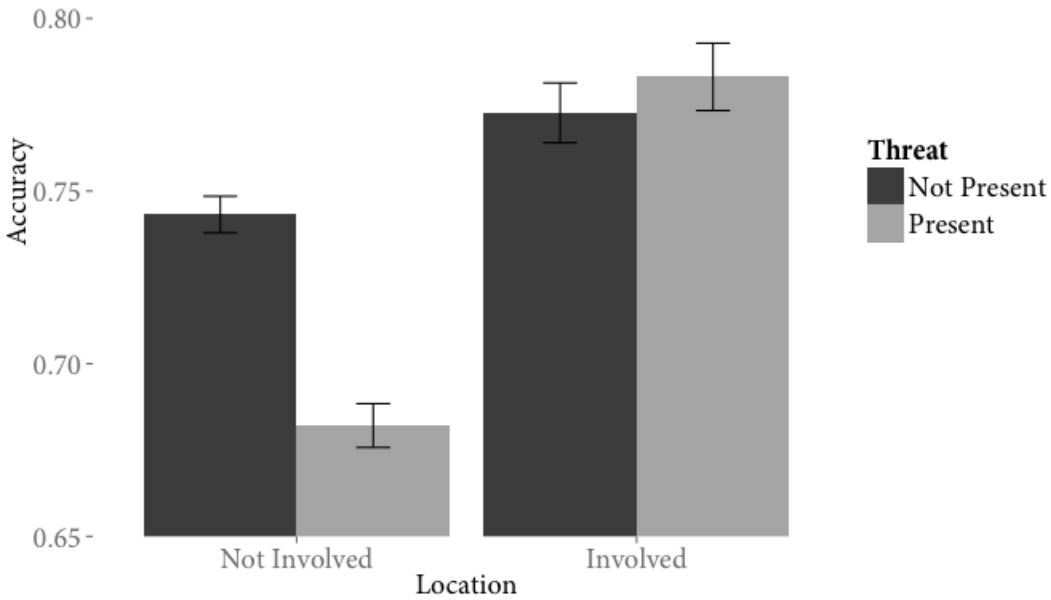


***Figure 3*: Illustration of interaction effect between Location and Threat variables across TCD studies, including two-sided standard error bars.**

Section 2: TOJ1

In parallel with the methods and results sections of chapter 4, we eliminated 4 participants (1 in the comparison group, 3 in the pain control group) and one outlier PSS score from the dataset. The final model needed no random effects (table 7) and showed a marginally significant four-way interaction effect (χ^2 = 3.26, p = .07) (table 8). To further investigate this complex interaction, we simplified the data by separating data from both groups (comparison group and pain control group).

Table 7

TOJ1 experiment: Step 1 – Determine random structure

Model	Test	Random term	Log L	df	χ^2	p
1	Initial fit	1	-664.17	18		
2	Random *Location* (1 vs 2)	1 + *Location*	-663.85	20	*0.65*	*.72*
3	Random *Threat* (1 vs 3)	1 + *Threat*	-664.17	20	*0.00*	*1*
Decision test model 2, 3: retain current model						

Table 8

TOJ1 experiment: Step 3 – Evaluate final model.

Factor	$\hat{ß}$	$SE(\hat{ß})$	χ^2	p
Intercept	1.10	3.50	0.09	.76
Threat	2.87	3.50	0.68	.41
Group	-0.81	3.50	0.05	.82

Modality	-0.75	3.50	0.05	.83
PCS	0.40	0.22	3.30	.07
Threat x Group	0.79	3.50	0.05	.82
Threat x Modality	-0.38	3.50	0.01	.91
Threat x PCS	0.32	0.22	2.06	.15
Group x Modality	-0.27	3.50	< 0.01	.94
Group x PCS	0.35	0.22	2.43	.12
Modality x PCS	0.19	0.22	0.77	.38
Threat x Group x Modality	9.14	3.50	6.84	< .01
Threat x Group x PCS	0.20	0.22	0.84	.36
Threat x Modality x PCS	0.24	0.22	1.18	.28
Group x Modality x PCS	0.15	0.22	0.45	.50
Threat x Group x Modality x PCS	-0.40	0.22	3.26	.07

In the comparison group, we found a significant three-way interaction (χ^2 = 5.40, p = .02) (table 9) (fig. 4). Visual inspection of this interaction effect suggested that increased pain catastrophizing scores are primarily associated with larger PSS values for somatosensory threat trials – that is, trials in which the order of tactile stimuli was to be judged, after being threatened with pain.

Table 9

TOJ1 experiment: Step 3 – Evaluate final model (data restricted to comparison group).

Factor	$\widehat{ß}$	$SE(\widehat{ß})$	χ^2	p
Intercept	1.86	4.67	0.16	.69
Threat	2.09	4.67	0.20	.65
Modality	-0.47	4.67	0.01	.92
PCS	0.06	0.28	0.04	.84
Threat x Modality	-9.52	4.67	4.16	.04
Threat x PCS	0.12	0.28	0.17	.68
Modality x PCS	0.05	0.28	0.02	.87
Threat x Modality x PCS	0.64	0.28	5.40	.02

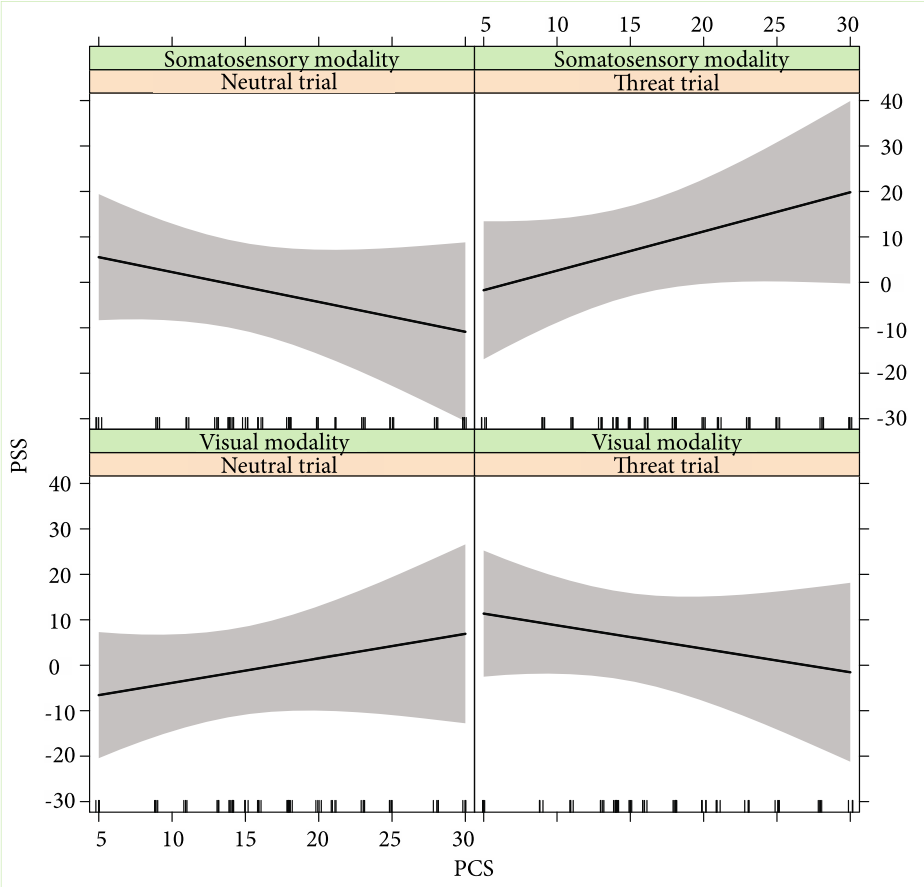


***Figure 4*: Visual illustration of the three-way interaction between Modality, Threat and PCS scores, in comparison group of TOJ1 study.**

In order to numerically verify this visual trend, we conducted separate analyses on visual trials and on somatosensory trials. This revealed a marginally significant interaction between Threat and PCS, but only for somatosensory trials (χ^2 = 3.21, p = .07) (fig. 5). This implies that the prioritization of somatosensory information, delivered to a body location that is under immediate threat of pain, is dependent on participants' tendency to catastrophize. In visual trials, such interaction effect was not detected.

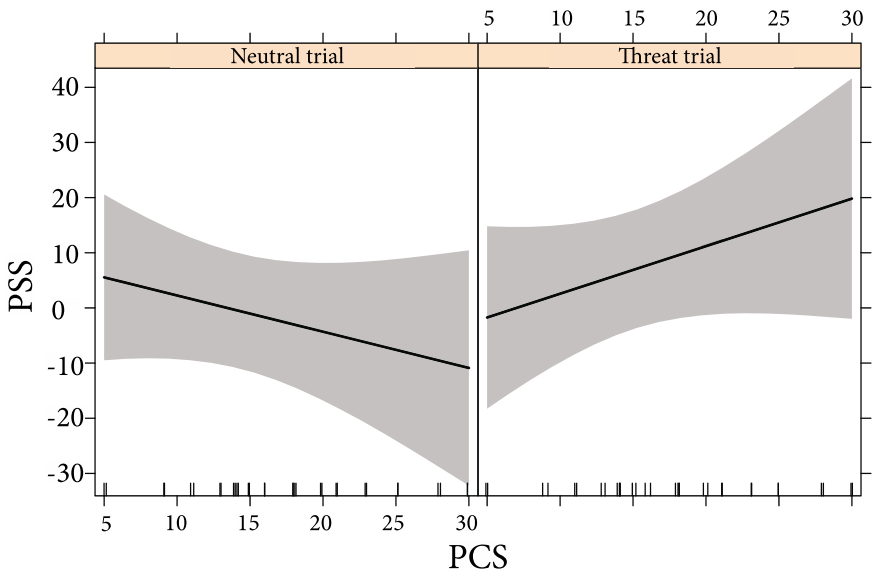


***Figure 3*: Visual illustration of the interaction between Threat and PCS scores, for somatosensory trials in pain control group of TOJ1 study.**

In the pain control group, the most parsimonious model did not include a three-way interaction between Threat, Modality and PCS. Instead, we found a significant interaction between Threat and Modality (χ^2 = 3.21, p = .07), as well as a main effect of Threat (χ^2 = 3.21, p = .07) and of PCS (χ^2 = 3.78, p = .05) (see table 10). The latter indicated that, when pain catastrophizing scores were higher, PSS measurements tended to be higher overall. This suggests that individuals scoring higher on dispositional pain catastrophizing tend to devote more attention to the threatened location, independent of the modality of incoming stimuli or the presence of immediate threat. Crucially, there was no evidence that pain catastrophizing moderated the effects of anticipated pain or attempts to control this pain on attention.

Table 10

TOJ1 experiment: Step 3 – Evaluate final model (data restricted to pain control group).

Factor	$\widehat{ß}$	$SE(\widehat{ß})$	χ^2	p
Intercept	0.25	5.67	< 0.01	.96
Threat	9.84	3.03	10.58	< 0.01
Modality	3.05	3.03	1.02	.31
PCS	0.75	0.39	3.78	.05
Threat x Modality	6.87	3.03	5.16	.02

Section 3: TOJ2

Parallel to method and results sections of chapter 5, we eliminated 3 participants (1 in the comparison group, 2 in the pain control group) whose accuracy on trials with the largest SOA (± 200 ms) fell under the cut-off level of 70 percent. Another participant showed a PSS value outside of the SOA range, leading to this participant's exclusion. This left us with 20 participants in the comparison group, and 18 participants in the pain control group.

The final model needed no random effect (table 11). It included a marginally significant interaction effect between Threat and Group (χ^2 = 3.51, p = .06), a marginally significant main effect of Group (χ^2 = 3.41, p = .07), and a significant main effect of Threat (χ^2 = 22.01, p < .001) (table 12). There was no main effect of PCS, nor did it interact with any of the other variables.

Table 11

TOJ2 experiment: Step 1 – Determine random structure.

Model	Test	Random term	Log L	df	χ^2	*p*
1	Initial fit	1	-365.57	10		
2	Random *Threat* (1 vs 2)	1 + *Threat*	-364.72	12	*1.70*	*.43*
Decision test model 2: retain current model						

Table 12

TOJ2 experiment: Step 3 – Evaluate final model.

Factor	$\widehat{ß}$	$SE(\widehat{ß})$	χ^2	*p*
Intercept	42.50	13.65	9.69	< .001
Threat	15.37	3.28	22.01	< .001
Group	9.52	5.26	3.40	.06
PCS	0.81	0.61	0.19	.19
Threat x Group	6.14	3.28	3.51	.06

Discussion

In the present study, we investigated the potential role of pain catastrophizing in attention to pain and pain-related features. In addition, we assessed the importance of the motivational context – more specifically, engaging in active attempts to control pain – in these effects. We did this by revisiting data from earlier experiments, crucially including dispositional pain catastrophizing scores in the respective statistical analyses.

In the **first** section, we built a new dataset by merging data from different TCD studies. With regard to attentional effects that are a result of either the anticipation of pain or efforts to avoid said pain, the analysis failed to support the role of pain catastrophizing. In other words, pain catastrophizing scores did not impact our measures of attention, nor did they influence the effect of other factors. On a separate note, this compound analysis provided additional evidence for the spatial prioritization of somatosensory stimuli stem presented at a threatened location. It did not support the modulatory role of pain control attempts in this prioritization effect.

In the **second** section, we revisited data from a TOJ study. The intention of this study was to investigate whether attentional prioritization of a particular location of the body, either due to the anticipation of pain at that location or the motivation to control the pain, was specific to the somatosensory modality or modality-independent. New analyses were conducted to include pain catastrophizing as a moderator. Results were inconsistent. We found some evidence that higher pain catastrophizing can be linked to stronger prioritization of somatosensory input, coming from a body location threatened with pain. This was only found in the comparison group – that is, in the group of participants that was not encouraged to avoid the painful stimuli. In the pain control group, on the other hand, pain catastrophizing had an effect on attention to the threatened location, but independent of either the threat manipulation or the modality of the TOJ stimuli. This suggests that, when motivational factors are at play, higher pain catastrophizing scores facilitate an overall attentional shift towards the threatened location.

In the **third** section, we revisited the second TOJ study. This study was designed to investigate the impact of anticipated pain and pain control attempts on attention to somatosensory information, relative to information from other modalities. Incorporating pain catastrophizing into the analyses proved inconsequential, as pain catastrophizing scores did not impact the model's outcome in any way.

In sum, the former series of analyses provides fragmentary and fickle evidence for the role of pain catastrophizing in attention to pain and pain-related features. Only one study suggested that dispositional pain catastrophizing could help explain parts of the experiment's causality. When considering this, several additional observations should be made.

First, we departed from models that intend to explain underlying processes in chronic pain (Eccleston & Crombez, 2007; Leeuw et al., 2007). In contrast, studies that were used in the present analyses included only healthy volunteers. During these studies, an artificial atmosphere of pain anticipation and goal pursuit was created in order to mimic contexts that chronic pain patients may come across. It need not be said that such laboratory setting, with atypical aversive stimulation and artificial motivation induction strategies, is lacking in the department of ecological validity. Chronic pain is a multifaceted issue, whose complexity surpasses our experimental manipulations (Gatchel, Peng, Peters, Fuchs, & Turk, 2007). Therefore, while it would be highly informative to find evidence for the impact of pain catastrophizing on attention in healthy participants, its absence is not an earthshaking finding. In part, this issue is easily remedied. Future research could use somatosensory paradigms, such as the TCD or TOJ task, to compare the impact of pain anticipation and control attempts on attention between healthy volunteers and chronic pain sufferers. It may

also be sensible to measure situational catastrophizing, rather than a dispositional tendency to engage in such thought. In healthy volunteers, the former ad hoc measurements have been found to bear a stronger correlation with experimental pain responses compared to dispositional pain catastrophizing scores (Campbell et al., 2010). This suggests that informative assessment of pain catastrophizing should include both of these measurement types.

A second remark that presents itself is the fact that, throughout our studies, experimental pain was comprised of electrocutaneous stimuli. While this stimulation was effective in evoking fear, it is hardly a commonly encountered form of pain. Moreover, it is evident that an external agent – the set of electrodes – delivers these stimuli. This argues strongly for reconsidering the use of electrocutaneous stimuli in favor of more ecologically valid pain, such as the induction of delayed onset muscle soreness (Clarkson & Tremblay, 1988). This refers to the unpleasant sensation that is typically felt in the muscles after unaccustomed physical activity.

A third worthwhile observation is that pain catastrophizing scores were average in our samples (all between 13 and 15, except TOJ2). This is comparable to an earlier study, where healthy students scored around 16.56 (SD 7.78) on the pain catastrophizing scale. In the same study, chronic back pain patients scored 21.99 (SD 9.31) and fibromyalgia patients scored 24.81 (SD 12.24) (Van Damme, Crombez, Bijttebier, Goubert, & Van Houdenhove, 2002). It may be that the pain catastrophizing scores of our subject samples did not have the appropriate range or variability necessary to detect moderating effects, further supporting the need for studies using clinical population samples.

Fourth, the combination of all three TCD studies further placed an earlier conclusion in question. While we had previously found evidence that pain control motivation was associated with a broadened attentional bias for the spatial feature of pain, generalizing this bias to safe contexts, our integrative analyses of similar studies failed to support this finding. Conversely, in TOJ1, we found a similar generalization effect. More specifically, results showed that participants who attempted to control their pain perceived all information stemming from the threatened location quicker, and this was proportionate to their dispositional pain catastrophizing scores. This prioritization effect was independent from the immediate presentation of threat or the modality of said information.

This may be particularly interesting in sight of clinical models that invoke excessive attention to pain-related information, or hypervigilance, in their explanation of chronic pain. Indeed, hypervigilance has been proposed to emerge when a person's present goal is related to pain control (Crombez, Van Damme, & Eccleston, 2005). Our results suggest that – when participants are prone to pain catastrophizing – such goal pursuit may install a spatial bias for all information coming from the jeopardized limb. This implies that not only somatosensory input is prioritized, but that this prioritization may occur in different modalities alike. Additionally, our analyses found this effect to be independent of the immediate expectation of pain, suggesting that this redirection of attention may manifest itself in a broad, contextual fashion. In light of these results, it appears likely that hypervigilant chronic pain patients' tendency to constantly monitor for threats may well be one that is never mitigated, not even in safe contexts.

Disclosures

This study was supported by a research grant (BOF11/STA/004) by the Special Research Foundation of Ghent University (BOF) awarded to S. Van Damme. There are no conflicts of interest that may arise as a result of this research.

References

Aldrich, S., Eccleston, C., & Crombez, G. (2000). Worrying about chronic pain: vigilance to threat and misdirected problem solving. *Behaviour Research and Therapy*, *38*(5), 457–470. doi:10.1016/S0005-7967(99)00062-5

Borkovec, T. D., Robinson, E., Pruzinsky, T., & DePree, J. A. (1983). Preliminary exploration of worry: Some characteristics and processes. *Behaviour Research and Therapy*, *21*(1), 9–16.

Campbell, C. M., Kronfli, T., Buenaver, L. F., Smith, M. T., Berna, C., Haythornthwaite, J. a., & Edwards, R. R. (2010). Situational Versus Dispositional Measurement of Catastrophizing: Associations With Pain Responses in Multiple Samples. *Journal of Pain*, *11*(5), 443–453.e2. doi:10.1016/j.jpain.2009.08.009

Clarkson, P. M., & Tremblay, I. (1988). Exercise-induced muscle damage, repair and adaptation in humans. *Journal of Applied Physiology*, *65*(1), 1–6.

Crombez, G., Van Damme, S., & Eccleston, C. (2005). Hypervigilance to pain: an experimental and clinical analysis. *Pain*, *116*(1-2), 4–7. doi:10.1016/j.pain.2005.03.035

Crombez, G., Viane, I., Eccleston, C., Devulder, J., & Goubert, L. (2013). Attention to pain and fear of pain in patients with chronic pain. *Journal of Behavioral Medicine*, *36*(4), 371–378. doi:10.1007/s10865-012-9433-1

Davis, C. E. (2014). Pain-related worry in patients with chronic orofacial pain. *The Journal of the American Dental Association*, *145*(7), 722–730.

De Paepe, A. L., Crombez, G., Spence, C., & Legrain, V. (2014). Mapping nociceptive stimuli in a peripersonal frame of reference: evidence from a temporal order judgment task. *Neuropsychologia*, *56*, 219–28. doi:10.1016/j.neuropsychologia.2014.01.016

Eccleston, C., & Crombez, G. (2007). Worry and chronic pain: a misdirected problem solving model. *Pain*, *132*(3), 233–236. doi:10.1016/j.pain.2007.09.014

Gable, P., & Harmon-Jones, E. (2010). The blues broaden, but the nasty narrows: attentional consequences of negative affects low and high in motivational intensity. *Psychological Science : A Journal of the American Psychological Society / APS*, *21*(2), 211–215. doi:10.1177/0956797609359622

Gatchel, R. J., Peng, Y. B., Peters, M. L., Fuchs, P. N., & Turk, D. C. (2007). The biopsychosocial approach to chronic pain: scientific advances and future directions. *Psychological Bulletin*, *133*(4), 581–624. doi:10.1037/0033-2909.133.4.581

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*(2), 65–70. Retrieved from http://www.jstor.org/stable/10.2307/4615733

Janssen, S. A. (2002). Negative affect and sensitization to pain. *Scandinavian Journal of Psychology*, *43*(2), 131–137. doi:10.1111/1467-9450.00278

Lackner, J. M., & Quigley, B. M. (2005). Pain catastrophizing mediates the relationship between worry and pain suffering in patients with irritable bowel syndrome. *Behaviour Research and Therapy*, *43*(7), 943–957. doi:10.1016/j.brat.2004.06.018

Leeuw, M., Goossens, M. E. J. B., Linton, S. J., Crombez, G., Boersma, K., & Vlaeyen, J. W. S. (2007). The fear-avoidance model of musculoskeletal pain: current state of scientific evidence. *Journal of Behavioral Medicine*, *30*(1), 77–94. doi:10.1007/s10865-006-9085-0

Legrain, V., Damme, S. Van, Eccleston, C., Davis, K. D., Seminowicz, D. a, & Crombez, G. (2009). A neurocognitive model of attention to pain: behavioral and neuroimaging evidence. *Pain*, *144*(3), 230–2. doi:10.1016/j.pain.2009.03.020

Spence, C., Baddeley, R., Zampini, M., James, R., & Shore, D. I. (2003). Multisensory temporal order judgments: When two locations are better than one. *Perception & Psychophysics*, *65*(2), 318–328. doi:10.3758/BF03194803

Sullivan, M. J. L., Thorn, B., Haythornthwaite, J. a, Keefe, F., Martin, M., Bradley, L. a, & Lefebvre, J. C. (2001). Theoretical perspectives on the relation between catastrophizing and pain. *The Clinical Journal of Pain*, *17*(1), 52–64. doi:10.1097/00002508-200103000-00008

Van Damme, S., Crombez, G., Bijttebier, P., Goubert, L., & Van Houdenhove, B. (2002). A confirmatory factor analysis of the Pain Catastrophizing Scale: invariant factor structure across clinical and non-clinical populations. *Pain*, *96*, 319–324. Retrieved from http://www.sciencedirect.com/science/article/pii/S0304395901004638

Van Damme, S., Crombez, G., & Eccleston, C. (2002). Retarded disengagement from pain cues: The effects of pain catastrophizing and pain expectancy. *Pain*, *100*(1-2), 111–118. doi:10.1016/S0304-3959(02)00290-7

Vanden Bulcke, C., Crombez, G., Spence, C., & Van Damme, S. (2014). Are the spatial features of bodily threat limited to the exact location where pain is expected? *Acta Psychologica*, *153*, 113–119. doi:10.1016/j.actpsy.2014.09.014

Vanden Bulcke, C., Van Damme, S., Durnez, W., & Crombez, G. (2013). The anticipation of pain at a specific location of the body prioritizes tactile stimuli at that location. *Pain*, *154*(8), 1464–8. doi:10.1016/j.pain.2013.05.009

Vlaeyen, J. W. S., & Linton, S. J. (2000). Fear-avoidance and its consequences in chronic musculoskeletal pain: A state of the art. *Pain*, *85*(3), 317–332. doi:10.1016/S0304-3959(99)00242-0

8 General discussion

It can be somewhat wearisome to finish piecing the puzzle together, only to discover that what you made is not quite what was depicted on the box cover. In this final chapter, we will take a look at the resulting – and the bigger – picture. We begin by reiterating our initial intentions. Then, we will summarize the main findings of our empirical studies, as well as critically evaluate if and how these findings accord with our expectations – or have failed to do so. We then discuss the results in relation to the theoretical framework informing our studies and examine their clinical implications. We conclude with observations and general suggestions of pertinence to future empirical work in this domain.

PRIMARY PREMISES (what we set out to do)

The main objective of the current dissertation was to examine the causal connection between motivational factors and attention to pain. Three principal predictions were made (Van Damme, Legrain, Vogt, & Crombez, 2010).

First, when one is immersed in a context of recurrent pain anticipation, this may – to a certain degree – automatically activate the goal to control this pain. Indeed, the occurrence of pain is evolutionary associated with an instinctively emerging motive to avoid, escape or minimize pain (Eccleston & Crombez, 1999). This can be considered as bottom-up priming of top-down mode of attentional selection (Folk & Remington, 2008). The attentional set hypothesis, as it is outlined in the neurocognitive model of attention to pain (Legrain et al., 2009), lends itself well to produce specific hypotheses on the consequences of such goal-directed attention. This hypothesis states that, when top-down factors

emphasize the immediate relevance of a particular stimulus, the features of this stimulus will be selected by attention with greater ease. Hence we predicted that the threat of pain – in spite of its irrelevance for the current primary goal – would shape the attentional set to include features of the anticipated aversive stimulus. In other words, we expected that individuals threatened with pain would more strongly attend to the features of the expected pain. This, in turn, should prompt attentional prioritization of stimuli that share features with the imminent noxious stimulus. More specifically, we hypothesized that the threat of pain would redirect attention towards the body site where this pain was expected to occur, ensuring that stimuli at that location would be given attentional priority (*spatial feature*). In addition, we proposed that such threat would cause somatosensory stimuli to be processed more swiftly compared to stimuli from other modalities, as pain is in itself a somatosensory occurrence (*modal feature*).

Second, and crucially, we were interested in the effects of active goal pursuit. Maladaptive pain control attempts – and the effects that such motivational factors have on attention – are quintessential components in multiple theoretical explanations of chronic pain (Eccleston & Crombez, 2007; Vlaeyen & Linton, 2000). In spite of this, very few studies investigate attentional effects of actively attempting to escape, control or minimize pain. In the course of this dissertation, we attempted to address this lacuna. We argued that installing pain control as a central goal would enhance attentional prioritization effects. While the mere presentation of painful stimuli can be expected to automatically elicit some degree of pain control motivation, this may be limited when control over these stimuli is impossible. We hypothesized that encouraging our participants to act on their instinct to avoid the experimental pain – and providing them with

instructions on how to pursue this aim – would further bring this pain control goal to the forefront, further emphasizing pain features in the attention set (Cave & Wolfe, 1990).

Third, we wished to investigate to what degree persistent thoughts, laden with negative affect, could moderate the previously hypothesized attentional effects. To accomplish this, we included a measure of dispositional pain catastrophizing in all our experiments. Pain catastrophizing, which has been described as "an exaggerated negative mental set brought to bear during actual or anticipated painful experiences" (Sullivan et al., 2001), is suggested to be a provocative precursor of excessive attention to pain – often referred to as 'hypervigilance' (Crombez, Van Damme, & Eccleston, 2005; Leeuw et al., 2007; Vlaeyen & Linton, 2000). Evidence that such moderation can be observed in healthy volunteers when they are placed in artificial contexts of recurrent pain would make a robust case for the validity of this assertion.

RALLYING RESULTS (what we found)

In **chapter 1**, we investigated whether attempts to control pain would redirect attention towards the body location where this pain was anticipated. To this purpose, we used a Tactile Change Detection (TCD) task. In this paradigm, participants are required to judge whether or not they sensed a difference between two subsequent patterns of somatosensory stimulation, which are each comprised of three simultaneous vibrations at three different body locations. These patterns were either identical, or one location was no longer stimulated in the second pattern, while another was in its stead. Each trial was preceded by one of two possible color cues. In half of all trials, the

cue denoted that one of the body locations (fixed per participant) was likely to receive a painful stimulus. This threat was enforced by occasionally administering a pain-eliciting electrocutaneous stimulus on that body site. In addition, we divided our sample into a pain control group and a comparison group. Participants assigned to the former group were encouraged to actively try and avoid the painful stimulus by quickly pressing a button, whereas those assigned to the latter group received no such instruction. Instead, they performed a comparison task that was not associated with the occurrence of pain. In reality, both groups received an equal amount of electrocutaneous stimuli. Our analyses indicated that, in the comparison group, participants better detected changes at the pain location when threat was presented. Critically, this prioritization of the pain location was more generalized in the pain control group, as it was observed in both threat trials and safe trials alike. This suggests that while the effect of anticipated pain on attention is instantaneous and short-lived, concurrent pain control pursuit broadens this prioritization.

Chapter 2 served to investigate the same hypotheses, though by means of an alternative task. In a ternary synchrony judgment (SJ3) paradigm, participants made judgments about the order in which two tactile stimuli were presented, one on each hand. They could respond by stating which side they perceived first, or alternatively, by giving a 'simultaneous' response. Half of all trials were preceded by a threat-indicative auditory cue, while the other half was preceded by a neutral cue. In case of threat, there was a chance of receiving a painful stimulus. Participants in the pain control condition were given the opportunity to execute a quick button press, which we instructed would lead to a lower chance of receiving electrocutaneous

stimulation. When such stimulation did occur, it was preceded by a feedback message that reinforced the contingency between a speedy response and pain avoidance. Participants in the comparison condition performed a comparable reaction time task that was not related to the experimental pain. They received the same feedback message, but on random trials. We found no evidence for spatial prioritization effects: neither due to the anticipation of pain nor due to attempts to control it.

Inspired by the results mentioned above, we investigated the role of feedback in **chapter 3**. More specifically, we set out to examine whether the prioritization of pain-related information can be construed as an adaptive strategy, designed to monitor the effectiveness of one's efforts towards pain management. To this end, we reprised the experimental design from our first TCD study (chapter 1), in which we again modeled threat trials and safe trials. In addition, we modeled a comparison group and a pain control group. Critically, a third group – the feedback group – was added to the experiment, which also received instructions to avoid the painful stimulus. However, they were told that a feedback message would be presented after they performed their avoidance action, which informed them whether or not it was successful ("Avoided" or "Not avoided"). We hypothesized that spatial prioritization effects would be reduced or abolished in this feedback group. No support could be found for this hypothesis, nor were we able to replicate the pattern of results obtained from the first TCD study (chapter 1). Therefore, we conducted a follow-up experiment that mimicked our initial TCD study. That is, we again included a comparison and pain control group, and associated half of all trials with the threat of pain through means of a set of predictive cues. Our analyses indicated that the anticipation of a

painful stimulus redirected attention towards the threatened body site in both groups. This spatial prioritization effect was in accordance with our first TCD study. We did not, however, find any group differences for said effect, belying the conclusions drawn from our initial experiment. Possible explanations for this discrepancy were discussed.

In **chapter 4**, we investigated whether threat-induced spatial prioritization of a location where pain is expected is particular to somatosensory stimuli, or rather modality-independent. We designed a temporal order judgment (TOJ) task in which participants judged the order of two stimuli that were administered to both hands, by stating which one they experienced first. These stimuli were either visual or tactile, depending on the nature of the experimental block. Additionally, one of these locations was threatened with pain in half of all trials, as predicted by one of two auditory cues. In half of these threat trials the first location was associated with pain, whereas the other location was threatened in the second half of the threat trials. Both the modality of the TOJ stimuli and the location of the anticipated pain were counterbalanced, and the participants were informed about this. Additionally, we investigated the role of pain control motivation. Similar to previous studies, we placed half of our sample in a comparison group, and the other half in a pain control group. The former executed a comparison task contingent on the nature of the cue, while the latter was encouraged to engage in pain control attempts. Results indicated that threat caused prioritization of somatosensory information, but only in the pain control group. No somatosensory prioritization was found in the comparison condition, nor was there any evidence that visual information was prioritized by either the expectation of pain or attempts to exert control

over its manifestation. While these results slightly deviated from our expectations, they did provide additional support for the importance of motivational factors in attention to pain-related information.

Our focus on the modal aspects of attention to pain continued in **chapter 5**. In this chapter, our aim was to investigate whether the threat of pain led to preferential processing of all somatosensory input compared to input from other modalities, and if this prioritization was augmented by active pain control attempts. In this second TOJ experiment, we contrasted visual input with somatosensory information within each trial. Participants judged which they perceived first, a visual stimulus or a tactile stimulus. Auditory cues predicted whether there was a possibility of receiving a painful electrocutaneous stimulus. Parallel to our previous studies, we established two groups. The pain control group was urged to attempt to avoid the painful stimulus, whereas the comparison group engaged in a similar task that was not related to pain control. Results indicated that threat led to prioritization of (innocuous) somatosensory stimuli over information from other modalities. We also found that participants in the pain control group exhibited this prioritization to a stronger degree. Interestingly, pain controllers showed such modal prioritization regardless of the immediate presence of threat, indicating that the emphasis on goal pursuit may generalize this effect to safe contexts.

Finally, in **chapter 6**, we reviewed the majority of the aforementioned experiments to explore the potential moderation of pain catastrophizing. This construct refers to one's individual inclination to engage in repetitive negative thought patterns as a result of being faced with the threat of pain. It

is a concept that has been described in models of chronic pain as a potential determining factor in the effects that anticipated pain and – maladaptive – pain control motivation may have on attention. As such, it was an apt candidate for moderation analyses. However, results were largely inconsistent. In one study, we found that more pain catastrophizing was associated with stronger spatial prioritization of somatosensory information coming from a threatened location of the body. When participants were engaged in pain control pursuit, this moderating effect was generalized to safe trials. It also became independent of the modality of the input, as the effect was no longer restricted to somatosensory trials, but visible in visual trials as well. No other studies offered any concrete evidence that pain catastrophizing played a significant role in their outcomes.

INTEGRATION, IMPLICATIONS AND THEORETICAL THROWBACK

(what this means for contemporary pain theories)

A significant part of our set of hypotheses was centered on the prediction that potentially imminent pain would lead to increased attention to pain features. Several previous studies have investigated how bodily threat may induce an attentional bias for pain-related information. Recently, a meta-analysis was published in this regard, providing us with a broader perspective on the matter (Crombez, Van Ryckeghem, Eccleston, & Van Damme, 2013). This meta-analysis included studies using a behavioral measure of attentional bias to pain, while considering studies in which the processing of pain-related information was not a part of the main task. Three experimental paradigms – often used in anxiety research (Cisler & Koster, 2010) – remained: the modified Stroop task (e.g., Pearce & Morley,

1989), the dot-probe task (e.g., Roelofs, Peters, Van Der Zijden, Thielen, & Vlaeyen, 2003), and the modified spatial cueing task (e.g., Van Damme, Crombez, & Eccleston, 2004). Additionally, the meta-analysis only considered studies that assessed attentional bias towards pain-related information, rather than pain itself. Importantly, the stimuli representing pain-relevant information in each of these studies were mostly images or words. Results indicated a small attentional bias towards pain-related words or pictures in both chronic pain patients and control subjects. It also showed that healthy volunteers' attention was biased towards signals of impending pain. However, the meta-analysis found no evidence for an attentional bias towards pain-related words or pictures in acute, procedural or experimental pain, when applied to healthy volunteers.

The research presented in this dissertation expands on these findings in several ways. First, throughout our empirical studies, we elected to use concrete sensory stimulation, such as electrocutaneous stimuli, tactile stimuli (vibrations) or visual stimuli (LED lights). Such stimuli have been argued to hold greater ecological validity than words or images. More specifically, it is not clear to what degree verbal representations are capable of activating the experimentally desired schemata (Crombez et al., 2013; Moritz et al., 2008). The same can be said of pictures, as they often involve multiple schemata simultaneously. In sum, it is not always evident if these stimuli are adequately associated with pain. By using straightforward sensory events in our experiments, we aspired to increase the ecological validity of our findings.

Second, our studies are mostly concerned with prioritized attention to pain features. This is not the only type of pain-related information that can be considered throughout our experiments. In fact, it could easily be argued

that the valence of our cues was particularly informative of (possible) pain. Anticipated pain and attempts to control its manifestation have been shown to prioritize attention towards such predictive signals of pain before (Notebaert et al., 2011). In contrast, our focus on features of the actual pain stimulus was derived from the neurocognitive model of attention to pain, and from the attentional set hypothesis it propagates (Legrain et al., 2009). The rationale behind this particular angle is in no small part based on clinical considerations, which we will elaborate on in an appropriately titled section.

Does anticipated pain prioritize a threatened location?

The first research question we focused on was whether the anticipation of pain at a specific location of the body would lead to increased attention for somatosensory input at that body site. This was largely confirmed, with some irregularities. We found evidence in favor of this assertion in multiple experiments. Among those affirmative answers were the results of chapter 1 and its replication in the second experiment of chapter 3, both indicating that somatosensory information was picked up with greater accuracy when it was delivered to a body site where pain was expected. This was further confirmed in an integrative analysis across all TCD studies (also including the first experiment in chapter 3). Additionally, results from the TOJ task in chapter 4 indicated that threat prioritized somatosensory input at the threatened location, albeit only in the pain control group. In the comparison group, however, no such prioritization was detected. In chapter 2, finally, our spatial prioritization hypothesis found no support. This may, however, have been caused primarily by methodological issues.

At present, there is additional evidence for the validity of this hypothesis. For instance, a recent TOJ study found that the anticipation of pain on one of both hands led to a faster perception of tactile stimulation on that hand (Vanden Bulcke, Van Damme, Durnez, & Crombez, 2013). In addition, results from follow-up studies suggested that this prioritization is not restricted to one specific location (e.g., the left lower arm), but that it possibly generalizes to the entire body part (e.g., the full length of the left arm) (Vanden Bulcke, Crombez, Spence, & Van Damme, 2014). This was further confirmed in a study using a TCD paradigm (Van Hulle, Durnez, Crombez, & Van Damme, 2015).

Importantly, results from chapter 4 suggested that this spatial prioritization was specific for somatosensory information. This is an interesting finding without precedents, as most of the aforementioned studies focus exclusively on somatosensory information. One previous TOJ study (Van Damme, Gallace, Spence, Crombez, & Moseley, 2009) found that somatosensory attention was biased towards a hand in front of which an image of physical threat (e.g., a knife stabbing a hand) was presented, significantly more so than attention towards auditory input. In contrast, such bias was significantly larger in the auditory modality when general threat (e.g., an exploding truck) was presented. The authors concluded that physically threatening cues induce a modality-specific effect on the processing of somatosensory information, and of generally threatening cues on auditory information processing. However, this study did not incorporate actual pain in its design, which underlines the novelty of the results gained in chapter 4. Crucially, still, our results were found to interact with our pain goal manipulation, which we discuss at length below.

Does anticipated pain prioritize somatosensory input?

As a second research question, we wanted to examine to what degree the expectation of pain can prioritize attention towards somatosensory information in general, compared to – directly competing – information from other modalities. We found support for this hypothesis in chapter 5. The threat of pain caused tactile stimuli to be processed relatively quicker than juxtaposed visual information.

Similar to the modal specificity of spatial prioritization, which we discussed in the previous segment, this result finds a precursor in a TOJ study (Jia, Shi, Zang, & Müller, 2013) using visual representations of threat. More specifically, this experiment demonstrated how images of near-body threat to prioritize tactile input over auditory information. Still, this study too cannot ascertain the effects of anticipated pain.

Of particular interest to the current finding of modal prioritization, a study by Langner and colleagues (Langner et al., 2011) suggested that expecting a stimulus to occur in a specific modality increases baseline activation in that respective sensory cortex, thus improving detection performance. A comparable result can be found in a study using a conditioning test stimulus paradigm, which found that painful conditioning stimuli facilitated processing of tactile test stimuli (Ploner, Pollok, & Schnitzler, 2004). Translated to the presently discussed hypothesis, it is then reasonable to assume that the anticipation of nociceptive stimuli – in itself a somatosensory event – better prepared participants to tackle somatosensory input.

The observation that somatosensory information is given priority when pain is expected is in line with existing theoretical views – such as the neurocognitive model of attention to pain – which state that such threat

may induce a particular set of attentional preferences that help us to prioritize goal-relevant features (Legrain et al., 2009), while inhibiting irrelevant input (Desimone & Duncan, 1995). This goal-directed mode of attentional selection – which we previously referred to as top-down selection – has been suggested to involve parts of the intraparietal cortex and superior frontal cortex (Corbetta & Shulman, 2002).

How does motivation factor in?

Up to this point, we have primarily discussed how the mere anticipation of pain can affect attention. A critical objective of the current dissertation, however, was to investigate how active engagement in pain control behavior could further modulate these processes. Throughout the empirical chapters, we have modeled this behavior by encouraging a portion of each respective subject sample – which we consistently referred to as the pain control group – to attempt to avoid experimental pain by promptly pressing a button in case of a pain-related cue.

In chapter 1, we found that the anticipation of pain at a certain location of the body caused somatosensory stimuli at that site to be prioritized by attention. Interestingly, activating a pain control goal seemed to generalize this effect to safe situations, as it was observed irrespective of the immediate imminence of a potential pain stimulus. This result could not be replicated, however, in follow-up TCD experiments (chapter 3). As such, the validity of this result is not without question. In addition, the SJ study that was conducted in chapter 2 failed to find evidence for the impact of pain control goals in the spatial prioritization of a threatened body site.

In contrast, findings from chapter 4 indicated that pain control motivation prioritized attention for somatosensory information. Interestingly, this effect was only significantly observable in that particular

group. In the comparison group a similar trend was visible, yet not in agreement with the significance criterion. As such, this study suggested that attempts to control pain critically amplified attention to somatosensory input from a threatened body site. Apart from supporting the importance of pain control attempts, this modality-specific result also hinted at the unique importance of the somatosensory modality.

This was reaffirmed in chapter 5, where we found that pain control attempts led to enhanced prioritization of somatosensory information, compared to when such attempts were not made. Remarkably, we found that participants in the pain control group directed more attention to somatosensory input even when there was no immediate threat. This constitutes a second instance where such goal-related generalization was found.

In sum, while the previous results indicated that the role of active goal pursuit should not be neglected, retrieving a consistent pattern of effects proved to be a precarious affair. However, several important factors should be taken into account when reviewing these findings, which we discuss in a later section.

Is pain catastrophizing a likely moderator?

Investigations of the pain catastrophizing construct have furthered our knowledge of its relation to a variety of pain-related outcomes, such as perceived pain intensity (Lackner & Quigley, 2005; Prins, Decuypere, & Van Damme, 2014; Schreiber et al., 2014), pain sensitivity, pain expression, clinical pain severity, depression and disability (Edwards, Bingham, Bathon, & Haythornthwaite, 2006; Sullivan et al., 2001). In addition, several neuroimaging experiments have supported the involvement of catastrophic thought in the processing of pain, reporting differential activation patterns

in areas related to affective processing of pain (ventral lateral PFC, rostral ACC and bilateral insula) and brain regions involved in the top-down modulation of attention to pain (negative correlation with caudal ACC and insular cortex) (Gracely et al., 2004; Quartana, Campbell, & Edwards, 2009; Seminowicz & Davis, 2006).

Interestingly, there has been some evidence that pain catastrophizing can be associated with increased attention for pain-related information. For instance, in a series of auditory discrimination tasks, researchers found that high pain catastrophizers showed a greater amount of attentional interference when threatened with pain (Crombez, Eccleston, Baeyens, & Eelen, 1998). The authors interpreted this finding by suggesting that catastrophizing thoughts may amplify somatosensory information. However, their experiment only measured attention to pain-related information – in this case, a high or low intensity electrocutaneous stimulus – in an indirect manner, by measuring the disruption of a primary task. Taking on a more direct approach, a number of studies demonstrated that a strong inclination towards pain catastrophizing could be associated with a difficulty to disengage attention from predictive signals of impending pain (Van Damme, Crombez, & Eccleston, 2002, 2004a; Van Damme et al., 2004b). Still, these studies teach us very little with regard to the link between negative thoughts and attention to pain features, such as its modality or expected location, specifically.

Our own examination of catastrophic thinking, modeling it as a potential moderator in the aforementioned hypotheses, yielded limited results. The sole study in which such effects were found was the unimodal TOJ study (chapter 4), where comparisons – that is, participants not engaging in attempted pain control – who reported a greater disposition towards catastrophizing showed greater prioritization of somatosensory

information in case of threat. Noteworthy, in the pain control group, we found that higher scores on the pain catastrophizing scale were associated with a speedier perception of information coming from the threated location, independent of modality (visual or somatosensory) or the immediate presentation of a threat-indicative cue. As such, this finding suggests that catastrophic thinking may play a part in the generalizing effect of pain control motivation on attention to pain features.

However, in the remainder of the experiments included in the moderation analyses, no interactions were found. While such moderation was not unthinkable, this lack of results is not overly shocking. On the one hand, robustly demonstrating the impact of negative pain-related thinking in healthy volunteers would have made a strong case for the validity of several explanatory models of chronic pain (Aldrich, Eccleston, & Crombez, 2000; Crombez et al., 2005; Eccleston & Crombez, 2007; Leeuw et al., 2007; Vlaeyen & Linton, 2000). If it were possible to consistently find evidence for such mechanisms in an artificial context of recurrent pain, they could be considered all the more plausible in chronic pain patients, who face such contexts on a daily basis (Gatchel, Peng, Peters, Fuchs, & Turk, 2007). On the other hand, it is precisely this idea that explains why our results should not be completely unexpected. Throughout our studies, we have always investigated attention in healthy undergraduate students, who did not qualify as chronic pain sufferers. As such, it may be unrealistic to assume that the variance in their dispositional catastrophizing scores can be used as an experimental equivalent of negative thought processes, the likes of which have been installed in chronic pain patients in the course of an extended period time. Case in point, measurements of pain catastrophizing in chronic pain patients – suffering from chronic low back pain and fibromyalgia –

have yielded substantially higher scores compared to healthy controls (Van Damme, Crombez, Bijttebier, Goubert, & Van Houdenhove, 2002).

ADDED ANNOTATIONS (what we haven't mentioned yet)

Attempted control does not equal perceived control

As is evident from our empirical chapters, at no point did participants in the pain control group exert actual control over the experimental pain – neither by influencing the intensity of the stimuli, their timing, nor their duration. Consequently, it is possible that at some time during the experiment, participants doubted the effectiveness of their avoidance actions. This was evident, for example, in self-reports of perceived control in chapter 1, which did not differ between the comparison and pain control group. Yet, there are several reasons why this does not imply that our goal manipulation was without merit.

First, our studies were not the first to implement goal induction in its present form. A previous study (Notebaert et al., 2011), designed to investigate attentional prioritization towards visual signals of threat, established pain control motivation in a similar fashion – that is, by associating pain avoidance with a quick button press. Importantly, this study demonstrated attentional prioritization in spite of the absence of contingence between avoidance behavior and the occurrence of pain. In addition, similar to our findings in chapter 1, no difference was found in self-reported perceived control in the experimental groups. These findings thus suggested that the goal to control pain – and not the actual perception of control – produced prioritization of pain-related signals. This argument also holds for our own experiments, particularly since we did find

significant differences in attempted control ratings across empirical chapters.

Second, there is evidence that undermining one's current goal pursuit does not diminish attention for goal-relevant information. It has been demonstrated that goal frustration can in fact lead to stronger activation of these goals (Moskowitz, 2002). In addition, the loss of control and, relatedly, attempts to control pain that cannot be controlled, have been associated with an increase in pain-related fear and attentional interference on a secondary task (Crombez, Eccleston, De Vlieger, Van Damme, & De Clercq, 2008). This is again reminiscent of the aforementioned models of chronic pain, which suggest that these patients are characterized by persistent and dysfunctional goal pursuit (Eccleston & Crombez, 2007; Leeuw et al., 2007). Indeed, chronic pain patients who fail to remove their pain after initial attempts often engage in a more narrow focus on the problem they are attempting to solve at the expense of other goals (Crombez et al., 2005; Van Damme, Crombez, & Eccleston, 2008). In addition, it has been demonstrated that failed attempts to control pain may lead to increased anger and heart rate responses, and in general, maintenance or aggravation of physiological and emotional responses (Janssen, Spinhoven, & Arntz, 2004). Correspondingly, the dysfunctional, futile nature of pain control attempts in the design of our experiments can be argued to provide an interesting quality – while attempted control is not equal to perceived or exerted control, it may yet be suitable parallel to chronic pain goal pursuit.

Notably, a significant amount of experimental studies have examined the effects of perceived control over pain on a variety of pain responses. For instance, the perception that pain can be avoided, escaped or minimized may cause this pain to be anticipated as less intense and less unpleasant (Vancleef & Peters, 2011), as well as actually being perceived as less intense

(Mohr, Leyendecker, Petersen, & Helmchen, 2012; Scharff, Turk, & Marcus, 1995; Weisenberg, Wolf, Mittwoch, Mikulincer, & Aviram, 1985). The potential effects of perceived control have been suggested to be due to the fact that controllability invites one to reappraise the painful experience (Arntz & Claassens, 2004). Functional magnetic resonance imaging has associated this modulation with activation of the anterolateral prefrontal cortex (alPFC) (Wiech et al., 2006). Interestingly, activation in the right alPFC was inversely correlated with participants' general control beliefs. Inadequate activation of this region may then explain how persistent control beliefs potentially give way to uninvited and paradoxical effects on pain perception. Importantly, none of these studies investigate how perceived control may influence attention to pain or pain-related information.

Anticipated pain does not equal actual pain

In this thesis, our primary interest was on the effects of anticipated pain, rather than actual painful stimulation. Therefore, we have consciously and consistently removed all pain trials from our analyses. That is not to say that pain may not influence concurrent sensory perception. For instance, it has been shown that perception of tactile stimuli may be reduced by contemporaneous nociception in both experimental pain (Bolanowski, Gescheider, Fontana, Niemiec, & Tromblay, 2001; Harper & Hollins, 2012) as well as chronic pain (Moseley, Gallace, & Spence, 2009; Moseley, Gallagher, & Gallace, 2012). However, it is important to distinguish these results from our own, as the former relate to sensory interactions between pain and tactile stimuli, while our interest lay with the cognitive mechanisms that are activated by the threat of pain.

Pain control does not (only) equal pain avoidance

In this doctoral thesis, we have attempted to consistently refer to our goal manipulation as 'the goal to control pain' or 'pain control goal'. Nonetheless, it should be noted that all of our experimental manipulations in this matter relied on attempted pain avoidance. This leaves out other potential instances of pain control, such as attempts to get away from ongoing pain (escape) or actions that are meant to alleviate pain (minimization). As we have argued before, we are mainly interested in cognitive processes that spawn in the wake of anticipated pain. Designing experiments in which pain can be escaped or minimized would produce unwanted sensory interactions, which would confound our results in terms of attention. However, it should be noted that this focus on avoidance partially compromises the ecological validity of our research. In contexts of chronic pain, for instance, it is often the case that pain is present over a longer period of time (Gatchel et al., 2007). As such, it would prove interesting to see future research focus on the effects of these different types of control behavior.

CLINICAL CONNECTION (how everything ties in with the real world)

Inspired by actual events

Throughout this dissertation, we have mainly investigated enhanced attention to pain features, brought on by anticipation of pain on the one hand, and attempts to exert control over its occurrence on the other hand. It is important to reaffirm that our research questions, by and large, were inspired by theoretical models of chronic pain (Eccleston & Crombez, 2007; Leeuw et al., 2007). Two main parallels can be found between these models and the design of our experiments.

First, as we argued extensively before, these models propose that some form of maladaptive motivation, directed towards alleviation or abolition of the pain, is at the core of persistent pain complaints. In our experiments, such dysfunctional goal pursuit was modeled by encouraging participants to attempt to avoid a painful stimulus – in spite of the fact that such control was impossible by design. Notably, this does not necessarily mean that participants were completely convinced of the ineffectiveness of their avoidance actions, given that pain was only present in a small percentage of threat trials (1 out of 11). We argued previously that these dysfunctional control attempts, and the ambiguity that encompasses their effectiveness, could serve as an artificial analogon for these clinical mechanisms.

In addition to being inspired by clinical settings, our focus on motivational factors is one that is present in a number of recently published theoretical perspectives (Van Damme et al., 2010; Wiech & Tracey, 2013). These studies critically advocate that two main principles should be taken into account when discussing pain-related attention: (1) pain is an intrinsic motivator and (2) pain is subject to external motivations. We believe that both of these ideas can be found in the present dissertation, as we investigate both the inherent motivational value of pain, as well as the impact of conscious efforts to influence its manifestation. The examination of goals other than pain control, that is, directed towards purposes not related to pain, is beyond the scope of this thesis. Still, there is some evidence that supports the potential impact of such goals on the functioning of attention to pain and concurrent pain goals. For instance, it has been shown that pursuit of a concurrent non-pain goal led to a decrease in pain-related attentional bias (Schrooten et al., 2012). In addition, the presence of competing goals in a pain-context was found to weaken one's tendency to engage in avoidance actions (Claes, Karos, Meulders, Crombez, & Vlaeyen,

2014). As pain often occurs within a pre-existing motivational setting, the importance of these goal interactions and their consequences for pain outcomes represents an important avenue for future research (Karsdorp & Vlaeyen, 2011; Van Damme et al., 2010).

A second parallel between chronic pain models and our experiments can be found in the concept of hypervigilance to pain. This refers to the phenomenon where attention is overly fixated on pain and pain-related information, particularly when one's current goal is related to pain control (Crombez et al., 2005). Explanatory chronic pain models often invoke this construct, proposing that hypervigilance is a critical precursor in the exacerbation of pain perception. When imagining hypervigilance, it is useful to think of an illustration. When someone is confronted with recurrent lower back pain, he or she may become preoccupied with attempts to alleviate or avoid this discomfort. As such, when situations arise that are threatening to the body, this individual may be more likely to scan the body for indications of pain. As such, we argue that our focus on the prioritization of pain features – as predicted by the attentional set hypothesis (Legrain et al., 2009) – can be seen as a functional equivalent of hypervigilance, and hence, particularly informative with regard to its underlying mechanisms.

To reiterate, throughout our experiments, we modeled a recurrent threat of pain, and (dysfunctional) attempts to control this threat. In addition, we investigated to what degree these variables were capable of redirecting attention towards pain features. Consequently, it could be reasoned that the totality of experiments served as a limited laboratory analogon for hypervigilance in chronic pain. In conclusion, we argue that our findings lend added credibility to the clinical models that served as inspiration for our research questions.

Evidently, the latter assertion merits a large caveat. As all our studies involved healthy undergraduate studies, extrapolation of our findings to a clinical population cannot be taken lightly. Additional research, designed to verify the transferability of our conclusions to chronic pain settings, is strongly recommended.

The gist of generalization

On three separate occasions, we have encountered evidence that – in the context of pursued pain control – prioritization effects make take on a more generalized form. Our first TCD study (chapter 1) indicated that the redirection of attention towards a location associated with pain becomes independent of the immediate anticipation of pain, hinting towards more contextualized prioritization of the spatial feature of pain. A second instance of generalization was found in our second TOJ study (chapter 5), where pain controllers were found to strongly attend to somatosensory information, irrespective of the possibility of impending pain. Finally, our overarching analyses in chapter 5 found some evidence that, in a setting of attempted pain control, participants prone to engage in catastrophic thought generally directed more attention to a location associated with pain. More specifically, results indicated that this spatial shift in attention occurred irrespective of the presentation of threatening cues, or the modality of the information presented at the pain-related location.

This pattern of results suggests that excessive attention for a threatened location may be triggered by a context of chronically recurrent painful events and – crucially – a preoccupation with managing these events by exerting control over them. This finding may be particularly interesting in the context of clinical hypervigilance (Crombez et al., 2005). Hypervigilance to pain has been suggested to emerge in 'abnormal'

situations, in which threat is recurrently present (Crombez, Eccleston, & Van Damme, 2004; Crombez et al., 2005). This description applies to each of our experiments, albeit on a smaller scale. Furthermore, hypervigilance is often associated with maladaptive motivation (Crombez et al., 2004; Eccleston & Crombez, 2007; Leeuw et al., 2007). This was modeled throughout our empirical chapters by including a pain control condition, in which participants attempted to control the occurrence of experimental pain stimuli. Finally, increased attention to pain has been associated with a higher tendency to engage in pain catastrophizing (Sullivan et al., 2001). Taken together, our findings suggest hypervigilance is an enduring, contextualized phenomenon, which may manifest itself in the shape of a durable alteration of the attention set (Legrain et al., 2009). In turn, this may cause attention to continuously prioritize somatosensory information or the site of the body with which pain is associated, even when such prioritization is not prompted by signals of threat. When pain catastrophizing is strongly present, attentional selection of information stemming from the pain location may even be generalized to non-somatosensory input.

The inadvertent effects of pain control behavior have been evidenced in previous research efforts. Using a differential conditioning paradigm, it was shown that avoidance behavior in a context of anticipated pain may hamper the extinction of pain-related fear (Volders, Meulders, De Peuter, Vervliet, & Vlaeyen, 2012). According to the fear-avoidance model, the fear of pain may be an important precursor to hypervigilance for pain, and may in turn elicit more persistent pain control behavior (Leeuw et al., 2007; Vlaeyen & Linton, 2000). Finally, it may be interesting to note that the phenomenon of fear generalization and generalized avoidance behavior – as an instrumental response to fear – is well established in anxiety literature (Dymond, Dunsmoor, Vervliet, Roche, & Hermans, 2014).

Tentative conclusions for clinical contexts

We have previously argued that our experiments represent a rudimentary induction of increased vigilance to pain, brought on by the threat of pain and attempts to control its manifestation. In several of our experiments, we have found indications that anticipated pain may lead to heightened detection of pain features, as predicted by the neurocognitive model of attention to pain (Legrain et al., 2009). Crucially, our results indicated that pain control attempts could enhance this attentional focus, or generalize it to – in principle – safe contexts. In turn, this pattern of attentional prioritization may eventually aggravate pain perception (Vlaeyen & Linton, 2000). Our findings thus hint towards the value of clinical interventions that are designed to counter such dysfunctional pain control pursuit. As a consequence, they favor approaches that center on acceptance are particularly useful in dealing with clinical afflictions such as chronic pain. Two prevalent – and closely related – strategies in this regard are Acceptance and Commitment Therapy (Hayes, Luoma, Bond, Masuda, & Lillis, 2006) and mindfulness-based approaches (Davis & Hayes, 2011; Kabat-Zinn, Lipworth, Burney, & Sellers, 1987). These treatments are both exemplars of the third generation of behavior therapy. This third wave of interventions does not concern itself with attempts to eliminate narrowly defined problems. Instead, it focuses on the context a problem presents itself in, and the manner in which this problem is experienced by the patient.

In support of such strategies, a recent meta-analysis found that mindfulness-based therapies were effective in improving depressive symptoms, anxiety, stress, quality of life and physical functioning (Gotink et al., 2015). Additionally, a meta-analytic review of experimental research on acceptance-based clinical approaches indicated that these strategies were

particularly effective in raising pain tolerance, while providing effects on pain intensity and negative affect that are at least similar to other emotion regulation strategies (Kohl, Rief, & Glombiewski, 2012).

LINGERING LIMITATIONS (what can be expanded upon)

While we have presently argued the merits of this doctoral dissertation and its results, this work is not without limitations. First, throughout this thesis, we have strictly used paradigms that incorporate somatosensory stimuli, including tactile and nociceptive stimuli. The reason for this was to optimize the ecological validity of our results, given general criticisms on the ecological validity of pain research (Crombez et al., 2013; Van Damme et al., 2010). However, these paradigms were not without drawbacks. This was first evidenced by our difficulty in obtaining consistent results using the tactile change detection paradigm (chapters 1 and 3). A possible explanation for these discrepancies can be sought in terms of statistical power. Calculating power for these experiments was exceptionally difficult, both due to the complexity of the design (involving a three-way interaction) and the model we used to analyze the results (a mixed-effect logistic regression model). Currently, there are no standardized methods to solve this problem. As a consequence, however, this left our experiments exposed. Typically, low power is associated with a lowered chance of detecting a true effect. However, it also reduces the chance that observed significance reflects true effects (Ioannidis, 2005). This may explain how the reproducibility of these particular results proved to be difficult. A similar issue can be found in our TOJ studies, in the sense that the complexity of the expected interaction and/or the particular set of used experimental stimuli made power

calculations difficult. An alternative, then, was to calculate post-hoc power. The value of this lies specifically with the investigation of statistically non-significant results (Lenth, 2007), and its usefulness can often be debated (O'Keefe, 2007).

Second, in several chapters we have used either TOJ or SJ paradigms. These paradigms contrast the processing speed of two temporally adjacent stimuli, and are useful to measure attentional shift to one or the other. The principal outcome used in these paradigms – the point of subjective simultaneity (PSS), is derived from fitting psychometric functions to proportions of responses (e.g., the amount of left-first responses on the total number of observations) per stimulus onset asynchrony (SOA). Often used psychometric functions, in this regard, are Gaussian curves (Spence, Shore, & Klein, 2001). Presently, however, we elected to implement functions based on independent-channels model – a choice that we have further substantiated in chapters 4 and 5 (Alcalá-Quintana & García-Pérez, 2013). The precision of PSS measurements is very much dependent on the total number of observations. For example, an accidental judgment error or erroneous button press does a lot more damage when there are 5 observations per SOA (20% shift of the respective data point) compared to when this SOA is presented 40 times (2.5% shift of this data point). However, while a recommendation for experiments with a large quantity of trials is methodologically grounded, there are several factors that can get in the way of achieving this. On the one hand, our participants are human. That means that they are cursed with a limited attention span (van Swinderen, 2007). Designing overly lengthy experiments would severely strain selective attention. Cutting these sessions up into different parts creates problems of its own, as this may cause in an equality of certain experimental parameters – such as perceived pain intensity, perceived

intensity of the tactile stimuli on either hand, et cetera. On the other hand, the nature of our research questions imposes a different restriction on these data: we need to compare several conditions. This means that the total number of observations must be divided by the number of within-variable level combinations. For example, half of the trials could be associated with threat, whereas the other half are not. We thus require not one, but two PSS measurements, each calculated using half of the total number of trials. Of course, we could design experiments where all variables were manipulated between subjects, but this would be very inefficient in terms of power and the total number of participants required.

Third, we have directed significant efforts towards the development of adaptive procedures, designed to obtain appropriate levels of stimulus intensity for each of our participants (see addendum). This was undoubtedly necessary, as it has been proven that people differ in terms of somatosensory sensitivity with regard to laterality, gender or the specific body site that is stimulated (Weinstein, 1968). Similarly, one's pain threshold may depend on the measurement site (Fillingim, Edwards, & Powell, 1999) or gender (Riley, Robinson, Wise, Myers, & Fillingim, 1998). We argue that the development and consistent use of adaptive procedures, designed to counter this inter- and intra-individual variation, remains of significant importance.

OPEN OPPORTUNITIES (what can be done in the future)

As we gathered our studies' results, several future opportunities became apparent. First, as we have discussed in chapter 6, it may be interesting to include situational measurements of pain catastrophizing when conducting future studies with healthy volunteers. It has been shown

that such situational measurements do not necessarily correlate with dispositional catastrophizing scores (Campbell et al., 2010). In addition, situational catastrophizing was found to bear a stronger connection to experimental pain responses. This may in part explain why our moderation analyses (chapter 6) came up with underwhelming results. We recommend the use of situational measurements when investigating attention to pain in healthy volunteers (Quartana et al., 2009).

Second, when comparing effects of threat and motivation on information from different modalities (in chapters 4 and 5), we have typically used visual information as an instance of non-somatosensory modalities. We have little reason to assume that our findings would differ if other modalities – such as sound – are implemented into our studies. Regardless, replication of our findings using such stimulation as a counterpart to tactile information would further bolster our findings, and validate the generalizability of our conclusions.

Third, as we have discussed a length earlier, our research questions draw heavily from theoretical models that center on chronic pain. However, as we have strictly used healthy undergraduate students, we cannot simply extrapolate our findings to such clinical contexts. Instead, we investigated how fundamental cognitive mechanisms could be manipulated by threat and maladaptive motivation. It is evident that it would be interesting to bring our research questions to a chronic pain population. In this regard, the modeling of ecologically valid pain control behavior would be particularly challenging. One possible avenue for experimentation lies in the inclusion of movements that are habitually associated with pain in that particular clinical subgroup. For instance, chronic low back pain patients may be apprehensive of being asked to lift heavy objects. Control, in this case, could be modeled by allowing participants to engage in avoidance or

escape behavior. That is, they may be instructed that a certain action could prevent them from being required to execute the feared movement, or they may be given a chance to choose to abort the requested movement.

Fourth, as we have discussed earlier, pain control behavior is not restricted to avoidance. Escape attempts, or actions directed towards minimization of the pain experience, may differ in their impact on attention. Given that chronic pain can easily be associated with these different coping responses, it would be interesting to conduct experiments that focus on the quality of pain control motivation. As we have hinted before, designing such experiments may bring forth distinct challenges. The use of thermal stimulation could be useful in this regard, as a high temperature stimulus could be administered over a longer period of time. This would allow the investigation of escape behavior – by stopping the stimulus – or other forms of pain management, such as lowering the intensity to levels that are still disagreeable.

CLOSING CONCLUSION (how we can draw the curtains)

The present dissertation investigated how the threat of pain – and critically, attempts to exert control over its manifestation – impacted attention to pain-related features. In a series of somatosensory experiments, we found evidence that anticipating pain redirected attention towards the body site where this pain was expected. In addition, one study indicated that this effect might be modality-specific, that is, particular to the somatosensory modality. When comparing contemporaneously competing input from different modalities, we found that the expectation of pain caused somatosensory input to be preferentially processed over information

from other modalities. Crucially, we found some evidence that (dysfunctional) pain control attempts modulate these prioritization effects, either by enhancing the effects or by generalizing them to safe situations. Still, these findings were not consistent across the board. In addition, the studies reported here did not support a connection between the aforementioned cognitive effects and a dispositional tendency towards pain catastrophizing. Supplementary efforts to investigate this may be appropriate. Finally, the present thesis investigates fundamental cognitive mechanisms that have been suggested to be involved in the maintenance and exacerbation of chronic pain, and as such, may eventually contribute to our understanding of dysfunctional attention in clinical settings.

References

Alcalá-Quintana, R., & García-Pérez, M. a. (2013). Fitting model-based psychometric functions to simultaneity and temporal-order judgment data: MATLAB and R routines. *Behavior Research Methods*, *45*, 972–98. doi:10.3758/s13428-013-0325-2

Aldrich, S., Eccleston, C., & Crombez, G. (2000). Worrying about chronic pain: vigilance to threat and misdirected problem solving. *Behaviour Research and Therapy*, *38*(5), 457–470. doi:10.1016/S0005-7967(99)00062-5

Arntz, A., & Claassens, L. (2004). The meaning of pain influences its experienced intensity. *Pain*, *109*(1-2), 20–25. doi:10.1016/j.pain.2003.12.030

Bolanowski, S. J., Gescheider, G. A., Fontana, A. M., Niemiec, J. L., & Tromblay, J. L. (2001). The effects of heat-induced pain on the detectability, discriminability, and sensation magnitude of vibrotactile stimuli. Somatosensory & motor research (Vol. 18). doi:10.1080/08990

Campbell, C. M., Kronfli, T., Buenaver, L. F., Smith, M. T., Berna, C., Haythornthwaite, J. a., & Edwards, R. R. (2010). Situational Versus Dispositional Measurement of Catastrophizing: Associations With Pain Responses in Multiple Samples. *Journal of Pain*, *11*(5), 443–453.e2. doi:10.1016/j.jpain.2009.08.009

Cave, K. R., & Wolfe, J. M. (1990). Modeling the role of parallel processing in visual search. *Cognitive Psychology*, *22*(2), 225–271. doi:10.1016/0010-0285(90)90017-X

Cisler, J. M., & Koster, E. H. W. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: An integrative review. *Clinical Psychology Review*, *30*(2), 203–16. doi:10.1016/j.cpr.2009.11.003

Claes, N., Karos, K., Meulders, A., Crombez, G., & Vlaeyen, J. (2014). Competing goals attenuate avoidance behavior in the context of pain. *Pain*, *15*(11), 1120–1129. doi:10.1016/j.jpain.2014.08.003

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews. Neuroscience*, *3*(3), 201–15. doi:10.1038/nrn755

Crombez, G., Eccleston, C., Baeyens, F., & Eelen, P. (1998). When somatic information threatens, catastrophic thinking enhances attentional interference. *Pain*, *75*(2-3), 187–198. doi:10.1016/S0304-3959(97)00219-4

Crombez, G., Eccleston, C., De Vlieger, P., Van Damme, S., & De Clercq, A. (2008). Is it better to have controlled and lost than never to have controlled at all? An experimental investigation of control over pain. *Pain*, *137*(3), 631–9. doi:10.1016/j.pain.2007.10.028

Crombez, G., Eccleston, C., & Van Damme, S. (2004). Hypervigilance and attention to pain, 1–4. Retrieved from http://opus.bath.ac.uk/6665/

Crombez, G., Van Damme, S., & Eccleston, C. (2005). Hypervigilance to pain: an experimental and clinical analysis. *Pain*, *116*(1-2), 4–7. doi:10.1016/j.pain.2005.03.035

Crombez, G., Van Ryckeghem, D. M. L., Eccleston, C., & Van Damme, S. (2013). Attentional bias to pain-related information: a meta-analysis. *Pain*, *154*(4), 497–510. doi:10.1016/j.pain.2012.11.013

Davis, D. M., & Hayes, J. A. (2011). What are the benefits of mindfulness? A practice review of psychotherapy-related research. *Psychotherapy (Chicago, Ill.)*, *48*(2), 198–208. doi:10.1037/a0022062

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*, 193–222. doi:10.1146/annurev.ne.18.030195.001205

Dymond, S., Dunsmoor, J. E., Vervliet, B., Roche, B., & Hermans, D. (2014). Fear Generalization in Humans: Systematic Review and Implications for Anxiety Disorder Research. *Behavior Therapy*. doi:10.1016/j.beth.2014.10.001

Eccleston, C., & Crombez, G. (1999). Pain demands attention. *Psychological Bulletin*, *125*(3), 356–366.

Eccleston, C., & Crombez, G. (2007). Worry and chronic pain: a misdirected problem solving model. *Pain*, *132*(3), 233–236. doi:10.1016/j.pain.2007.09.014

Edwards, R. R., Bingham, C. O., Bathon, J., & Haythornthwaite, J. A. (2006). Catastrophizing and pain in arthritis, fibromyalgia, and other rheumatic diseases. *Arthritis Care and Research*. doi:10.1002/art.21865

Fillingim, R. B., Edwards, R. R., & Powell, T. (1999). The relationship of sex and clinical pain to experimental pain responses. *Pain*, *83*(3), 419–425.

Folk, C. L., & Remington, R. W. (2008). Bottom-up priming of top-down attentional control settings. *Visual Cognition*, *16*(2-3), 215–231. doi:10.1080/13506280701458804

Gatchel, R. J., Peng, Y. B., Peters, M. L., Fuchs, P. N., & Turk, D. C. (2007). The biopsychosocial approach to chronic pain: scientific advances and future directions. *Psychological Bulletin*, *133*(4), 581–624. doi:10.1037/0033-2909.133.4.581

Gotink, R. a., Chu, P., Busschbach, J. J. V., Benson, H., Fricchione, G. L., & Hunink, M. G. M. (2015). Standardised Mindfulness-Based Interventions in Healthcare: An Overview of Systematic Reviews and Meta-Analyses of RCTs. *Plos One*, *10*(4), e0124344. doi:10.1371/journal.pone.0124344

Gracely, R. H., Geisser, M. E., Giesecke, T., Grant, M. a B., Petzke, F., Williams, D. A., & Clauw, D. J. (2004). Pain catastrophizing and neural responses to pain among persons with fibromyalgia. *Brain*, *127*(4), 835–843. doi:10.1093/brain/awh098

Harper, D. E., & Hollins, M. (2012). Is touch gating due to sensory or cognitive interference? *Pain*, *153*(5), 1082–1090. doi:10.1016/j.pain.2012.02.011

Hayes, S. C., Luoma, J. B., Bond, F. W., Masuda, A., & Lillis, J. (2006). Acceptance and Commitment Therapy: Model , processes and outcomes, *44*, 1–25. doi:10.1016/j.brat.2005.06.006

Ioannidis, J. P. A. (2005). Why most published research findings are false. *PLoS Medicine*. doi:10.1371/journal.pmed.0020124

Janssen, S. A., Spinhoven, P., & Arntz, A. (2004). The effects of failing to control pain: an experimental investigation. *Pain*. Retrieved from http://ac.els-cdn.com/S0304395903004548/1-s2.0-S0304395903004548-main.pdf?_tid=a38bc4aa-3cb7-11e4-9d0a-00000aacb361&acdnat=1410772194_a6f9d3220649a9bbcd9ada8b5c83d307

Jia, L., Shi, Z., Zang, X., & Müller, H. J. (2013). Concurrent emotional pictures modulate temporal order judgments of spatially separated audio-tactile stimuli. *Brain Research*, *1537*, 156–163. doi:10.1016/j.brainres.2013.09.008

Kabat-Zinn, J., Lipworth, L., Burney, R., & Sellers, W. (1987). Four-Year Follow-Up of a Meditation-Based Program for the Self-Regulation of Chronic Pain: Treatment Outcomes and Compliance. *The Clinical Journal of Pain*. doi:10.1097/00002508-198703010-00010

Karsdorp, P. A., & Vlaeyen, J. W. S. (2011). Goals matter: Both achievement and pain-avoidance goals are associated with pain severity and disability in patients with low back and upper extremity pain. *Pain*, *152*(6), 1382–1390. doi:10.1016/j.pain.2011.02.018

Kohl, A., Rief, W., & Glombiewski, J. A. (2012). How effective are acceptance strategies? A meta-analytic review of experimental results. *Journal of Behavior Therapy and Experimental Psychiatry*, *43*(4), 988–1001. doi:10.1016/j.jbtep.2012.03.004

Lackner, J. M., & Quigley, B. M. (2005). Pain catastrophizing mediates the relationship between worry and pain suffering in patients with irritable bowel syndrome. *Behaviour Research and Therapy*, *43*(7), 943–957. doi:10.1016/j.brat.2004.06.018

Langner, R., Kellermann, T., Boers, F., Sturm, W., Willmes, K., & Eickhoff, S. B. (2011). Modality-specific perceptual expectations selectively modulate baseline activity in auditory, somatosensory, and visual cortices. *Cerebral Cortex*, *21*(12), 2850–2862. doi:10.1093/cercor/bhr083

Leeuw, M., Goossens, M. E. J. B., Linton, S. J., Crombez, G., Boersma, K., & Vlaeyen, J. W. S. (2007). The fear-avoidance model of musculoskeletal pain: current state of scientific evidence. *Journal of Behavioral Medicine*, *30*(1), 77–94. doi:10.1007/s10865-006-9085-0

Legrain, V., Damme, S. Van, Eccleston, C., Davis, K. D., Seminowicz, D. a, & Crombez, G. (2009). A neurocognitive model of attention to pain: behavioral and neuroimaging evidence. *Pain*, *144*(3), 230–2. doi:10.1016/j.pain.2009.03.020

Lenth, R. V. (2007). Post Hoc Power : Tables and Commentary. *Science*.

Mohr, C., Leyendecker, S., Petersen, D., & Helmchen, C. (2012). Effects of perceived and exerted pain control on neural activity during pain relief in experimental heat hyperalgesia: a fMRI study. *European Journal of Pain (London, England)*, *16*(4), 496–508. doi:10.1016/j.ejpain.2011.07.010

Moritz, S., Fischer, B. K., Hottenrott, B., Kellner, M., Fricke, S., Randjbar, S., & Jelinek, L. (2008). Words may not be enough! No increased emotional Stroop effect in obsessive-compulsive disorder. *Behaviour Research and Therapy*, *46*(9), 1101–1104. doi:10.1016/j.brat.2008.05.005

Moseley, G. L., Gallace, A., & Spence, C. (2009). Space-based, but not arm-based, shift in tactile processing in complex regional pain syndrome and its relationship to cooling of the affected limb. *Brain : A Journal of Neurology*, *132*(Pt 11), 3142–51. doi:10.1093/brain/awp224

Moseley, G. L., Gallagher, L., & Gallace, A. (2012). Neglect-like tactile dysfunction in chronic back pain. *Neurology*, *79*(4), 327–332. doi:10.1212/WNL.0b013e318260cba2

Moskowitz, G. B. (2002). Preconscious effects of temporary goals on attention. *Journal of Experimental Social Psychology*, *38*(4), 397–404. doi:10.1016/S0022-1031(02)00001-X

Notebaert, L., Crombez, G., Vogt, J., De Houwer, J., Van Damme, S., & Theeuwes, J. (2011). Attempts to control pain prioritize attention towards signals of pain: an experimental study. *Pain*, *152*(5), 1068–1073. doi:10.1016/j.pain.2011.01.020

O'Keefe, D. J. (2007). Brief Report: Post Hoc Power, Observed Power, A Priori Power, Retrospective Power, Prospective Power, Achieved Power: Sorting Out Appropriate Uses of Statistical Power Analyses. *Communication Methods and Measures*. doi:10.1080/19312450701641375

Pearce, J., & Morley, S. (1989). An experimental investigation of the construct validity of the McGill Pain Questionnaire. *Pain*, *39*(1), 115–121. doi:10.1016/0304-3959(89)90182-6

Ploner, M., Pollok, B., & Schnitzler, A. (2004). Pain facilitates tactile processing in human somatosensory cortices. *Journal of Neurophysiology*, *92*(3), 1825–1829. doi:10.1152/jn.00260.2004

Prins, B., Decuypere, A., & Van Damme, S. (2014). Effects of mindfulness and distraction on pain depend on individual differences in pain catastrophizing: An experimental study. *European Journal of Pain*, *18*(9), 1307–1315.

Quartana, P. J., Campbell, C. M., & Edwards, R. R. (2009). Pain catastrophizing: a critical review. *Expert Rev Neurother*, *9*(5), 745–758. doi:10.1586/ERN.09.34.Pain

Riley, J. L., Robinson, M. E., Wise, E. A., Myers, C. D., & Fillingim, R. B. (1998). Sex differences in the perception of noxious experimental stimuli: A meta-analysis. *Pain*, *74*(2-3), 181–187. doi:10.1016/S0304-3959(97)00199-1

Roelofs, J., Peters, M. L., Van Der Zijden, M., Thielen, F. G. J. M., & Vlaeyen, J. W. S. (2003). Selective attention and avoidance of pain-related stimuli: A dot-probe evaluation in a pain-free population. *Journal of Pain*, *4*(6), 322–328. doi:10.1016/S1526-5900(03)00634-5

Scharff, L., Turk, D. C., & Marcus, D. A. (1995). The relationship of locus of control and psychosocial-behavioral response in chronic headache. *Headache*, *35*(9), 527–533. doi:10.1111/j.1526-4610.1995.hed3509527.x

Schreiber, K. L., Campbell, C. C., Martel, M. O., Greenbaum, S., Wasan, A. D., Borsook, D., … Edwards, R. R. (2014). Distraction analgesia in chronic pain patients: The impact of catastrophizing. *Anesthesiology*, *121*, 1292–1301.

Schrooten, M. G. S., Van Damme, S., Crombez, G., Peters, M. L., Vogt, J., & Vlaeyen, J. W. S. (2012). Nonpain goal pursuit inhibits attentional bias to pain. *Pain*, *153*(6), 1180–1186. doi:10.1016/j.pain.2012.01.025

Seminowicz, D. a., & Davis, K. D. (2006). Cortical responses to pain in healthy individuals depends on pain catastrophizing. *Pain*, *120*(3), 297–306. doi:10.1016/j.pain.2005.11.008

Spence, C., Shore, D. I., & Klein, R. M. (2001). Multisensory prior entry. *Journal of Experimental Psychology: General*, *130*(4), 799–832.

Sullivan, M. J. L., Thorn, B., Haythornthwaite, J. a, Keefe, F., Martin, M., Bradley, L. a, & Lefebvre, J. C. (2001). Theoretical perspectives on the relation between catastrophizing and pain. *The Clinical Journal of Pain*, *17*(1), 52–64. doi:10.1097/00002508-200103000-00008

Van Damme, S., Crombez, G., Bijttebier, P., Goubert, L., & Van Houdenhove, B. (2002). A confirmatory factor analysis of the Pain Catastrophizing Scale: invariant factor structure across clinical and non-clinical populations. *Pain*, *96*, 319–324. Retrieved from http://www.sciencedirect.com/science/article/pii/S0304395901004638

Van Damme, S., Crombez, G., & Eccleston, C. (2002). Retarded disengagement from pain cues: The effects of pain catastrophizing and pain expectancy. *Pain*, *100*(1-2), 111–118. doi:10.1016/S0304-3959(02)00290-7

Van Damme, S., Crombez, G., & Eccleston, C. (2004a). Disengagement from pain: The role of catastrophic thinking about pain. *Pain*, *107*(1-2), 70–76. doi:10.1016/j.pain.2003.09.023

Van Damme, S., Crombez, G., & Eccleston, C. (2004b). The anticipation of pain modulates spatial attention: evidence for pain-specificity in high-pain catastrophizers. *Pain*, *111*(3), 392–399. doi:10.1016/j.pain.2004.07.022

Van Damme, S., Crombez, G., & Eccleston, C. (2008). Coping with pain: A motivational perspective. *Pain*, *139*(1), 1–4. doi:10.1016/j.pain.2008.07.022

Van Damme, S., Gallace, A., Spence, C., Crombez, G., & Moseley, G. L. (2009). Does the sight of physical threat induce a tactile processing bias? Modality-specific attentional facilitation induced by viewing threatening pictures. *Brain Research*, *1253*, 100–106. doi:10.1016/j.brainres.2008.11.072

Van Damme, S., Legrain, V., Vogt, J., & Crombez, G. (2010). Keeping pain in mind: a motivational account of attention to pain. *Neuroscience and Biobehavioral Reviews*, *34*(2), 204–213. doi:10.1016/j.neubiorev.2009.01.005

Van Hulle, L., Durnez, W., Crombez, G., & Van Damme, S. (2015). Detection of tactile change on a bodily location where pain is expected. *Perceptual & Motor Skills: Perception*, *120*(1), 219–231.

Van Swinderen, B. (2007). The attention span of a fly. *Fly*, *1*(3), 187–189.

Vancleef, L. M. G., & Peters, M. L. (2011). The influence of perceived control and self-efficacy on the sensory evaluation of experimentally induced pain. *Journal of*

Behavior Therapy and Experimental Psychiatry, *42*(4), 511–7. doi:10.1016/j.jbtep.2011.05.006

Vanden Bulcke, C., Crombez, G., Spence, C., & Van Damme, S. (2014). Are the spatial features of bodily threat limited to the exact location where pain is expected? *Acta Psychologica*, *153*, 113–119. doi:10.1016/j.actpsy.2014.09.014

Vanden Bulcke, C., Van Damme, S., Durnez, W., & Crombez, G. (2013). The anticipation of pain at a specific location of the body prioritizes tactile stimuli at that location. *Pain*, *154*(8), 1464–8. doi:10.1016/j.pain.2013.05.009

Vlaeyen, J. W. S., & Linton, S. J. (2000). Fear-avoidance and its consequences in chronic musculoskeletal pain: A state of the art. *Pain*, *85*(3), 317–332. doi:10.1016/S0304-3959(99)00242-0

Volders, S., Meulders, A., De Peuter, S., Vervliet, B., & Vlaeyen, J. W. S. (2012). Safety behavior can hamper the extinction of fear of movement-related pain: An experimental investigation in healthy participants. *Behaviour Research and Therapy*, *50*(11), 735–746. doi:10.1016/j.brat.2012.06.004

Weinstein, S. (1968). Intensive and extensive aspects of tactile sensitivity as a function of body part, sex and laterality. In D. R. Kenshalo (Ed.), *The Skin Senses* (pp. 195–200). IL: Thomas Springfield.

Weisenberg, M., Wolf, Y., Mittwoch, T., Mikulincer, M., & Aviram, O. (1985). Subject versus experimenter control in the reaction to pain. *Pain*, *23*(2), 187–200. doi:10.1016/0304-3959(85)90059-4

Wiech, K., Kalisch, R., Weiskopf, N., Pleger, B., Stephan, K. E., & Dolan, R. J. (2006). Anterolateral prefrontal cortex mediates the analgesic effect of expected and perceived control over pain. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *26*(44), 11501–9. doi:10.1523/JNEUROSCI.2568-06.2006

Wiech, K., & Tracey, I. (2013). Pain, decisions, and actions: A motivational perspective. *Frontiers in Neuroscience*, *7*(7 APR), 1–12. doi:10.3389/fnins.2013.00046

Addendum:

Thoughts on adaptive procedures

Introduction

Many experiments make use of stimuli that vary in terms of intensity. Sounds can be presented louder or quieter, lights can be bright or dim and somatosensory sensations can be robust or barely perceivable. The importance of this intensity dimension lies with on the topic of research. Some attention-oriented studies, for instance, make use of stimuli presented at threshold level. This cut-off level marks the minimal intensity at which the stimulus must be presented for it to be detectable. In theory, a stimulus presented at a lower intensity can never be consciously distinguished, while a stronger stimulus is increasingly easier to detect. It requires little argument that, due to individual differences, the threshold point is not the same for everyone. Other studies, revolving around pain topics, make use of disagreeable stimuli. In this sort of research, it is important to know how applied pain stimuli are perceived by the participant. This perception can be modified by different psychological and physiological factors (Gatchel, Peng, Peters, Fuchs, & Turk, 2007), which may individually differ. In other words, accompanying cognitive, emotional and even behavioral reactions cannot be assumed to be equal for every other person.

As the previous examples demonstrate, it is important to be able to fine-tune stimulus levels to cater to specific experimental needs. This can be done in several ways. For instance, experiment leaders can simply alter stimulus levels by hand while repeatedly gauging for participants' reactions.

This method lacks a predefined systematic format, making it unfit for scientific purposes. Indeed, it is imperative that every participant is subjected to the same method, eliminating as much experimenter-induced variance as possible.

Methodology

In the following paragraphs, we will discuss a selection of adaptive methods, as well as their logical relationship to one another. Note that this section does not offer a fully comprehensive review of these procedures, but rather a selection that is particularly relevant to somatosensory experiments, such as the ones described in this dissertation.

Procedures

The following procedures are designed so that previous stimulus levels and responses determine the stimulus on any current trial. They are commonly referred to as *adaptive procedures* (Levitt, 1970; Treutwein, 1995). In actuality, they are a subset of what is known as sequential experiments, i.e., experiments in which the course of the experiment is dependent on the continuously collected data. This dependency usually translates into either an effect on the number of observations or on the choice of stimulus levels.

A first attempt at fine-tuning stimulus levels during the course of the procedure is called the *method of limits*. In this method, a stimulus that has a high probability of receiving a positive response is presented to the subject. If the subject does indeed respond positively, the stimulus level is decreased

by a fixed step in intensity. The magnitude of this decrement called the *step size*. Then, a new stimulus is presented at the adjusted intensity level. This process is repeated until the first negative response it obtained. This shift in response is called a *reversal*. After this reversal, the result is determined as the average of the last two stimulus levels. This method, however, is far from ideal. Both the initial intensity level as well as the step size can bias the eventual result (Brown & Cane, 1959). On top of that, most observations are placed at a distance of the point we want to approach. This means that a large amount of data goes to waste.

These disadvantages are addressed in the *staircase method*. Similar to the method of limits, this procedure decreases stimulus intensity following a positive response, while increasing it after a negative response. Contrary to the former method, the staircase procedure does not stop after a first reversal. Instead, it is advised to continue the procedure until six or eight reversals have occurred (Wetherill & Levitt, 1965). In this manner, an adequate observations center around the point of interest. This also reduces any biasing effects that are spawned due to the distance to the initial stimulus level. Another advantage is that this procedure takes into account any drift in participant perception that may occur during the procedure. For instance, it is possible that participants' sensitivity changes as a result of the repeated stimulation. The step size, however, can still be troublesome. If the step size is too large, it is possible we do not approach the desired level close enough, continuously hovering over it instead. If the steps are too small on the other hand, it may take a very long time to adequately converge on our point of interest. This has to be accounted for in designing the procedure, i.e. in defining step size and initial intensity level. A final, important

shortcoming inescapably lies with the sequential nature of the stimulus presentation. When participants experientially infer the rule with which stimulus levels are being determined, they can also adjust their corresponding response pattern. For example, if participants become aware that high ratings lead to a systematic reduction in stimulus levels (e.g., painful electrocutaneous stimuli), they may be inclined to adjust their responses accordingly – regardless of their actual pain perception. This too can lead towards a shifted and hence erroneous result.

The latter issue is addressed in the *double random staircase (DRS) method.* By randomly presenting stimuli from one of two paralleling yet separate staircases, stimulus predictability can be avoided. More specifically, two simple staircase methods are interleaved into one, randomly jumping from one to another. This way it is more difficult for a participant to detect a sequential pattern for the stimulus adjustment. It is evident that, as the procedure continues, both staircases are expected to approach the desired intensity mark. There are still a few issues with this approach. For one, the step size problem remains, as it is still invariable. It can thus be either too large or too small, implying a lack of precision or reduced effectiveness, respectively. Additionally, it should be noted that the starting values should be chosen with care. Ideally, the resulting end value of the stimulus level should be within range of these starting values, so that convergence is optimal.

In the course of this PhD candidature, this double random staircase method served as a crux for several stimulus level related procedures. In the following sections, we will discuss how the resulting data can be used to

determine the sought-after stimulus levels. Some modifications were made in order to fit the needs of our experiments.

Extracting results

Upon completing any of the above described staircase procedure, the question remains: which value is to be considered the best estimation of the desired result? The most obvious answer would be to look at the final staircase values. Given that staircase methods are designed in a way that they will converge on the wanted stimulus level, we can expect the approximation to increase in quality with the number of observations. Therefore, provided that this number was sufficiently high, the convergence should be complete when the procedure reaches its end point. When two staircases are being used simultaneously, an average of both terminating values can be made. If a procedure could designed with perfect parameters and applied to a perfectly consistent participant, these values ought to be equal, resulting in an identical average. As both of these matters are quasi-impossible to obtain, this will seldom be the case. Still, the average can be viewed as a good approximation of the desired stimulus level. As most procedures used in the framework of this PhD candidature are relatively small-scaled and straightforward, this result will often be used.

There are more complicated, and arguably more precise ways in which we can obtain a resulting value from the staircase data. One of these ways consists of analyzing so called 'runs'. A run is defined as the series of values between two reversals – the points in the procedure where a participant switches from a positive to a negative response, or vice versa. By taking the middle point of every even run and averaging these values, a more precise approximation of the desired intensity level can be made. Indeed, this

method can be considered more robust due to several reasons. The main advantage, however, is that this method involves more data points, thus making it less susceptible to temporary perceptual drifts around the end of the procedure. This manner of obtaining stimulus intensity values benefits from a surplus of observation points, and thus can better compensate for temporary fluctuations given a long series of data points. If on the other hand the procedure is too short or initial intensity values too extreme (potentially causing the presence of only one run), this method will likely fail. Still, this method should be considered preferential.

Modifications

In the framework of this project, several custom adaptive procedures were designed. Instead of presenting the participant with a dichotomous answering selection (e.g., "I felt something" vs. "I did not feel something"), certain adaptive procedures employed a rating scale. Examples of such scales include pain intensity scales (a score from 0 to 10), and comparing scales (e.g., "I felt it a lot less", "I felt it a little less", "I felt it equally intensely", "I felt it a little more" or "I felt it a lot more"). Responses on these scales were used to adapt staircase values, similar to the original method, with some modifications. The presence of several response options provided us with a means to alter step size corresponding to the given answer. If the participants' response was more distant from the intended response, it was advisable to use a larger increment or decrement when determining the next staircase value. For instance, if a participant reports a stimulus to be *a lot* stronger than a reference stimulus, it is justifiable to decrease the stimulus level more significantly compared to when the stimulus is reportedly felt a *little* stronger. This way, stimulus intensity could be adapted more rapidly and more efficiently.

Another variation was the manner in which several body locations could be calibrated at the same time. For example, when examining pain thresholds for two locations, we can use two double random staircase procedures. Complete randomization of these procedures, however, results in a quadruple combination of staircases. This way it becomes practically impossible for participants to infer an underlying algorithm, while the procedure itself gradually converges on its intended measurements.

Finally, staircase procedures typically only allow two types of responses: those leading to a step-up in the stimulus intensity level, and those leading to a step-down. As we have just discussed, our rating scales often included a response that does not imply a change in stimulus intensity level. If we are interested in determining a painful stimulus that rated by the participant as a 7 on an 11-point scale (0 to 10), then such a response implies that the desired stimulus intensity level is reached. Similarly, if a participant reports a stimulus to be equally intense as a reference stimulus, no changes should be made. In this case, the aforementioned data extraction methods are still valid. Alternatively, it is possible to calculate an average of all these values (that is, all the 7's or all the "equally intense" responses), and use that value in the subsequent experiment.

Closing words

In the above paragraphs, we have discussed a number of basic principles with regard to the administration of psychophysical adaptive procedures. It should be noted that there are a large number of significantly

more complex methods, which can be expected to lead to more precise results (Treutwein, 1995). However, in the context of somatosensory experiments, time is often of the essence. If the participant is exposed to an excessive amount of stimuli prior to the experiment, or if his or her attention has already been strained, this may be at the cost of the principal experiment. As such, the decision upon an appropriate balance between speed and accuracy remains at the experimenter's discretion.

References

Brown, J., & Cane, V. R. (1959). An analysis of the limiting method. *British Journal of Statistical Psychology*, *12*(2), 119–126.

Gatchel, R. J., Peng, Y. B., Peters, M. L., Fuchs, P. N., & Turk, D. C. (2007). The biopsychosocial approach to chronic pain: scientific advances and future directions. *Psychological Bulletin*, *133*(4), 581–624. doi:10.1037/0033-2909.133.4.581

Levitt, H. (1970). Transformed up-down methods in psychoacoustics. *The Journal of the Acoustical Society of America*.

Treutwein, B. (1995). Adaptive psychophysical procedures. *Vision Research*, *35*(17), 2503–2522. doi:10.1016/0042-6989(95)00016-S

Wetherill, G. B., & Levitt, H. (1965). Sequential estimation of points on a psychometric function. *British Journal of Mathematical & Statistical Psychology*, *18*(1), 1–10.

Acknowledgements

It is done. Now come the thank-you's. It's tradition. It is also tradition to thank your promoter first. Stefaan, I'll be right with you.

I'm thanking Nathalie first. See what I did there, Nathalie? Broke tradition for you, like it was nothing. How could I not? Being with you has turned my life upside down. That's a good thing, considering that I was probably inverted to begin with. I've never been so confident, so at ease about the future with anyone before. You're one of the main reasons why other people would consider me imperturbable (slightly surprised that Word didn't underline that spelling on the first go). You're also one of the few people who know when I'm anything but. You've come to mean the world to me, more than I sometimes let on. You're beautiful in every way, and I love you.

Stefaan, it's quite obvious that I owe you a significant paragraph in this segment. For one, this little booklet has my name on it only because you gave me the opportunity to author it. I believe some might have considered that a bold move. I know I can be a bit forgetful, unorthodox, or generally chaotic. Point being, I'm not exactly a by-the-books guy, for the most part. You, as my promoter, didn't seem too bothered by any of this. Instead, you always valued results over regulations. And 'your door was always open', as they say – quite literally so. I must have randomly dropped in a dozen times, presenting questions that ranged from the trivial to the fundamental, without ever being sent away to reschedule a meeting at a more convenient time. It's also hard not to be impressed by the promptness of your feedback, comments and corrections on any and all forms of written documents that I ever sent your way. If I weren't so sure that you actually have a very busy schedule, I would almost suspect that your sole occupation is to sit around and wait for me to run into some academic obstacle, with which I could use some help. I have seen and heard enough from colleagues to know that your openness, trust and responsiveness are things that I cannot take for granted. So, thank you very much for your guidance over the past four years.

I would also like to thank my Guidance Committee – prof. dr. Jan De Houwer, prof. dr. Sven Müller and prof. dr. Ilse Van Diest – for

attending the (post)meetings, providing me with new insights, telling me when something was a bad idea, and bearing with me when I did it anyway.

Further, I want to thank prof. dr. Miguel García-Pérez for being so helpful with some of the methodological aspects of my TOJ experiments, as well as for answering all of my questions were answered extensively – regardless of their inherent intellectual value (or lack thereof). Miguel, we'll probably never meet, but you're a pretty cool guy in my book.

Prof. dr. Bart Soenens, I swear I still want to start writing on that manuscript of ours. Thanks for still being one of the more ideological researchers that I know. Your open-minded approach to science in general is still pretty inspiring to me. Also, your taste in music is kick-ass. High five.

In the words of chanting soccer hooligans worldwide, you'll never walk alone. Thank you Amanda, Ama, Annick, Charlotte, Dimitri, Elke, Geert, Lien, Lies, Liesbet, Marieke V., Nele, Sara, Sophie, Stefaan and Tine, for being on my team. And of course, not to forget, the former players: Annabelle, Emelien, Lore and Marieke D. Without the lot of you, the pain meetings would have been very awkward and lonely. On a more serious note, thank you for all the chats, tips, help, social entertainment (the gossip was inescapable), and support. It's been real.

A special thank you to the two people I've consistently shared an office with over the past years: Annick and Charlotte. If it weren't for the pair of you, I would have probably missed a lot more meetings and deadlines than I already did. Thanks for making work a lot more fun, too. Making light of the encumbrances of academic life is always more fun in likeminded company. Also, I doubt that I'll ever forget the highpoint of our triumvirate, that unholy night in Florence. We should do that over some time, minus the early morning poster session. I'll bring the crackers.

I should *not* thank a large part of my friends. When discussing the possibility of them being mentioned in these acknowledgements, the response I got from Benjamin was 'what for?' Well, mate, you don't tell me what to do. Thanks for the laughs, the camaraderie, the

drinking solidarity, burdening me with your sorrows, always having been willingly burdened with my own, and generally, for having my back. Benjamin, Jinse, Tiemen, Cedric, Cedric, and Peter, you're a bunch of wankers, and I'm glad that you're my friends.

Shout-out to the guys at Brasa Ghent, Ashkan, Ben, Marijn, Gert, Anthony, GJ and all the others. Thanks for speeding up the aging process of my body, one sparring session at a time. Yet if anyone has to break me down, I'll happily let you guys have the honor.

Anand, you big weirdo, thanks for proofreading (part of) this manuscript. But more importantly, thanks for being a stand-up guy – even in the face of adversity. I sincerely hope that you keep finding your own way, and that life stops hurling lemons at your face. Seriously, you need a break. If anyone qualified reads this, give this guy a professorship. I swear he's probably the sharpest scientific mind I've ever come across. Don't ever stop being you, friend, the world could use a little more batman.

Moeke, papa, in mijn vorige dankwoord heb ik jullie bedankt voor 'alles'. Dat was geen manier om het dankwoord snel af te ronden. Ik heb jullie gewoon ook echt alles te danken. Jullie hebben mij de betekenis van de woorden "onvoorwaardelijke liefde" geleerd. Ik hoop dat ik ooit half zoveel zal betekenen voor mijn kinderen als jullie nu voor mij betekenen. Dan zal ik weten dat ik me goed van mijn taak gekweten heb.

Marieke, ik ben zeer blij dat we uit de oorlogsfase van de puberteit gegroeid zijn. Intussen hebben we al een stortvloed aan levenservaringen gedeeld, van (licht) benevelde feestjes tot transcontinentale tripjes. Gewoon een beetje samen opgegroeid dus, eigenlijk. De innerlijke kracht die jij bezit is ronduit imposant. Ik weet dat je soms zelf het gevoel hebt dat dit allesbehalve zo is, maar neem er mijn woord maar voor aan. Vallen doet iedereen. Jezelf telkens weer overeind hijsen, daar is kracht voor nodig. En Elke, jou heb ik altijd vanuit het grote-broer-perspectief gezien. Ik weet dat je vroeger naar me opkeek, al heb ik nooit helemaal begrepen waarom. Wel, Elke, ik kijk naar jou op. Je hebt al snel heel bewust je eigen weg gekozen, tegen de verwachtingen in. Je slaagt er ook keer op keer in om je angsten te overwinnen door op een podium te stappen met je hoorn in

de aanslag. Machtig. Jullie zijn twee van de belangrijkste mensen in mijn leven, en dat zullen jullie altijd zijn. Ik zie jullie graag.

OMA, OMDAT JE HIER MOEILIJK OP KAN INZOOMEN ZAL IK EEN BEETJE HELPEN. BEDANKT VOOR AL DE GEZELLIGE BABBELS, WAARIN DE WIJSHEID DER JAREN ZICH ALTIJD WEL – HEEL STIEKEM – LAAT GELDEN. OOK BEDANKT VOOR DE VELE POGINGEN OM MIJ VET TE MESTEN. HET IS NOG ALTIJD NIET GELUKT, MAAR IK HEB RESPECT VOOR JE VOLHARDING. IK WEET DAT JE DEUR ALTIJD VOOR MIJ – EN AL JE KLEINKINDEREN – OPENSTAAT. EN KIJK, JE STAAT ALWEER IN EEN DOCTORAAT! NIET SLECHT VOOR IEMAND DIE HAAR EIGEN SCHRANDERHEID (WAAR IK ROTSVAST VAN OVERTUIGD BEN) ALTIJD ZO ONDERWAARDEERT, TOCH?

Nog een dankwoordje voor de familie Schouppe. Hugo, Nadine, Paula, Evert, Kim, Dieter en Eveline, bedankt voor de verwelkoming (nu al meer dan twee jaar geleden). Het heeft in elk geval niet lang geduurd voor ik me bij jullie thuis voelde. Volgende keer ga ik weer mee op vakantie, beloofd. Jerôme en erwtje, jullie waren er nog niet om mij te verwelkomen, maar wij gaan nog maten worden. Ook beloofd. En Nadine, this is the longest English text I've ever written (or care to ever write again). How am I doing? One thing's for certain, I'm having a whale of a time. Jolly good!

Alright, on with it. I'd like to offer a quick round of appreciation for a couple more of my friends. Here we go. Thank you: Asta Morris, Ardbeg, Ardmore, Balblair, Bowmore, Coal Ila, Gordon & MacPhail, Clynelish, Glen Deveron, Glenfarclas, Glenfiddich, Glenmorangie, Highland Park, Kilchoman, Laphroaig, Talisker and Tamdhu. You've all been real pals, especially in these last few months. The same goes for Monster, Nalu and Red Bull. What you lack in finesse, you make up for in enthusiasm. I'll miss you guys. (But not for too long.)

Finally, I want to thank Nathalie again. Thanks for being mine. Thank you for your endless support, your amazing cooking, your tolerance for my inane singing (I bet this surprises a bunch of people), and your apparent appreciation of my ambitious attempts at amusement (another astonishing alliteration). In the end, it couldn't have been anyone else but you. I love you.

See what I did there, Nathalie? You're my first and my last.

And you say I'm not romantic.

Wouter
19/06/15

Data storage fact sheets

Data storage fact sheet, Chapter 1

% Data Storage Fact Sheet (version: May 5, 2014)
% Data Storage Fact Sheet <Phd Wouter Durnez, Chapter 1>
% Author: Wouter Durnez
% Date: 5/05/2014

1. Contact

1a. Main researcher

- name: Wouter Durnez
- address: Henri Dunantlaan 2, 9000 Gent
- e-mail: Wouter.Durnez@UGent.be

1b. Responsible ZAP (if different from the main researcher)

- name: Stefaan Van Damme
- address: Henri Dunantlaan 2, 9000 Gent
- e-mail: Stefaan.VanDamme@UGent.be

If a response is not received when using the above contact details, please send an email to data-ppw@ugent.be or contact Data Management, Faculty of Psychology and Educational Sciences, Henri Dunantlaan 2, 9000 Ghent, Belgium.

2. Information about the datasets to which this sheet applies

* Reference of the publication in which the datasets are reported:
  - Durnez, W., & Van Damme, S. (2015). Trying to Fix a Painful Problem: The Impact of Pain Control Attempts on the Attentional Prioritization of a Threatened Body Location. The Journal of Pain, 16(2), 135-143.
  - Durnez, W. (2015). How pain control attempts guide attention: An experimental analysis. Chapter 1, Experiment 1 (Unpublished doctoral dissertation). Ghent University

* Which datasets in that publication does this sheet apply to?:

All datasets reported in publication and PhD dissertation chapter.

3. Information about the files that have been stored

3a. Raw data

* Have the raw data been stored by the main researcher? [X] YES / [ ] NO
If NO, please justify:

* On which platform are the raw data stored?
[x] researcher PC
[ ] research group file server
[ ] research group file server via DICT
[x] responsible ZAP PC

* Who has direct access to the raw data (i.e., without intervention of another person)?
[x] main researcher
[x] responsible ZAP
[ ] all members of the research group
[ ] all members of UGent
[ ] other (specify): ...

3b. Other files

* Which other files have been stored?
- [x] file(s) describing the transition from raw data to reported results. Specify:
R-scripts: - TCD_MixedModelAnalyses.R;
- TCD_QuestionnaireAnalyses.R

- [ ] file(s) containing processed data. Specify:
- [x] file(s) containing analyses. Specify: see other files, R-scripts contain analyses' syntax, running them gives results.
- [ ] files(s) containing information about informed consent. Specify: ...
- [ ] a file specifying legal and ethical provisions. Specify: ...
- [x] file(s) that describe the content of the stored files and how this content should be interpreted. Specify: See other files, R-scripts contain additional information.
- [ ] other files. Specify:

* On which platform are these other files stored?
- [x] individual PC
- [ ] research group file server
- [X] other: responsible ZAP PC
.

```
    * Who has direct access to these other files (i.e.,
without intervention of another person)?
    - [x] main researcher
    - [x] responsible ZAP
    - [ ] all members of the research group
    - [ ] all members of UGent
    - [ ] other (specify): ...

    4. Reproduction
```

```
    * Have the results been reproduced?: [ ] YES / [x]
NO
    * If yes, by whom (add if multiple):
    - name
    - address
    - affiliation
    - e-mail
```

Data storage fact sheet, Chapter 2

```
    % Data Storage Fact Sheet (version: July 16, 2015)
    % Data Storage Fact Sheet <Phd Wouter Durnez,
Chapter 2>
    % Author: Wouter Durnez
    % Date: 16/06/2015

    1. Contact
```

```
    1a. Main researcher
```

```
    - name: Wouter Durnez
    - address: Henri Dunantlaan 2, 9000 Gent
    - e-mail: Wouter.Durnez@UGent.be

    1b. Responsible ZAP (if different from the main
researcher)
```

```
    - name: Stefaan Van Damme
    - address: Henri Dunantlaan 2, 9000 Gent
    - e-mail: Stefaan.VanDamme@UGent.be

    If a response is not received when using the above
contact details, please send an email to
data-ppw@ugent.be or contact Data Management, Faculty
of Psychology and Educational Sciences, Henri
Dunantlaan 2, 9000 Ghent, Belgium.

    2. Information about the datasets to which this
sheet applies
```

* Reference of the publication in which the datasets are reported:
- Durnez, W. (2015). How pain control attempts guide attention: An experimental analysis. Chapter 2, Experiment 1 (Unpublished doctoral dissertation). Ghent University

* Which datasets in that publication does this sheet apply to?:
All datasets reported in PhD dissertation chapter.

3. Information about the files that have been stored

3a. Raw data

* Have the raw data been stored by the main researcher? [X] YES / [ ] NO
If NO, please justify:

* On which platform are the raw data stored?
[x] researcher PC
[ ] research group file server
[ ] research group file server via DICT
[x] responsible ZAP PC

* Who has direct access to the raw data (i.e., without intervention of another person)?
[x] main researcher
[x] responsible ZAP
[ ] all members of the research group
[ ] all members of UGent
[ ] other (specify): ...

3b. Other files

* Which other files have been stored?
- [x] file(s) describing the transition from raw data to reported results. Specify:
R-scripts: - SJ_MixedModelAnalysesAcc.R;
- SJ_MixedModelAnalysesRT.R
- SJ_QuestionnaireAnalyses.R

- [ ] file(s) containing processed data. Specify:
- [x] file(s) containing analyses. Specify: see other files, R-scripts contain analyses' syntax, running them gives results.
- [ ] files(s) containing information about informed consent. Specify: ...
- [ ] a file specifying legal and ethical provisions. Specify: ...

- [x] file(s) that describe the content of the stored files and how this content should be interpreted. Specify: See other files, R-scripts contain additional information.
- [ ] other files. Specify:

* On which platform are these other files stored?
- [x] individual PC
- [ ] research group file server
- [X] other: responsible ZAP PC
.
* Who has direct access to these other files (i.e., without intervention of another person)?
- [x] main researcher
- [x] responsible ZAP
- [ ] all members of the research group
- [ ] all members of UGent
- [ ] other (specify): ...

4. Reproduction

* Have the results been reproduced?: [ ] YES / [x] NO
* If yes, by whom (add if multiple):
- name
- address
- affiliation
- e-mail

Data storage fact sheet, Chapter 3

% Data Storage Fact Sheet (version: July 16, 2015)
% Data Storage Fact Sheet <Phd Wouter Durnez, Chapter 3>
% Author: Wouter Durnez
% Date: 16/06/2015

1. Contact

1a. Main researcher

- name: Wouter Durnez
- address: Henri Dunantlaan 2, 9000 Gent
- e-mail: Wouter.Durnez@UGent.be

1b. Responsible ZAP (if different from the main researcher)

- name: Stefaan Van Damme

- address: Henri Dunantlaan 2, 9000 Gent
- e-mail: Stefaan.VanDamme@UGent.be

If a response is not received when using the above contact details, please send an email to data-ppw@ugent.be or contact Data Management, Faculty of Psychology and Educational Sciences, Henri Dunantlaan 2, 9000 Ghent, Belgium.

2. Information about the datasets to which this sheet applies

* Reference of the publication in which the datasets are reported:
- Durnez, W. (2015). How pain control attempts guide attention: An experimental analysis. Chapter 3, Experiment 1 & 2 (Unpublished doctoral dissertation). Ghent University

* Which datasets in that publication does this sheet apply to?:
All datasets reported in PhD dissertation chapter.

3. Information about the files that have been stored

3a. Raw data

* Have the raw data been stored by the main researcher? [X] YES / [ ] NO
If NO, please justify:

* On which platform are the raw data stored?
[x] researcher PC
[ ] research group file server
[ ] research group file server via DICT
[x] responsible ZAP PC

* Who has direct access to the raw data (i.e., without intervention of another person)?
[x] main researcher
[x] responsible ZAP
[ ] all members of the research group
[ ] all members of UGent
[ ] other (specify): ...

3b. Other files

* Which other files have been stored?
- [x] file(s) describing the transition from raw data to reported results. Specify:
R-scripts: - TCD2_MixedModelAnalyses.R; (Exp 1)

```
            - TCD2_QuestionnaireAnalyses.R   (Exp 1)
            - TCD3_MixedModelAnalyses.R;     (Exp 2)
            - TCD3_QuestionnaireAnalyses.R   (Exp 2)


    - [ ] file(s) containing processed data. Specify:
    - [x] file(s) containing analyses. Specify: see other files, R-scripts contain analyses' syntax, running them gives results.
    - [ ] files(s) containing information about informed consent. Specify: ...
    - [ ] a file specifying legal and ethical provisions. Specify: ...
    - [x] file(s) that describe the content of the stored files and how this content should be interpreted. Specify: See other files, R-scripts contain additional information.
    - [ ] other files. Specify:

    * On which platform are these other files stored?
    - [x] individual PC
    - [ ] research group file server
    - [X] other: responsible ZAP PC
    .
    * Who has direct access to these other files (i.e., without intervention of another person)?
    - [x] main researcher
    - [x] responsible ZAP
    - [ ] all members of the research group
    - [ ] all members of UGent
    - [ ] other (specify): ...

    4. Reproduction
```

```
    * Have the results been reproduced?: [ ] YES / [x] NO
    * If yes, by whom (add if multiple):
    - name
    - address
    - affiliation
    - e-mail
```

Data storage fact sheet, Chapter 4

```
    % Data Storage Fact Sheet (version: July 16, 2015)
    % Data Storage Fact Sheet <Phd Wouter Durnez, Chapter 4>
    % Author: Wouter Durnez
    % Date: 16/06/2015
```

1. Contact

1a. Main researcher

- name: Wouter Durnez
- address: Henri Dunantlaan 2, 9000 Gent
- e-mail: Wouter.Durnez@UGent.be

1b. Responsible ZAP (if different from the main researcher)

- name: Stefaan Van Damme
- address: Henri Dunantlaan 2, 9000 Gent
- e-mail: Stefaan.VanDamme@UGent.be

If a response is not received when using the above contact details, please send an email to data-ppw@ugent.be or contact Data Management, Faculty of Psychology and Educational Sciences, Henri Dunantlaan 2, 9000 Ghent, Belgium.

2. Information about the datasets to which this sheet applies

* Reference of the publication in which the datasets are reported:
  - Durnez, W. (2015). How pain control attempts guide attention: An experimental analysis. Chapter 4, Experiment 1 (Unpublished doctoral dissertation). Ghent University

* Which datasets in that publication does this sheet apply to?:
All datasets reported in PhD dissertation chapter.

3. Information about the files that have been stored

3a. Raw data

* Have the raw data been stored by the main researcher? [X] YES / [ ] NO
If NO, please justify:

* On which platform are the raw data stored?
[x] researcher PC
[ ] research group file server
[ ] research group file server via DICT
[x] responsible ZAP PC

* Who has direct access to the raw data (i.e., without intervention of another person)?

[x] main researcher
[x] responsible ZAP
[ ] all members of the research group
[ ] all members of UGent
[ ] other (specify): ...

3b. Other files

* Which other files have been stored?
- [x] file(s) describing the transition from raw data to reported results. Specify:
R-scripts: - TOJ1_MixedModelAnalyses.R;
- TOJ1_QuestionnaireAnalyses.R

- [ ] file(s) containing processed data. Specify:
- [x] file(s) containing analyses. Specify: see other files, R-scripts contain analyses' syntax, running them gives results.
- [ ] files(s) containing information about informed consent. Specify: ...
- [ ] a file specifying legal and ethical provisions. Specify: ...
- [x] file(s) that describe the content of the stored files and how this content should be interpreted. Specify: See other files, R-scripts contain additional information.
- [ ] other files. Specify:

* On which platform are these other files stored?
- [x] individual PC
- [ ] research group file server
- [X] other: responsible ZAP PC
.
* Who has direct access to these other files (i.e., without intervention of another person)?
- [x] main researcher
- [x] responsible ZAP
- [ ] all members of the research group
- [ ] all members of UGent
- [ ] other (specify): ...

4. Reproduction

* Have the results been reproduced?: [ ] YES / [x] NO
* If yes, by whom (add if multiple):
- name
- address
- affiliation
- e-mail

Data storage fact sheet, Chapter 5

% Data Storage Fact Sheet (version: July 16, 2015)
% Data Storage Fact Sheet <Phd Wouter Durnez, Chapter 5>
% Author: Wouter Durnez
% Date: 16/06/2015

1. Contact

1a. Main researcher

- name: Wouter Durnez
- address: Henri Dunantlaan 2, 9000 Gent
- e-mail: Wouter.Durnez@UGent.be

1b. Responsible ZAP (if different from the main researcher)

- name: Stefaan Van Damme
- address: Henri Dunantlaan 2, 9000 Gent
- e-mail: Stefaan.VanDamme@UGent.be

If a response is not received when using the above contact details, please send an email to data-ppw@ugent.be or contact Data Management, Faculty of Psychology and Educational Sciences, Henri Dunantlaan 2, 9000 Ghent, Belgium.

2. Information about the datasets to which this sheet applies

* Reference of the publication in which the datasets are reported:
  - Durnez, W., & Van Damme, S. (under revision). Let it be? Pain control attempts amplify attention for somatosensory information. Submitted to Psychological Research.
  - Durnez, W. (2015). How pain control attempts guide attention: An experimental analysis. Chapter 5, Experiment 1 (Unpublished doctoral dissertation). Ghent University

* Which datasets in that publication does this sheet apply to?:
All datasets reported in PhD dissertation chapter.

3. Information about the files that have been stored

3a. Raw data

```
    * Have the raw data been stored by the main
researcher? [X] YES / [ ] NO
    If NO, please justify:

    * On which platform are the raw data stored?
    [x] researcher PC
    [ ] research group file server
    [ ] research group file server via DICT
    [x] responsible ZAP PC

    * Who has direct access to the raw data (i.e.,
without intervention of another person)?
    [x] main researcher
    [x] responsible ZAP
    [ ] all members of the research group
    [ ] all members of UGent
    [ ] other (specify): ...

    3b. Other files
```

```
    * Which other files have been stored?
    - [x] file(s) describing the transition from raw
data to reported results. Specify:
     R-scripts:  - TOJ2_MixedModelAnalyses.R;
                 - TOJ2_QuestionnaireAnalyses.R

    - [ ] file(s) containing processed data. Specify:
    - [x] file(s) containing analyses. Specify: see
other files, R-scripts contain analyses' syntax,
running them gives results.
    - [ ] files(s) containing information about
informed consent. Specify: ...
    - [ ] a file specifying legal and ethical
provisions. Specify: ...
    - [x] file(s) that describe the content of the
stored files and how this content should be
interpreted. Specify: See other files, R-scripts
contain additional information.
    - [ ] other files. Specify:

    * On which platform are these other files stored?
    - [x] individual PC
    - [ ] research group file server
    - [X] other: responsible ZAP PC
    .
    * Who has direct access to these other files (i.e.,
without intervention of another person)?
    - [x] main researcher
    - [x] responsible ZAP
    - [ ] all members of the research group
    - [ ] all members of UGent
    - [ ] other (specify): ...
```

4. Reproduction

* Have the results been reproduced?: [ ] YES / [x] NO
* If yes, by whom (add if multiple):
- name
- address
- affiliation
- e-mail

Data storage fact sheet, Chapter 6

% Data Storage Fact Sheet (version: July 16, 2015)
% Data Storage Fact Sheet <Phd Wouter Durnez, Chapter 6>
% Author: Wouter Durnez
% Date: 16/06/2015

1. Contact

1a. Main researcher

- name: Wouter Durnez
- address: Henri Dunantlaan 2, 9000 Gent
- e-mail: Wouter.Durnez@UGent.be

1b. Responsible ZAP (if different from the main researcher)

- name: Stefaan Van Damme
- address: Henri Dunantlaan 2, 9000 Gent
- e-mail: Stefaan.VanDamme@UGent.be

If a response is not received when using the above contact details, please send an email to data-ppw@ugent.be or contact Data Management, Faculty of Psychology and Educational Sciences, Henri Dunantlaan 2, 9000 Ghent, Belgium.

2. Information about the datasets to which this sheet applies

* Reference of the publication in which the datasets are reported:
- Durnez, W. (2015). How pain control attempts guide attention: An experimental analysis. Chapter 6. (Unpublished doctoral dissertation). Ghent University

* Which datasets in that publication does this sheet apply to?:
All datasets reported in PhD dissertation chapter.

3. Information about the files that have been stored

3a. Raw data

* Have the raw data been stored by the main researcher? [X] YES / [ ] NO
If NO, please justify:

* On which platform are the raw data stored?
[x] researcher PC
[ ] research group file server
[ ] research group file server via DICT
[x] responsible ZAP PC

* Who has direct access to the raw data (i.e., without intervention of another person)?
[x] main researcher
[x] responsible ZAP
[ ] all members of the research group
[ ] all members of UGent
[ ] other (specify): ...

3b. Other files

* Which other files have been stored?
- [x] file(s) describing the transition from raw data to reported results. Specify:
R-scripts: - ALL_TCD_MMA.R;
- ALL_TOJ_MMA.R

- [ ] file(s) containing processed data. Specify:
- [x] file(s) containing analyses. Specify: see other files, R-scripts contain analyses' syntax, running them gives results.
- [ ] files(s) containing information about informed consent. Specify: ...
- [ ] a file specifying legal and ethical provisions. Specify: ...
- [x] file(s) that describe the content of the stored files and how this content should be interpreted. Specify: See other files, R-scripts contain additional information.
- [ ] other files. Specify:

* On which platform are these other files stored?
- [x] individual PC
- [ ] research group file server
- [X] other: responsible ZAP PC

```
    .
    * Who has direct access to these other files (i.e.,
without intervention of another person)?
    - [x] main researcher
    - [x] responsible ZAP
    - [ ] all members of the research group
    - [ ] all members of UGent
    - [ ] other (specify): ...

    4. Reproduction
```

```
    * Have the results been reproduced?: [ ] YES / [x]
NO
    * If yes, by whom (add if multiple):
    - name
    - address
    - affiliation
    - e-mail
```

Nederlandstalige samenvatting

Inleiding

Pijn is van onmiskenbare evolutionaire waarde. Het voelen van pijn stelt ons in staat om fysieke bedreigingen – toekomstige of tegenwoordige schendingen van de lichamelijke integriteit – op te merken, en daar vervolgens gepast op te reageren (Chapman, Tuckett, & Song, 2008; Eccleston & Crombez, 1999). Pijn is evenwel geen strikt fysiologische of biomedische aangelegenheid. In de afgelopen decennia hebben onderzoekers evidentie verzameld voor de rol van psychologische en sociale factoren. Deze bevindingen lagen mee aan de wieg van een paradigmatische verschuiving naar het huidige biopsychosociale perspectief (Gatchel, Peng, Peters, Fuchs, & Turk, 2007). Eén van deze niet-biomedische determinanten is in voorbij onderzoek bijzonder interessant gebleken om de werking van pijnmechanismen te helpen ontsluieren, zowel vanuit een theoretisch als een klinisch oogpunt – het psychologische construct 'aandacht'.

Een bruikbare definitie van aandacht wordt gegeven door Allport, die het definieerde als '*selection-for-action*' (Allport, 1989). Zijn visie houdt twee antagonistische principes in. Enerzijds moeten onze huidige doelen en handelingen afgeschermd kunnen worden van irrelevante distractoren. Anderzijds is het van vitaal belang dat bepaalde noodsituaties onmiddellijk onze aandacht kunnen onderbreken, zodat we snel en gepast kunnen reageren. In het cognitief-affectieve model van aandacht voor pijn wordt beschreven hoe pijn, als archetypisch alarmsignaal, onvermijdelijk de aandacht wil opeisen (Eccleston & Crombez, 1999). De grootte van deze *bottom-up* vraag naar aandacht wordt mee bepaald door de intensiteit, de

nieuwheid en de voorspelbaarheid van de pijn (Crombez, Baeyens, & Eelen, 1994; Eccleston, 1994; Lin, Hsieh, Yeh, & Niddam, 2014). Dit model heeft evenwel weinig oog voor zogeheten *top-down*, doelgerichte factoren. Het nastreven van een doel kan, in interactie met eerder vernoemde *bottom-up* invloeden, aandachtsprocessen immers ook bijsturen. Deze principes worden verder geëxpliciteerd in het neurocognitieve model van aandacht voor pijn (Legrain et al., 2009). Volgens dit model kunnen *top-down* doelen bepalen welke stimuluskenmerken prioritair geselecteerd moeten worden (*attention set* hypothese) en hoeveel aandacht aangewend moet worden om het doel te bereiken (*attention load* hypothese). Het belang van *top-down* invloeden wordt verder omarmd in hedendaagse pijnvisies (Van Damme, Legrain, Vogt, & Crombez, 2010; Wiech & Tracey, 2013), die benadrukken dat pijn nooit in een motivationeel vacuüm optreedt. Wanneer pijn irrelevant is voor het huidige doel, zal het toch aandacht opeisen. Wanneer het doel wel pijngerelateerd is – zoals het trachten te vermijden, ontsnappen of algemeen controleren van pijn – kan dit de aandacht sterker richten naar pijnrelevante informatie (e.g., Notebaert et al., 2011).

Het belang van motivatie komt bovendien duidelijk naar voor in verklarende modellen over chronische pijn, zoals het *fear-avoidance* model (Leeuw et al., 2007; Vlaeyen & Linton, 2000) of *misdirected problem solving* model (Eccleston & Crombez, 2007). Deze modellen delen een aantal grondbeginselen. Zo wordt gesteld dat het angstvallig en hardnekkig nastreven van dysfunctionele pijncontroledoelen, gepaard met een verhoogde aandacht voor bedreigende informatie (of *hypervigilantie*), aan de basis ligt van verergerende pijnklachten. Deze escalatie versterkt op zijn beurt opnieuw de drang om de pijn onder controle te krijgen. Negatieve cognitieve patronen, zoals het onderhouden van catastroferende gedachten

over de verwachte pijn (Sullivan, Bishop, & Pivik, 1995), vormen vaak de brandstof voor deze maladaptieve spiraal.

Doelstellingen

Uit deze bemerkingen mag blijken dat het zinvol is om de effecten van motivationele factoren op aandacht voor pijn verder te onderzoeken. In dit proefschrift werden drie centrale hypothesen onderzocht. **Ten eerste** stelden we dat het verwachten van een pijnstimulus automatisch het instinctieve doel om verder vermijden of ontsnappen induceert. De *attentional set* hypothese (Legrain et al., 2009) stelt dat, in dit geval, kenmerken van de pijnstimulus sterker in aanmerking zullen komen voor aandachtsselectie – of *geprioriteerd* zullen worden. Zo verwachtten we dat de anticipatie van pijn op een bepaalde lichaamslocatie de aandacht zal vestigen op deze locatie, waardoor andere (somatosensorische) stimuli op deze plaats ook sneller verwerkt zullen worden. Daarnaast verwachtten we dat dreigende pijn somatosensorische informatie zou prioriteren over input vanuit andere modaliteiten – zoals visuele informatie. **Ten tweede** voorspelden we dat het vooropstellen van een pijncontroledoel deze effecten in de hand zou werken. Specifieker verwachtten we dat nastreven van het doel om pijn te vermijden – ongeacht de doeltreffendheid van deze handelingen – het opnemen van pijnkenmerken in de *attentional set* zou versterken. Dit werd onderzocht door participanten aan te moedigen om actieve pijnvermijdingspogingen te ondernemen. **Ten derde** werd in deze thesis onderzocht in welke mate een dispositie tot pijncatastroferen – t.t.z., het onderhouden van persistente, negatieve gedachten gericht op de pijnbeleving – de eerder vermelde effecten kon modereren. Om dit te bereiken werd in elk experiment een

meting genomen van dispositioneel pijncatatroferen (Van Damme, Crombez, Bijttebier, Goubert, & Van Houdenhove, 2002). Belangrijk bij het onderzoeken van deze hypothesen was dat onze paradigmata gebruik maakten van somatosensorische stimuli. Het belang van dergelijke onderzoeksopzetten werd immers meermaals benadrukt, teneinde de ecologische validiteit van experimentele bevindingen te optimaliseren (Crombez, Van Ryckeghem, Eccleston, & Van Damme, 2013; Van Damme et al., 2010).

Bevindingen

In **hoofdstuk 1** bestudeerden we of pijncontrolepogingen de aandacht zouden richten naar de lichaamslocatie waar deze pijn verwacht werd. We onderzochten dit met behulp van een *tactile change detection* (TCD) taak. In dit paradigma oordeelden participanten over de gelijkheid van twee opeenvolgende patronen van tactiele stimulatie. Een tactiel patroon bestaat hier uit drie simultane trillingen, toegediend op drie verschillende lichaamslocaties. Ofwel waren deze patronen identiek, ofwel werd één locatie niet langer gestimuleerd in het tweede patroon, terwijl een andere locatie wel actief werd. Elke trial werd voorafgegaan door een van twee mogelijke kleurencues. In de helft van alle trials gaf deze cue aan dat op één van de locaties (vast per participant) mogelijk een pijnlijke electrocutane prikkel toegediend zou worden. Dit was het geval in 1 op 11 dreigtrials. In de andere helft van de trials was de cue niet geassocieerd met pijn. De helft van onze participantengroep werd toebedeeld bij de pijncontrole groep. Deze participanten werden aangemoedigd om actieve pogingen te ondernemen de pijn te vermijden door snel op een knop te drukken. De

andere helft van de participanten (vergelijkingsgroep) voerde een gelijkaardige taak uit, zij het niet geassocieerd met pijncontrole. Beide groepen kregen even veel pijnlijke prikkels, zodat de interpretatie van de resultaten hier niet van kon afhangen. We vonden dat participanten in de vergelijkingsgroep beter veranderingen opmerkten op dreigingstrials wanneer de pijnlocatie – t.t.z., de locatie waar pijn verwacht werd – betrokken was in de verandering. Een kritieke bevinding was dat deze prioritering van de pijnlocatie een meer gegeneraliseerd karakter vertoonde in de pijncontrolegroep, aangezien het effect zowel in neutrale als in dreigingstrials naar voor kwam.

Dezelfde hypothese werd onderzocht in **hoofdstuk 2**, zij het met behulp van een alternatief paradigma. In een ternaire *synchrony judgment* (SJ3) taak beoordeelden participanten de volgorde waarmee twee tactiele stimuli werden gepresenteerd, één op elke hand. Ze konden antwoorden door uit te spreken welke kant ze eerst gewaar werden, of door een 'simultaan' response te geven. De dreigingsmanipulatie verliep gelijkaardig aan hoofdstuk 1, zij het dit keer door middel van auditieve i.p.v. visuele cues. Ook hier werden participanten in de pijncontrolegroep aangemoedigd controle te proberen uitoefenen over de experimentele pijn. Deze participanten werd verteld dat ze de kans op een pijnlijke prikkel konden verminderen door snel te drukken op een voetpedaal bij het horen van een dreigcue. Wanneer een pijnstimulus voorviel, werd deze voorafgegaan door een feedbackboodschap die het verband tussen de vermijdingshandeling en het voorkomen van een pijnprikkel moest versterken. Participanten in de vergelijkingsgroep voerden opnieuw een gelijkaardige reactietijdtaak uit, niet gerelateerd aan pijncontrole. In dit experiment werd geen evidentie

gevonden voor spatiale prioritering ten gevolge van verwachte pijn, noch ten gevolge van pijncontrolepogingen.

Geïnspireerd door de combinatie van de voorgaande hoofdstukken, werd in **hoofdstuk 3** de rol van feedback verder onderzocht. In dit hoofdstuk wilden we nagaan of de prioritering van pijnkenmerken kan beschouwd worden als een adaptieve strategie, die tot doel heeft om de doeltreffendheid van pijncontrolepogingen na te gaan. Om dit te bewerkstelligen, hernamen we het experimentele opzet (TCD) van hoofdstuk 1, inclusief dreigingsmanipulatie en doelmanipulatie. Cruciaal in dit opzet was de toevoeging van een derde groep – de feedbackgroep – die ook instructies kreeg om de pijnstimulus te proberen vermijden. Deze groep kreeg bovendien feedback over de doeltreffendheid van hun vermijdingsactie, die hun meedeelde of deze succesvol was ("Vermeden") or niet ("Niet vermeden"). Onze verwachting was dat spatiale prioritering minder sterk zou worden, of zou verdwijnen, ten gevolge van deze feedback. Dit kon echter niet bevestigd worden. Bovendien slaagden we er niet in de resultaten van hoofdstuk 1 te repliceren.

Als gevolg van dit onvermogen om eerdere bevindingen te reproduceren, werd een follow-up experiment opgezet dat parallel was aan het initiële TCD experiment. Dit hield in dat we opnieuw een vergelijkingsgroep en een pijncontrolegroep modelleerden, en dat de helft van alle trials met de dreiging van pijn geassocieerd werd door middel van voorspellende visuele cues. De analyses van dit experiment gaven weer dat de verwachting van een pijnlijke stimulus de aandacht richtte naar de bedreigde lichaamslocatie in beide groepen. We vonden echter geen groepsverschillen voor dit effect, waardoor de robuustheid van de eerdere resultaten met betrekking tot pijncontrole (hoofdstuk 1) aan het wankelen

werd gebracht. Mogelijke verklaringen voor deze verschillen werden aangehaald.

In **hoofdstuk 4** onderzochten we of de spatiale prioritering van een met pijn bedreigde locatie specifiek is voor de somatosensorische modaliteit, of eerder onafhankelijk is van de modaliteit van de binnenkomende informatie. We ontwierpen een *temporal order judgment* (TOJ) studie waarin participanten de volgorde van twee op de handen toegediende stimuli beoordeelden, door te rapporteren welke volgens hen eerst kwam. Deze stimuli waren visueel of tactiel, afhankelijk van het experimentele blok waarin de participanten zich bevonden. Er was opnieuw een dreigingsmanipulatie met auditieve cues, evenals een doelmanipulatie die gelijkaardig was aan de vorige hoofdstukken (vergelijkingsgroep en pijncontrolegroep). Zowel de modaliteit van de TOJ stimuli als de verwachte locatie van de pijnstimulus werden gecontrabalanceerd. Deze werden telkens meegedeeld aan de participanten aan het begin van elk blok (b.v., nu komen enkel visuele trials, en electrocutane stimuli komen rechts). De resultaten gaven aan dat de dreiging van pijn zorgde voor een prioritering van de somatosensorische informatie, zij het enkel in de pijncontrolegroep. Er werd geen somatosensorische prioritering gevonden in de vergelijkingsgroep. Dit was enigszins verrassend, aangezien dit resultaat al verschillende malen eerder gevonden werd (Vanden Bulcke, Crombez, Spence, & Van Damme, 2014; Vanden Bulcke, Van Damme, Durnez, & Crombez, 2013). Daarnaast was er geen evidentie dat visuele informatie geprioriteerd werd door de verwachting van pijn enerzijds, of door pijncontrolepogingen anderzijds. Hoewel deze resultaten onze verwachtingen niet volledig konden bevestigen, onderschrijven ze het

belang van motivationele factoren in aandacht voor pijn en pijngerelateerde informatie.

In **hoofdstuk 5** gingen we verder in op de modaliteitsfacetten van aandacht voor pijn. In dit hoofdstuk wilden we nagaan of de dreiging van pijn kon zorgen voor preferentiële verwerking van somatosensorische informatie, vergeleken met informatie van andere modaliteiten. Bovendien onderzochten we of actieve pijncontrolepogingen deze prioritering konden versterken. In deze tweede TOJ taak contrasteerden we tactiele prikkels met visuele prikkels. Participanten gaven aan of ze eerst een lampje zagen flikkeren, of dat ze eerst een trilling voelden. Auditieve cues voorspelden of er een kans was dat ze een pijnlijke electrocutane stimulus zouden ontvangen. Bovendien werden participanten opnieuw in een vergelijkingsgroep en een pijncontrolegroep verdeeld. De pijncontrolegroep werd aangespoord de pijnlijke prikkel te proberen vermijden, terwijl de vergelijkingsgroep een gelijkaardige *filler* reactietijdtaak kreeg die niet gerelateerd was aan pijncontrole. We vonden dat dreiging zorgde voor prioritering van (pijnloze) somatosensorische stimulatie, wanneer deze in competitie ging met informatie van een andere modaliteit. Daarnaast vonden we dat participanten in de pijncontrolegroep deze prioritering sterker vertoonden. Een interessante bemerking was bovendien dat deze participanten dergelijke prioritering vertoonden, onafhankelijk van de valentie van de cue (dreiging of neutraal). Dit kan er opnieuw op wijzen dat de nadruk op pijncontrole kan zorgen voor een generalisatie van aandachtseffecten naar een veilige context.

In **hoofdstuk 6**, tenslotte, werden een aantal studies uit de vorige hoofdstukken (1, 3, 4 & 5) verder bekeken om de potentieel modererende rol van pijncatastroferen te onderzoeken. Dit construct wordt, zoals eerder

vermeld, in een aantal theorieën over chronische pijn aangehaald als mogelijke determinant van de aandachtseffecten ten gevolge van dreiging en – dysfunctionele – pijncontrolepogingen. Onze resultaten waren echter inconsistent. In één studie vonden we dat meer pijncatastroferen geassocieerd was met sterkere spatiale prioritering van somatosensorische informatie, toegediend op een locatie waar pijn verwacht wordt. Wanneer participanten pijncontrole nastreefden, werd deze moderatie veralgemeend naar visuele trials, evenals naar trials die geen dreiging bevatten. In geen enkele van de andere studies, echter, werd concrete evidentie gevonden dat pijncatastroferen een significante rol speelde in het tot stand komen van de gevonden effecten.

Conclusie

Het doel van deze doctoraatsdissertatie was het onderzoeken hoe de dreiging van pijn – en in het bijzonder, pogingen om controle uit te oefenen over het werkelijke voorkomen van deze pijn – aandacht voor pijnkenmerken kon versterken. In een serie somatosensorische experimenten werd evidentie gevonden voor de spatiale prioritering van een met pijn bedreigde lichaamslocatie. Deze bevinding treedt een aantal recente publicaties bij (Van Hulle, Durnez, Crombez, & Van Damme, 2015; Vanden Bulcke et al., 2014, 2013). Daarenboven suggereerden onze bevindingen dat dit effect specifiek was voor de somatosensorische modaliteit, en niet voorkwam bij andere modaliteiten (zoals de visuele modaliteit). Verder vonden we dat de verwachting van pijn zorgde voor een – algemene – prioritering van somatosensorische informatie, wanneer deze in rechtstreekse competitie ging met informatie van andere modaliteiten.

Bovendien vonden we dat (dysfunctionele) pijncontrolepogingen deze effect enbeïnvloedden, door ze enerzijds te generaliseren naar veilige contexten en anderzijds te versterken bij onmiddellijke dreiging. Het patroon van resultaten was evenwel niet volledig consistent over alle experimenten heen. We vonden ook geen (experimenteel) verband tussen de bovenvermelde aandachtseffecten en een dispositie tot pijncatastroferen. Additioneel onderzoek is hier aangewezen, waarbij mogelijk een onderscheid gemaakt moet worden tussen dispositioneel en situationeel catastroferen (Campbell et al., 2010). Tenslotte wil de huidige thesis, door het onderzoeken van fundamentele cognitieve mechanismen waarvan gesuggereerd werd dat ze een rol kunnen spelen in het onderhouden en verergeren van chronische pijn, een bijdrage leveren tot ons begrip van dysfunctionele aandacht in een klinische context.

Bibliografie

Allport, A. (1989). Visual Attention. In M. I. Posner (Ed.), *Foundation of Cognitive Science* (pp. 631–682). Hillsdale, NJ: Erlbaum.

Campbell, C. M., Kronfli, T., Buenaver, L. F., Smith, M. T., Berna, C., Haythornthwaite, J. a., & Edwards, R. R. (2010). Situational Versus Dispositional Measurement of Catastrophizing: Associations With Pain Responses in Multiple Samples. *Journal of Pain*, *11*(5), 443–453.e2. doi:10.1016/j.jpain.2009.08.009

Chapman, C. R., Tuckett, R. P., & Song, C. W. (2008). Pain and Stress in a Systems Perspective: Reciprocal Neural, Endocrine, and Immune Interactions. *Journal of Pain*, *9*(2), 122–145. doi:10.1016/j.jpain.2007.09.006

Crombez, G., Baeyens, F., & Eelen, P. (1994). Sensory and temporal information about impending pain: The influence of predictability on pain. *Behaviour Research and Therapy*, *32*(6), 611–622. doi:10.1016/0005-7967(94)90015-9

Crombez, G., Van Ryckeghem, D. M. L., Eccleston, C., & Van Damme, S. (2013). Attentional bias to pain-related information: a meta-analysis. *Pain*, *154*(4), 497–510. doi:10.1016/j.pain.2012.11.013

Eccleston, C. (1994). Chronic pain and attention: a cognitive approach. The British Journal of Clinical Psychology / the British Psychological Society, 33 (Pt 4), 535–547.

Eccleston, C., & Crombez, G. (1999). Pain demands attention. *Psychological Bulletin*, *125*(3), 356–366.

Eccleston, C., & Crombez, G. (2007). Worry and chronic pain: a misdirected problem solving model. *Pain*, *132*(3), 233–236. doi:10.1016/j.pain.2007.09.014

Gatchel, R. J., Peng, Y. B., Peters, M. L., Fuchs, P. N., & Turk, D. C. (2007). The biopsychosocial approach to chronic pain: scientific advances and future directions. *Psychological Bulletin*, *133*(4), 581–624. doi:10.1037/0033-2909.133.4.581

Leeuw, M., Goossens, M. E. J. B., Linton, S. J., Crombez, G., Boersma, K., & Vlaeyen, J. W. S. (2007). The fear-avoidance model of musculoskeletal pain: current state of scientific evidence. *Journal of Behavioral Medicine*, *30*(1), 77–94. doi:10.1007/s10865-006-9085-0

Legrain, V., Van Damme, S., Eccleston, C., Davis, K. D., Seminowicz, D. A., & Crombez, G. (2009). A neurocognitive model of attention to pain: behavioral and neuroimaging evidence. *Pain*, *144*(3), 230–2. doi:10.1016/j.pain.2009.03.020

Lin, C.-S., Hsieh, J.-C., Yeh, T.-C., & Niddam, D. M. (2014). Predictability-mediated pain modulation in context of multiple cues: An event-related fMRI study. *Neuropsychologia*, *64*, 85–91. doi:10.1016/j.neuropsychologia.2014.09.021

Notebaert, L., Crombez, G., Vogt, J., De Houwer, J., Van Damme, S., & Theeuwes, J. (2011). Attempts to control pain prioritize attention towards signals of pain: an experimental study. *Pain*, *152*(5), 1068–1073. doi:10.1016/j.pain.2011.01.020

Sullivan, M. J. L., Bishop, S., & Pivik, J. (1995). The pain catastrophizing scale: Development and validation. *Psychological Assessment*, *7*, 524–535.

Van Damme, S., Crombez, G., Bijttebier, P., Goubert, L., & Van Houdenhove, B. (2002). A confirmatory factor analysis of the Pain Catastrophizing Scale: invariant factor structure across clinical and non-clinical populations. *Pain*, *96*, 319–324. Retrieved from http://www.sciencedirect.com/science/article/pii/S0304395901004638

Van Damme, S., Legrain, V., Vogt, J., & Crombez, G. (2010). Keeping pain in mind: a motivational account of attention to pain. *Neuroscience and Biobehavioral Reviews*, *34*(2), 204–213. doi:10.1016/j.neubiorev.2009.01.005

Van Hulle, L., Durnez, W., Crombez, G., & Van Damme, S. (2015). Detection of tactile change on a bodily location where pain is expected. *Perceptual & Motor Skills: Perception*, *120*(1), 219–231.

Vanden Bulcke, C., Crombez, G., Spence, C., & Van Damme, S. (2014). Are the spatial features of bodily threat limited to the exact location where pain is expected ? *Acta Psychologica*, *153*, 113–119. doi:10.1016/j.actpsy.2014.09.014

Vanden Bulcke, C., Van Damme, S., Durnez, W., & Crombez, G. (2013). The anticipation of pain at a specific location of the body prioritizes tactile stimuli at that location. *Pain*, *154*(8), 1464–8. doi:10.1016/j.pain.2013.05.009

Vlaeyen, J. W. S., & Linton, S. J. (2000). Fear-avoidance and its consequences in chronic musculoskeletal pain: A state of the art. *Pain*, *85*(3), 317–332. doi:10.1016/S0304-3959(99)00242-0

Wiech, K., & Tracey, I. (2013). Pain, decisions, and actions: A motivational perspective. *Frontiers in Neuroscience*, *7*(7 APR), 1–12. doi:10.3389/fnins.2013.00046