MORE THAN MEETS THE EYE: VISUAL ATTENTION BIASES IN INDIVIDUALS WITH CHRONIC PAIN

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Abstract

The present study used eye-tracking technology to assess whether individuals who report chronic pain direct more attention to sensory pain-related words than do pain-free individuals. A total of 113 participants (51 with chronic pain, 62 pain-free) were recruited. Participants completed a dot-probe task, viewing neutral and sensory pain-related words while their reaction time and eye movements were recorded. Data were analyzed by mixed-design ANOVA with Group (chronic pain vs. pain-free) and Word type (sensory pain vs. neutral). Results showed a significant Group x Word type interaction effect for number of fixations, average visit duration, and late phase fixation duration, all greater for sensory pain vs. neutral words in the chronic pain group. None of the effects for reaction time was significant. Findings support the hypothesis that individuals with chronic pain display attentional biases towards pain-related stimuli and demonstrate the value of eye-tracking technology in measuring differences in visual attention variables.

Dedication

This thesis is dedicated to Kris for

supporting me unconditionally and for

moving across the country for me.

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Chapter One: Introduction & Literature Review

Chronic pain affects nearly 25% of Canadians (Boulanger, Clark, Squire, Cui, & Horbay, 2007) and 15% of Americans (Hardt, Jacobsen, Goldberg, Nickel, & Buchwald, 2008). The resultant burden of chronic pain affects the individual, community, health care, and society. Chronic pain is frequently accompanied by a myriad of difficulties, including depression (Miller & Cano, 2009), anxiety (Asmundson & Katz, 2009), disability (Tripp, VanDenKerkhof, & McAlister, 2006), lowered quality of life (Dillie, Fleming, Mundt, & French, 2008), and impaired social relationships (Turk et al., 2008). At a societal level, costs related to chronic pain range between $560 to $635 billion annually in the United States (Gaskin & Richard, 2012), with an additional $61 billion dollars lost due to diminished productivity or absenteeism (Stewart, Ricci, Chee, Morganstein, & Lipton, 2003). Therefore, understanding various biological, psychological, and social factors that contribute to the development and maintenance of pain is essential. Recently, evidence has shown that individuals with chronic pain pay more attention to pain and pain-related cues in the environment than do people who are pain-free (Schoth, Nunes, & Liossi, 2012). However, previous studies have methodological flaws that challenge the validity of the findings, including relying on indirect measures to assess attentional biases such as self-report questionnaires and reaction time tasks.

The present thesis involves an examination of attentional biases in individuals with chronic pain using eye-tracking methodology within a dot-probe task. In the first chapter, a comprehensive definition of pain and models of pain are provided. This is followed by a discussion of attentional biases, including a description of various models of pain that predict the role of attentional biases in the development, maintenance, and experience of pain. The most common way of measuring attentional biases, the dot-probe task, is explained, detailing

limitations with its methodology. Next, a description of different phases of attentional processing is provided followed by a presentation of the primary hypotheses. Chapter two describes the methods used in the present project, including the participants, materials, behavioral measures, self-report measures, procedure, and statistical analysis. Chapter three describes how the data was prepared and the results. The findings for each hypothesis are described. Finally, chapter four discusses the findings in the context of previous research on pain and attentional biases. Clinical implications and limitations are described.

Chronic Pain

Definition. International Association for the Study of Pain (IASP) defines 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, p. 210). In contrast, there is no universally accepted definition for chronic pain. It has been described as pain that has persisted for a significant period of time past the normal time of healing (Bonica, Loeser, Chapman, Fordyce, & Domenowske, 1990), which varies according to the type of injury. However, some pain conditions are not expected to heal, such as rheumatoid arthritis, osteoarthritis, and multiple sclerosis, and therefore would not be considered chronic according to this definition. Additionally, when pain causes changes to the central nervous system, it is difficult to determine what would constitute an appropriate healing time. These difficulties make a definition contingent on healing time problematic (Merskey & Bogduk, 1994).

Chronic pain is more commonly described on the basis of its duration. Nonmalignant (non-cancer) pain persisting for longer than three months (Bouhassira, Lantéri-Minet, Attal, Laurent, & Touboul, 2008; Harstall & Ospina, 2003; van Hecke, Torrance, & Smith, 2013) or six months (Johansen, Romundstad, Nielsen, Schirmer, & Stubhaug, 2012; Landmark, Romundstad,

Dale, Borchgrevink, & Kaasa, 2012; Schopflocher, Taenzer, & Jovey, 2011) are commonly used cut-offs for determining when pain becomes chronic. Although these criteria are still problematic, it is still the most regularly used definition of chronic pain. Some epidemiological studies also use additional inclusion criteria for the frequency (e.g., pain must be experienced on most days) and severity of the experienced pain (e.g., pain must be at least of moderate to severe intensity). This conservative method may risk excluding many painful conditions that may remit for a period of time, as with migraine headaches and irritable bowel syndrome (Merskey & Bogduk, 1994).

The causes of chronic pain are complex. Extensive research has been conducted on the pathophysiological mechanisms contributing to pain and three distinct pathways have been identified: nociceptive, inflammatory, and neuropathic pain (Costigan, Scholz, & Woolf, 2008). These mechanisms are described in detail below, although it is important to note that chronic pain is embedded in a unique psychosocial and cultural context for each individual (Gatchel, Peng, Peters, Fuchs, & Turk, 2007a).

Nociceptive pain. Nociceptive pain is an immediate sensory response to noxious environmental stimuli. Stimuli produces electrical activity that activates peripheral terminals of unmyelinated C-fibers and myelinated Aδ-fibers (Costigan et al., 2008). The signal is transmitted along the primary afferent nerve to the spinal dorsal horn and on to the brain, where the physical sensation is processed and perceived as pain. This type of pain is associated with acute pain, such as pain due to breaking a bone, burning a hand, or scraping a knee. Nociceptive pain is generally considered to be adaptive, as it serves as a warning signal to alert to the possibility of damage: for example, after breaking an arm, the resultant discomfort may motivate the injured person to seek medical attention that would facilitate healing and prevent further damage (Costigan et al.,

2008; Woolf, 2004). The importance of nociceptive pain is also evident in individuals who are born without the capacity to experience pain, as with congenital insensitivity to pain (Woolf, 2004). Individuals with this condition are not aware when they become injured; therefore, the injured part of the body may continue to be used normally without seeking medical intervention, which can cause further damage, infections, or diseases. These conditions may go unnoticed by the person with congenital insensitivity to pain until they become more serious or potentially fatal (Cox et al., 2006).

Inflammatory pain. Inflammatory pain is associated with swelling due to damaged tissue (Costigan et al., 2008). It develops as a result of tissue damage and inflammation. The damaged cells release chemical mediators that stimulate proinflammatory cytokines and receptors (Costigan et al., 2008). Sensitization of the central nervous system may also occur. Inflammation causes the tissue to become more sensitive and reactive to external stimuli, preventing further contact with the area that may aggravate damage and delay healing (Woolf, 2004). Inflammatory pain in the absence of tissue damage is also possible, as with rheumatoid arthritis (Michaud, Bombardier, & Emery, 2007).

Neuropathic pain. Neuropathic pain is caused by changes in the nervous system resulting from peripheral nerve damage (e.g., due to trauma, infection, disease) or central nervous system damage (e.g., due to stroke, spinal cord injury, autoimmune disorders; Costigan et al., 2008). Neuropathic pain is typically considered and treated with reference to the physiological origin (e.g., trauma, disease) if available (Dworkin et al., 2007). However, the core feature of neuropathic pain is brain plasticity, as the experience of pain extends beyond tissue healing (Costigan et al., 2008). Neuropathic pain may be experienced as burning, shooting, paresthesias (i.e., an abnormal sensation; Merskey & Bogduk, 1994), or electrical shock-like. Conditions

characterized by neuropathic pain include diabetic neuropathy, complex regional pain syndrome, and fibromyalgia (Woolf, 2004).

Models of pain. Pain has been conceptualized in different ways over time. Early theories explained pain as an automatic reflex, where pain intensity corresponded directly to the extent of tissue damage (Descartes, 1644). However, this view of pain predicted a one-to-one correspondence between stimulus and response and was unsatisfactory for a wide variety of pain conditions, including phantom limb pain and pain hypersensitivity (i.e., allodynia). The gate control theory by Melzack and Wall (1965) was the first to propose a mechanism that included the influence of psychological, social, and cultural influences. Later, the biopsychosocial model of chronic pain was developed to emphasize how biological, psychological, and social factors interact to shape the perception of pain (Gatchel et al., 2007a). Relevant models to the present project are discussed below.

Pain specificity theory. One of the earliest models of pain was developed by Descartes (1644) who proposed that tissue injury directly causes pain: following contact with a noxious stimulus, pain signals travel up the spinal cord to the brain, directly causing the sensation of pain as a reflex. As stated by Descartes, "by pulling one end of a cord, you ring a bell which hangs at the other end" (1644). This was the earliest of the so-called "specificity theories" that propose that pain intensity has a one-to-one correspondence to the pain stimulus and the brain is not actively involved in modulating the experience. Others offered modifications of this model, but essentially the thinking remained the same (Melzack & Katz, 2013). This simplistic model does not account for possible mediating variables, such as expectations, affect, environment, and cultural context. The model provided novel, testable ideas for pain management: if the experience of pain is relayed from pain receptors directly to the brain, interrupting the

connection should theoretically lead to less intense pain. This led to interventions based on severing nerves and brain surgery, which were largely unsuccessful and had severe side effects, creating an impetus for a new model of pain (Melzack, 1973).

Gate control theory of pain. Dissatisfaction with the pain specificity model led to the development of the gate control theory of pain by Melzack and Wall (1965). At this time, a plausible explanation was still unavailable for clinical conditions such as phantom limb pain, hypersensitivity to touch, or insensitivity to pain, and the existence of specific pain receptors, as predicted by the model, had not been identified (Melzack, 1973). These gaps were accounted for in the gate control theory of pain. At the basic science level, the gate control theory hypothesized that sensory stimulation is transmitted to three spinal cord systems (substantia gelantinosa in the dorsal horn, dorsal-column fibers that project to the brain, and first central transmission "T" cells in the dorsal horn). The model makes three major propositions: substantia gelatinosa is a gate control system that influences the afferent patterns before they influence the T cells; afferent patterns in the dorsal column system act, at least in part, as a central control trigger that activates selective brain processes that influence the modulating properties of the gate control system, and; T cells activate neural mechanisms that comprise the action system responsible for response and perception (Melzack & Wall, 1965). In other words, there is a gating system that can either block or allow sensation signals. Whether or not the gate is "open" or "closed" is influenced by mood, previous experience, personal experience, context, mood, and other variables. After, the messages return down the spinal cord. Altogether, this contributes to the experience of pain and demonstrates that the brain is not a passive recipient of messages, but an active creator of the experience of pain: pain is the brain, not in tissue stimulation, and this determines the pain we experience (Melzack & Wall, 1965).

The gate control theory of pain changed the way that health care professionals and researchers thought about pain (Mendell, 2013). Through proposing specific novel mechanisms, the theory provided many testable hypotheses that inspired thousands of research studies. Although not all of the specific mechanisms have been supported, several lasting pain management strategies were developed on the basis of predictions made by the model, such as Transcutaneous Electrical Nerve Stimulation (TENS). TENS treats pain by applying mild electrical current, typically with electrodes, on the surface of the skin where pain is experienced or on a related area (Johnson & Martinson, 2007). According to the gate control theory, by stimulating large fibers with something like TENS, this reduces the activity in T cells, closing the gate. Although it is uncertain whether this is the precise mechanism that produces the effect, the treatment does have important clinical utility without the negative side effects of some pharmacological treatments (e.g., for chronic musculoskeletal pain; Johnson & Martinson, 2007). The legacy of the gate control theory is that it continues to inspire critical thinking regarding pain mechanisms and treatment to the present day (Dickenson, 2002; Mendell, 2013), including the neuromatrix theory (Melzack, 1999) and pain genetics (Melzack & Katz, 2013).

Biopsychosocial model of pain. The gate control theory of pain was the first formal theory of pain to introduce non-biological mechanisms in a model of pain. However, it did not make specific predictions for how the mechanisms specifically modulate the pain experience. In contrast, the biopsychosocial model of pain suggests that there are specific central processes (biological, somatic, cognitive, and affective), peripheral processes (autonomic, endocrine, and immune systems), genetic predispositions, and sociocultural contexts that contribute to the experience of pain (Gatchel et al., 2007a). This view emphasizes that a "concentration on the biomedical and exclusion of the psychosocial distorts perspectives and even interferes with

patient care" (Engel, 1977, p. 131). Subsequent research has explored specific psychological and social factors contributing to pain in more detail. In particular, it has been established that psychological variables are linked to the development and maintenance of chronic pain (Gatchel, Peng, Peters, Fuchs, & Turk, 2007b). Constructs related to anxiety are well-established, linking levels of pain catastrophizing (Picavet, Vlaeyen, & Schouten, 2002), fear of pain (Yang, Jackson, Gao, & Chen, 2012), sensitivity to anxiety or illness (Zvolensky, Goodie, McNeil, Sperry, & Sorrell, 2001), pain anxiety (McCracken & Dhingra, 2002), state anxiety (Asmundson & Katz, 2009), sensitivity to pain traumatization (Kleiman, Clarke, & Katz, 2011), pain vigilance (Aldrich, Eccleston, & Crombez, 2000), and acceptance of chronic pain (McCracken & Eccleston, 2005) to the experience of pain. Social determinants are also important antecedents to pain (Craig & Fashler, 2014), the experience of pain (Goubert, Vlaeyen, Crombez, & Craig, 2011), the communication of pain (Craig, 2009), and provision of aid to those in pain (Craig, 2009). Overall, the biopsychosocial model of pain emphasizes that unique psychological and social factors must be considered in conjunction with biological factors in order to provide a comprehensive perspective of the pain experience of each individual. For this reason, the present study will consider relevant pain-related psychological factors in the exploration of visual attention biases in individuals with chronic pain.

Attentional Biases

Definition. A cognitive bias, also referred to as an information processing bias, refers to the way that individuals attend to, process, interpret, and remember stimuli in the environment (Pincus & Morley, 2001). Cognitive biases can be further sub-divided into three categories: attentional biases, interpretive biases, and memory biases. The biases are not mutually exclusive and continuously influence one another throughout cognitive processing.

An attentional bias refers to an increased (hypervigilant) or decreased (avoidant) allocation of attentional resources to a type of stimulus. In the context of pain, the stimulus refers to a threatening object, such as stimuli related to pain. There is no consensus as to whether attentional biases are conscious and deliberate or unconscious and automatic and this has received little empirical investigation; however, it is generally considered that the earlier the bias is evident, the more automatic it is (Crombez, Van Ryckeghem, Eccleston, & Van Damme, 2013; Keogh, Thompson, & Hannent, 2003). Attentional biases have traditionally been assessed with the dot-probe task, a visual attention paradigm in which the participant is required to respond as quickly as they can to neutral- and threat-related stimuli, although the data remain mixed on the magnitude of the effect (Crombez et al., 2013; Schoth et al., 2012). This may be attributable to limitations in its measurement.

An interpretation bias refers to the way in which an individual processes information that is ambiguous: in these contexts, the individual uses pre-existing schemas to infer meaning of the situation (Mathews & MacLeod, 2005). Interpretation biases may be present when the stimulus is first encountered, in anticipation of the ensuing stimuli (i.e., the future), or following the presentation of the stimuli (i.e., the past; Mathews & MacLeod, 2005). It is suggested that individuals with pain will tend to process stimuli related to pain more readily than neutral stimuli in comparison to healthy controls. This has been empirically evaluated with paradigms such as the homophone task, where a participant is told one word that has two possible meanings: a neutral meaning and a threatening meaning (e.g., “pane” and “pain”; Mathews & MacLeod, 2005). The participant is instructed to write down the spelling of the word without being provided a definition and the interpretation bias is determined on the basis of the definition of the words (i.e., neutral or threatening) that are written down. Evidence shows that individuals with

chronic pain write down more threatening words (e.g., related to health, pain, or illness) in comparison to neutral words, whereas this bias is not evident in individuals without pain (e.g., Edwards & Pearce, 1994; Pincus, Pearce, McClelland, Farley, & Vogel, 1994; Pincus, Pearce, & Perrott, 1996).

A memory bias refers to a tendency to recall specific events with increased frequency (Blaney, 1986). This is hypothesized to affect how memory is initially encoded (i.e., information congruent with a specific schema is more likely to be encoded; Klein & Kihlstrom, 1986) and what type of material is recalled at a given time (i.e., information congruent with the activated schema are accessed more readily; Johnson & Spence, 1997). Memory can also be biased by mood: according to the state congruity bias, material that is congruent with present mood is more readily recalled (Christianson & Safer, 1996). In individuals with chronic pain, this may be exhibited with a greater tendency to recall pain-related information, especially if the individual is presently experiencing pain (Pincus & Morley, 2001). This is frequently assessed with word recall (i.e., the number of neutral and pain-related words recalled; Johnson & Spence, 1997), recognition (i.e., the number of neutral and pain-related words recognized; Gerrig & Bower, 1982), and autobiographical memory (i.e., increased recall of autobiographical memories related to the present emotional state; Christianson & Safer, 1996). Overall, evidence for a memory bias in individuals with chronic pain is robust (Pincus & Morley, 2001).

Models of pain and attentional biases. The interaction between chronic pain and attentional biases is complex. Several models have been proposed to explain how attention may contribute to the development, maintenance, and experience of pain.

Beck's schema theory. Beck's Schema Theory (Beck & Clark, 1997; Beck, Emery, & Greenberg, 1985) proposes that individuals process information in a selective way according to

pre-existing schemas. Stimuli that are related to an individual's schemas (i.e., congruent with their personal associative networks, unique to each person) are more likely to be encoded, to be interpreted in relation to the schema, and to be retrieved more readily. This model was originally developed to describe maladaptive processing in individuals with anxiety and depression, although the principles can readily be applied to individuals with chronic pain, where the maladaptive schemas would be related to pain. Additionally, anxiety and depression are highly comorbid with chronic pain (Demyttenaere et al., 2007; Katz, Pagé, Fashler, & Rosenbloom, in press; Von Korff et al., 2005) and likely contribute to biases in this population.

Schema Enmeshment Model of Pain. In the Schema Enmeshment Model of Pain, Pincus and Morley (2001) make specific predictions regarding the schemas that may account for processing biases in chronic pain. They predict that schemas regarding pain, illness, and self are over-processed regardless of the presence of comorbid anxiety, depression, or other emotional dysregulation: experiencing pain will increase the personal relevance of pain and illness to the self, becoming enmeshed over time. In some individuals, the enmeshment of the pain and self-schemas may become maladaptive, resulting in a disproportional amount of attentional processing towards pain-related stimuli (Pincus & Morley, 2001). This model implicates the role of attentional, interpretive, and memory biases in the maintenance of distress and pain.

Fear Avoidance Model of Pain. The Fear Avoidance Model of pain was developed as an attempt to explain increased risk of disability in individuals with chronic low back pain (Vlaeyen & Linton, 2000). Following an injury or the development of pain, acute discomfort is experienced. If this is met with low fear and continued engagement in daily activities, recovery is facilitated. However, if acute pain is misinterpreted as threatening, this may cause pain catastastriphizing, characterized by helplessness, rumination, and symptom magnification

(Sullivan et al., 2001). This may lead to fear of pain and/or re-injury, as well as creating symptoms of pain anxiety, which is characterized by hypervigilance towards pain (i.e., a bias towards information related to pain). This may lead to active avoidance of activities that may produce painful sensations, in turn causing disuse, muscular reactivity, and/or deconditioning that can increase the likelihood of re-injury (Vlaeyen & Linton, 2000). This model emphasizes the role of attentional and interpretation biases, rather than memory biases, in chronic pain. More specifically, it predicts that at-risk individuals will orient to threatening stimuli quickly (such as stimuli associated with pain) and will be less able to disengage, followed by intentional avoidance of threatening stimuli.

Misdirected Problem-Solving Model. The Misdirected Problem-Solving Model sees worry as a central mechanism in the development and maintenance of distress and pain (Eccleston & Crombez, 2007). The model predicts that individuals with chronic pain regularly worry about their pain. Worry may be about the causes and the possible consequences of the pain. Pain is also distracting, interrupting daily functioning (Eccleston & Crombez, 1999). As a result, this causes hypervigilance to pain and continuously captures attention. Since pain is typically placed in a biomedical problem frame, the model predicts that this may provide a solution or treatment opportunity that will alleviate worry. However, if the treatment strategy is unsuccessful, the problem remains unsolved, which can create more worry. The model predicts that individuals with chronic pain get stuck in a loop of worry called the "perseverance loop" beginning by approaching the problem of pain with a rigid "biomedical problem frame" (i.e., the only solution to the present problem is the removal of pain), engaging in problem solving behavior that is unsuccessful (i.e., the pain continues to persist), which leaves the problem unsolved and creates more worry. A possible way to break the loop is to reframe the problem

(i.e., the pain) to create a context where the problem can be solved (Eccleston & Crombez, 2007). This model predicts that hypervigilance to pain will contribute to biasing attention towards painful stimuli.

Motivational Account of Pain Attention. The previous models suggest that attentional biases towards pain develop over time and remain fairly consistent across different contexts. The Motivational Account of Pain Attention suggests that attentional biases are fluid, changing depending on the specific goal-pursuit and motivation of the individual (Van Damme, Legrain, Vogt, & Crombez, 2010). The model assumes that there are two primary contexts in which attentional biases can manifest. First, when the individual is pursuing a goal unrelated to pain when pain occurs and captures attention unintentionally. The bias towards the sensory experience may be small since pain is not relevant to the present goal (although this is subject to the nature of the pain and the goal). Second, if the individual is pursuing a goal related to pain, especially related to pain management, larger attentional biases are predicted to occur due to congruence with the present goal pursuit. This model considers attentional biases to be dynamic and subject to change depending on the present goal of the individual.

Measuring attentional biases. Attentional biases have traditionally been inferred using paradigms such as the dot-probe task that use reaction time as the primary outcome measure. The dot-probe task typically involves the simultaneous presentation of a threat word and a neutral word on either side of a computer screen (MacLeod, Mathews, & Tata, 1986). The two words remain on the screen for a short duration after which a dot is presented in the location of one of the words. The participant is to indicate the side of the screen on which the dot appears as quickly and accurately as possible by pressing one of two keys. The presence of an attentional bias toward threat-related stimuli is inferred by a shorter mean reaction time to the dot when it is

presented in the location of the threat word than when the dot is presented in the location of the neutral word (MacLeod et al., 1986).

Evidence for attentional biases toward pain-related information in individuals with chronic pain is inconsistent (Asmundson, Carleton, & Ekong, 2005a; Crombez et al., 2013; Dear, Sharpe, Nicholas, & Refshauge, 2011; Haggman, Sharpe, Nicholas, & Refshauge, 2010; Pincus & Morley, 2001) and may be related to the methodological limitations in its measurement. Most prominently, the primary outcome measure of the task is reaction time, an indirect indicator of attention; it assumes that faster reaction times accurately reflect selective visual attention towards the threatening stimulus. A more accurate index of visual attention would be a measure of the eye movements of participants. To date, only one study that I am aware of has investigated visual attention patterns in the dot-probe task using eye-tracking technology in individuals with chronic pain (Yang, Jackson, & Chen, 2013). The authors tracked the eye movements of 24 adults with and without chronic pain who were either high or low in fear of pain during a modified dot-probe task. The dot-probe task stimuli consisted of pain-neutral, health catastrophe-neutral, and neutral-neutral word pairs. The results did not show significant differences in reaction time according to pain status, fear of pain, or word type. However, compared with individuals who did not have chronic pain, those with chronic pain had shorter first fixation durations to health catastrophe words. These results suggest that eye-tracking is a more sensitive at identifying attentional biases than the tradition reaction time measure used for the dot-probe task (Sharpe, 2013).

Traditional dot-probe tasks are also limited in their ability to capture attentional biases across phases of visual attention (Sharpe, 2013). Current evidence indicates that there is a larger effect size of visual biases toward pain-related stimuli later in attentional processing, identified

when the exposure duration of word pairs is over 1000 ms. (Crombez et al., 2013; Schoth et al., 2012). This finding suggests that different mechanisms of attentional processing are operating depending on the exposure duration of the stimulus during the dot-probe task, although this has yet to be investigated with eye-tracking technology. Overall, it is evident that the classical dot-probe task using only reaction time has severe limitations. Consequently, it should be abandoned in light of new and more ecologically valid measures such as those determined by eye-tracking technology. In order to evaluate this conclusion, the present study will examine reaction time outcome measures in the dot-probe task to evaluate differences between individuals with and without chronic pain. This will permit a comparison with commonly used eye-tracking variables related to the frequency and duration visual attention measures.

Phases of attentional processing. Attention is a continuous process that changes over time. Visual attention phases represent periods of attentional processing that are qualitatively and temporally distinct. However, there is no consensus regarding what the attentional phases are, their specific qualities, or their duration (Posner, 1980). Posner (1994) hypothesized that there are only three phases that each have a unique neural basis: disengagement of attention from a stimulus (associated with activation of the posterior parietal lobe), orientation of attention towards a new stimulus (associated with activation of the superior colliculus), and engagement of attention on a new stimulus (associated with activation of the lateral pulvinar nucleus). Additional phases that have been described include orientation, engagement, maintenance, disengagement, re-engagement, and avoidance. It is possible that different phases are important in distinct ways in the development and maintenance of attentional biases in individuals with chronic pain (Crombez et al., 2013). It is difficult to separately examine phases since there is likely a substantial overlap between phases and individual variation in the course of phases.

Therefore, in order to examine specific phases, most research has associated a specific time period that is proposed to be related with the specific attentional phase. Different proposed phases are discussed in more detail below.

Orientation & initial engagement (<500 ms.). The orientation phase of attention is the initial period of attentional activation towards a new stimulus. It is hypothesized to occur before the first 500 ms. of looking at a stimulus (e.g., Bradley, Mogg, & Millar, 2000; Gamble & Rapee, 2009; Schoth et al., 2012). Posner (1980) describes this phase as "aligning attention with a source of sensory input or internal semantic structure stored in memory". Early orientation is associated with unconscious awareness of the stimuli, a finding that is supported by neuroimaging studies (e.g., Öhman, 2005). Initial orientation towards threatening stimuli is an adaptive process that facilitates fast and effective responses to environmental threats. This response pattern is more pronounced in anxiety disorders (Mogg & Bradley, 2002; Mogg, Bradley, Millar, & White, 1995) where the orientation attentional bias is considered to be in excess of what is evolutionary adaptive (Koster, Verschuere, Crombez, & Van Damme, 2005).

The initial engagement phase of attention is defined as when attention first settles on a new stimulus (Koster, Crombez, Verschuere, Van Damme, & Wiersema, 2006). Engagement occurs immediately following orientation and has been hypothesized to occur between 100-500 ms. Similar to orientation, attentional engagement is considered to be a largely unconscious process (Koster et al., 2006). Due to the close proximity in time between orientation and engagement, previous investigations have had difficulty distinguishing between the two phases using the dot-probe task. In most cases, they are differentiated using different exposure duration for stimuli presentation, typically between 30-500 ms. However, the same exposure times are interchangeably attributed to an orientation bias (e.g., Schoth & Liossi, 2010) and/or to an

engagement bias (e.g., Koster et al., 2005). Due to this unclear distinction, studies investigating both orientation and engagement biases are considered together below.

Orientation and engagement attentional biases have not been consistently identified in populations with chronic pain. Any biases towards threatening stimuli are interpreted as evidence of an orientation and/or engagement attentional bias. For example, Liossi, Schoth, Bradley, and Mogg (2009) did not find a significant difference comparing individuals suffering from chronic daily headaches ($N = 15$) to healthy controls ($N = 18$) in a dot-probe task using pain-related and neutral words. Similarly, using a dot-probe task, Asmundson, Kuperos, and Norton (1997) found no differences between individuals with chronic pain ($N = 19$) and healthy controls ($N = 22$). However, they did find that individuals that were high in fear of pain showed a greater attentional bias towards threatening words in comparison to individuals that were low in fear of pain. In contrast, Khatibi, Dehghani, Sharpe, Asmundson, and Pouretemad (2009) found that individuals with musculoskeletal pain displayed a bias towards pain faces in a dot-probe task when the stimuli was presented for 300 ms. They also found that this effect was more pronounced in individuals with a high level of fear of pain. Due to these inconsistent findings, Schoth et al. (2012) recently performed a meta-analysis of ten studies that used the visual dot-probe to consolidate current research. They found a small effect of .29 (Hedge's adjusted g) for orientation attentional biases in individuals with chronic pain. Overall, there is evidence of a small orientation attentional bias towards threatening stimuli in individuals that experience chronic pain.

In addition to reaction time, biases in orientation have begun to be measured with novel experimental technology. Since visual attention is typically accompanied by eye movements, eye-tracking methodology is an intuitive new way to investigate attentional biases. Previous

studies have used the direction and duration of eye movements to describe orientation. Specifically, the duration of the delay before the first fixation, the direction of the first fixation, and the duration of the first fixation have all been used to measure visual orientation biases (Vervoort, Trost, Prkachin, & Mueller, 2013; Yang et al., 2013).

Maintenance (between 500-2000 ms.). The maintenance phase of attention is defined as continuous attention to the stimuli. It occurs after orientation and engagement towards a stimulus and has been investigated in previous research using an exposure time between 500-2000 ms. This phase is considered to be more conscious and related to worry (Crombez et al., 2013; Donaldson, Lam, & Mathews, 2007), which is common in individuals with chronic pain (De Vlieger, Crombez, & Eccleston, 2006; Eccleston, Crombez, Aldrich, & Stannard, 2001).

Liossi and Schoth have conducted several studies investigating the time course of attentional biases in individuals with chronic pain. Using the dot-probe task, Liossi et al. (2009) compared health controls ($N = 18$) to people suffering from chronic daily headaches ($N = 15$). They used two exposure times: 500 ms. to reflect an orientation bias and 1250 ms. to reflect a maintenance bias. In this study, they only found differences between the two groups when the stimuli was presented for 1250 ms. In another investigation comparing individuals with chronic headache ($N = 17$) to healthy controls ($N = 21$), images were used as the visual stimuli (images of pain-related and neutral facial expressions). The results showed that participants with chronic headache pain displayed a bias for both exposure times (500 and 1250 ms.; Schoth & Liossi, 2010). A similar study recruited 40 patients with chronic tension-type headache and 40 healthy controls (Liossi, White, & Schoth, 2011). Pain, anger, social, and neutral words were included in a visual dot-probe for either 500 or 1250 ms. A bias to pain-related words was only evident when exposure time was 1250 ms. by chronic headache group versus controls (Liossi et al., 2011). In

their 2012 meta-analysis, Schoth et al. examined the presence of a maintenance bias as measured with the visual dot-probe task for individuals with chronic pain. They found a modest effect size of maintained attention (Hedges' adjusted g = .42). Similar conclusions were drawn from a recent meta-analysis examining the effect of subliminal and supraliminal exposure durations, concluding that "conscious and elaborative processes are critical for attentional biases to emerge" (Crombez et al., 2013, p. 507).

Maintenance biases have also been measured using eye-tracking methodology. Yang et al. (2013) used two eye-movement indices to measure maintenance attentional biases towards the threatening stimuli: the duration of the first fixation and the total gaze duration. According to this criteria, and using a longer exposure time of 2000 ms., they did not find differences comparing chronic pain (N = 24) versus pain-free (N = 24) individuals or between individuals high in fear of pain (N = 11) and low in fear of pain (N =13). Total gaze duration has also been used in other investigations as an index of attentional maintenance (e.g., Vervoort et al., 2013).

Disengagement (between 500-2000 ms.). The disengagement phase of attention is defined as the period when attention is withdrawn from the current stimuli (Van Damme, Crombez, & Eccleston, 2004). This is predicted to occur approximately 500-2000 ms. following initial orientation. Difficulty disengaging from threatening stimuli is another important dimension of attentional biases and it may be more difficult to disengage from a threatening stimulus if an attentional bias is present (Fox, Russo, Bowles, & Dutton, 2001). It is suggested that disengagement more reliably distinguishes between people with low and high anxiety (e.g., Derryberry & Reed, 2002; Fox et al., 2001).

Disengagement has been investigated with the dot-probe task. Baum, Schneider, Keogh, and Lautenbacher (2013) utilized a dot-probe task with images of faces that displayed a neutral

expression paired with a painful, angry, or joyful expression. Each pair was presented twice, once for 100 ms. and once for 500 ms. to 100 pain-free participants. At 500 ms., but not 100 ms., participants avoided pain and angry faces more than neutral faces. Participants high in fear of pain attended more to painful and angry faces at 100 ms. and showed greater disengagement to painful and angry faces at 500 ms. Koster, Crombez, Verschuere, and De Houwer (2004) made an effort to distinguish between attentional engagement and disengagement by looking at different reaction time indices rather than solely the exposure time of stimuli. They proposed that by comparing congruent, incongruent, and neutral trials on the dot-probe task, comparing congruent trials to neutral trials will reflect engagement and comparing incongruent trials to neutral trials will reflect disengagement. For pain-free participants, they found a congruency effect to mild and high threat pictures, suggesting that an engagement but not a disengagement bias is present in this population.

Re-engagement (between 500-2000 ms.). Re-engagement is defined as when attention is redirected to a new stimulus. This stage occurs immediately after disengagement (between 500-2000 ms.; Heeren, Lievens, & Philippot, 2011). Difficulties re-engaging with new stimuli are synonymous with difficulty disengaging from stimuli, although they are investigated in different ways. Re-engagement is investigated more frequently with attempts to modify attentional biases, whereas disengagement is more typically investigated to identify the presence of a bias. For example, according to the counter-bias hypothesis, facilitating re-engagement with new, non-threatening stimuli can create a new and more adaptive bias (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002). That is, training can modify maladaptive biases.

The counter-bias hypothesis was recently investigated in a study by Heeren et al. (2011). They created four training conditions, each presenting participants with pictures of faces

(threatening and neutral) using a modified Posner spatial cueing task. The first condition trained participants to disengage from threat (disengage condition), the second condition trained participants to only attend to non-threatening pictures (re-engage condition), the third condition trained participants to disengage from threat and to re-engage with non-threatening pictures (disengage/re-engage condition), and the fourth condition did not train the participants (control condition). Seventy-nine participants with generalized social anxiety disorder participated. For the disengage condition and the disengage/re-engage condition, there were three notable findings following training: participants reported less anxiety in an experimental speech task, less behavioral anxiety was observed by unbiased raters during the speech task, and the attentional bias towards threatening stimuli was significantly reduced. Overall, this study provides support of the importance of re-engagement and disengagement of threatening stimuli for individuals with social anxiety (Heeren et al., 2011). Similar studies have not yet been explored in populations with chronic pain.

Avoidance (between 500-2000 ms.). Avoidance refers to a process whereby attention towards a stimulus is evaded. This is predicted to occur at any point following orientation, between 500-2000 ms. (Hermans, Vansteenwegen, & Eelen, 1999). Avoidance of threatening stimuli is well-established in anxiety disorders, such as post-traumatic stress disorder (Bar-Haim et al., 2010) and social anxiety (Moukheiber et al., 2010), although findings are inconsistent in pain populations. The vigilance-avoidance hypothesis has been developed to help explain the contradictory finding that individuals may show a bias both towards and away from threatening stimuli (Mathews, 1990). The hypothesis predicts that attention is initially drawn to threatening stimuli but then it is drawn away from the threat. This pattern is apparent in phobias (Fox, 2004) and may be related to the development of chronic pain: Lautenbacher et al. (2010) found that a

bias towards positive words in a dot-probe task predicted levels of postopertative pain three and six months following surgery.

Summary. In sum, visual attention biases may differ across visual attention phases. In the classical dot-probe task, differences across visual attention phases are assessed with varying exposure durations of word pairs, i.e., if the word pairs are presented for 2000 ms., the corresponding attentional bias assessed with reaction time is associated with the avoidance and/or re-engagement of attention. Using eye-tracking as an outcome measure provides a continuous measure of visual attention, permitting the capture of attention at different visual attention phases within the same trial, i.e., if the word pairs are presented for 2000 ms., visual attention can be examined between specific time intervals (e.g., between 0-500 ms., 500-1000 ms., and 1000-2000 ms.). Therefore, one of the aims of the present study is to examine different phases of visual attention in individuals with and without chronic pain.

Burden of attentional biases. Attentional biases to pain-related information are implicated as contributing to the cause and maintenance of chronic pain (Eccleston & Crombez, 1999; Schoth et al., 2012). That is, it is proposed that there is something about the way that individuals selectively process stimuli in the environment that contributes to pain. However, currently there is limited experimental evidence supporting the causal role of attentional biases in individuals with chronic pain: the majority of predictions are generalized from research in other conditions, most notably anxiety disorders. For example, Mogg et al. (1995) found that attentional biases at initial testing are predictive of anxiety levels at follow-up. Although subtle, attentional biases towards stimuli with a negative valence have been found to increase levels of anxiety and negative mood experimentally using a modified dot-probe task where the probe was always behind the threat words or the neutral words (MacLeod et al., 2002). Li, Tan, Qian, and

Liu (2008) found similar results in the opposite direction, where training participants to attend non-threatening stimuli in the dot-probe task led to lower levels of anxiety. Finally, pain itself demands attention that can lead to impaired performance when a high level of cognitive performance is required (Eccleston & Crombez, 1999). These negative consequences point to a need to better understand and to create interventions to modify negative attentional biases.

Hypotheses

The present study was designed to target previous methodological limitations by tracking participants' eye movements during a dot-probe task in order to evaluate attentional biases to sensory pain-related words in individuals with chronic pain. Based on the literature reviewed above, five primary hypotheses were tested in the present study. In comparison to pain-free participants, individuals with chronic pain will: (1) exhibit a faster reaction time to sensory pain-related words than neutral words in the dot-probe task; (2) attend to sensory pain-related words more frequently; (3) exhibit a different pattern of sustained attention to sensory pain-related and neutral words; (4) show an attentional bias towards sensory pain-related words at different phases of visual attentional processing; and (5) all participants will show significant, positive correlations between reaction time scores, visual attention measures, and self-reported pain-related psychological factors.

Chapter Two: Methods

The study was approved by the York University Research Ethics Board (Human Participants Review Subcommittee). Written informed consent was obtained from participants prior to beginning the study.

Recruitment

Participants were recruited through York University's Undergraduate Research Participant Pool (URPP). Before participants enroll in studies, they complete a prescreening survey composed of questions submitted by various faculty research laboratories. Responses to questions determine the studies that are visible to the student. For the present study, the question "do you experience physical pain on a regular basis?" was included to determine the approximate prevalence of chronic pain among undergraduate students completing the prescreen questionnaire. Of the 3,163 students that responded, 655 (20.71%) positively endorsed the statement, 2,508 (79.29%) did not, and 26 declined to respond. Due to the disproportionate number of students that report experiencing pain regularly, two study postings were created: one was visible to students who positively endorsed the prescreen question related to pain and the other was visible only to students who did not. Participants received one course credit for completing the study.

Materials

Hardware. Eye movements were tracked using a Tobii T60 XL eye-tracker with a 24-inch widescreen monitor and a 60 Hz data rate (Tobii® Technology, Falls Church, VA, USA). The eye-tracker is integrated into the monitor, allowing participants to move their heads freely throughout the study. The Tobii T60 XL has an accuracy rate of 0.5 degrees and less than .03 degrees drift, leading to minimal differences between what the participant is looking at and what

the equipment is recording. The eye-tracker uses a 3D eye model that manages eye movements according to the reflection, size, shape, and refractive quality of the eyes of each participant. Eye calibration uses feedback from two forms of pupil tracking, dark and bright, to ensure the consistent and accurate tracking of participants' eyes. Two Dell Precision T3400 Intel® Core™ 2 Quad CPU, each with 4 GB of RAM, were interfaced to facilitate data collection from both software programs (E-Prime and Tobii Studio Pro). The display resolution for the dot-probe protocol was 800 x 600 pixels to optimize video capture and data transfer between the two computers. The study took place in a windowless room in order to standardize the lighting for all participants.

Software. E-Prime 2.0 Professional (Psychology Software Tools, Inc., Sharpsburg, PA, USA) was used to design, display, collect, and prepare data for the dot-probe task (Schneider, Eschman, & Zuccolotto, 2002). E-Prime provides millisecond precision in the capture of reaction times. The protocol for the present study was designed in E-Studio, E-Merge was used to combine the data from each participant, and E-DataAid was used to prepare the data for export. Tobii Studio Professional 2.0 captured participant eye movements with time-sensitive markers programmed into the dot-probe design (Tobii® Technology, 2010). E-Prime and Tobii Studio software programs were interfaced with E-Prime 2.0 extensions for Tobii (Psychology Software Tools, 2011) to permit the simultaneous collection of reaction time and gaze data. Superfluous software and start-up programs on both computers were deleted and both were removed from the local network to increase processing speeds. The final data set was analyzed with SPSS 20 (version 20.0, IBM, Armonk, NY, USA).

Verbal stimuli. Words were selected from previous research using the dot-probe paradigm to test attentional biases in chronic pain populations

Table 1: Word pairs.

Sensory Pain - Neutral	Neutral - Neutral
throbbing - blender	bath - soap
pounding - television	brushing - decorate
sharp - telephone	clean - chair
aching - door	mugs - lamp
burning - radio	cook - dust
dull - window	decorated - household
tender - stove	dusted - plants
sore - fur	floor - steps
gnawing - computer	furniture - magazines
hurting - pillow	doorknob - bathroom
shooting - table	bedroom - surface
stabbing - chair	stair - table
cramping - barrel	water - house
heavy - patio	vase - tidy
splitting - washer	towels - bedspread

Note. Adapted from Asmundson, Wright, & Hadjistavropoulos, (2005).

(Asmundson et al., 1997; Asmundson, Wright, & Hadjistavropoulos, 2005b; Keogh, Ellery, Hunt, & Hannent, 2001; Snider, Asmundson, & Wiese, 2000; Vago & Nakamura, 2011). Words related to the sensory experience of pain were selected over words related to other aspects of the pain experience (e.g., affective experience of pain, antecedents of pain, or consequences of pain) as sensory pain words are related to larger effects in previous research (Crombez et al., 2013). The sensory pain words were originally drawn from the McGill Pain Questionnaire, a detailed questionnaire designed to describe diverse aspects of pain (Melzack, 1975). Sensory pain and

neutral words were matched for word length and frequency (Kucera & Francis, 1967). See Table 1 for a complete list of the word pairs.

Behavioral Measures

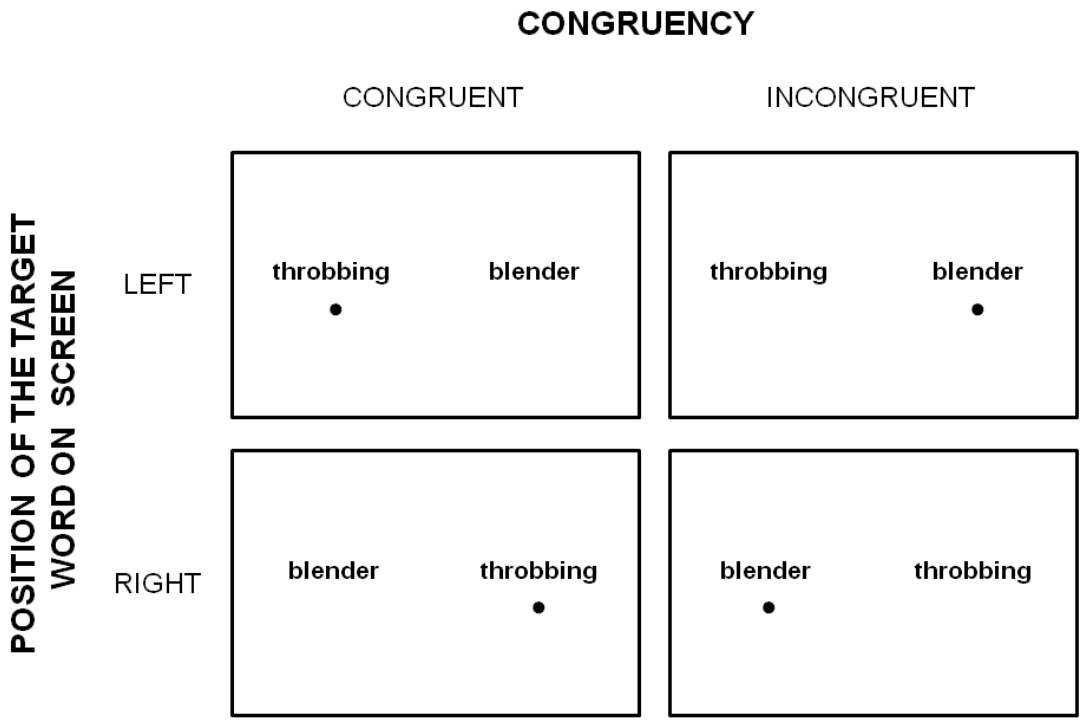
During the dot-probe task, various behavioral measures were assessed. Reaction time (in milliseconds) was recorded to capture the speed of participant responses to the location of the dot-probe. In addition, measures of visual attention were collected to determine the duration, frequency, and patterns of the participants' gaze.

Reaction time (RT) measures. For each participant, a congruency index, incongruency index, and neutral comparison index was computed.

Congruent, incongruent, and neutral comparison indexes. These indexes are based on calculations by Koster et al. (2004) and Roelofs, Peters, Fassaert, and Vlaeyen (2005). A trial is considered to be congruent when the dot-probe appears in the location on the screen where the target word (i.e., the sensory pain word) was presented and incongruent when the dot-probe appears in the location of the neutral word (see Figure 1). Each condition considers the location of the word and of the dot-probe to balance individual differences in preference to look at one side of the computer screen more than the other, regardless of the location or type of word. The indexes are based on four mean reaction time scores, $\overline{\mathrm{RT}}_{\mathrm{tldr}}$, $\overline{\mathrm{RT}}_{\mathrm{trdr}}$, $\overline{\mathrm{RT}}_{\mathrm{trdl}}$, and $\overline{\mathrm{RT}}_{\mathrm{tldl}}$, which are computed by taking the mean of the 15 trials in each condition. In each formula, "t" is the target (sensory pain word), "d" is the dot-probe, "l" is the left position on the screen, and "r" is the right position on the screen.

The congruency index is calculated by taking the grand mean of the mean RTs of congruent trials that are presented on the right and left sides of the computer screen: $\overline{\mathrm{RT}}_{\mathrm{congruent}} = (\overline{\mathrm{RT}}_{\mathrm{tldl}} + \overline{\mathrm{RT}}_{\mathrm{trdr}})/2$. Similarly, the incongruent index is calculated by taking the

Figure 1: Visual depiction of counter-balanced trials of words presented during the dot-probe task. Sensory pain word (target, t) on left (l) side of screen followed by the dot (d) on the left side of the screen (left, congruent or "tldl"), sensory pain word on left side of screen followed by the dot on the right (r) side of the screen (left, incongruent or "tldr"), sensory pain word on right side of screen followed by the dot on the right side of the screen (right, congruent or "trdr"), and sensory pain word on right side of screen followed by the dot on the left side of the screen (right, incongruent or "trdl").



grand mean of the mean RTs of the responses of incongruent trials that are presented on the right and left sides of the computer screen: . The neutral comparison index is calculated from the neutral-neutral pairs and to permit comparison with the congruent and incongruent indexes. It is calculated by taking the grand mean of the mean reaction times for the neutral word pairs: .

Visual attention measures. Tobii I-VT fixation filter settings were used to classify fixations, since they provide validated and robust function parameter values that are easily replicated for future research. As such, maximum gap interpolation (i.e., merging) of fixations

was set to 75 ms., the max angle between fixations was 0.5°, and fixations had to be greater than 60 ms (Komogortsev, Gobert, Jayarathna, Koh, & Gowda, 2010). These settings provide accurate fixation classifications for most research (Komogortsev et al., 2010). Additionally, data was screened for validity and only used if the data collected was associated with the correct eye.

Gaze patterns were recorded for the duration of the dot-probe task. Currently, there are no accepted standard dependent variables associated with eye-tracking within a dot-probe paradigm due to the novelty of its use. Therefore, we modeled our dependent variables in part based on a recent study (Yang et al., 2012) and in part on theoretical predictions. The following dependent variables are based on eye movements recorded within a region on the left and right sides of the screen defined by the experimenter as an "area of interest" (AOI). An AOI, 250 pixels in length by 107 pixels in height, was demarcated at mirror image regions on the (center and midline of the) left and right sides of the screen within which word stimuli were presented.

Fixations. Two variables were calculated based on visual fixations for each word type (sensory pain and neutral): "number of fixations" is the number of times the participant's eyes focused on a sensory pain or neutral word within its respective AOI and "average fixation duration" is the mean time associated with all fixations.

Visits. A "visit" is defined by one or more contiguous eye-movements within an AOI (i.e., a visit is ended when the eyes move outside the AOI). Two variables were calculated based on visits to the sensory pain word AOI or neutral word AOI. The "number of visits" is the total number of visits to the sensory pain word AOI or neutral word AOI and "average visit duration" is the mean time spent looking during all visits to the sensory pain word AOI or neutral word AOI.

Presentation phase. To investigate whether gaze patterns vary during different stages of visual processing/attention, we calculated the total fixation duration for three different periods of stimulus presentation: "early phase total fixation duration" (0-500 ms); "middle phase total fixation duration" (500-1000 ms); and "late phase total fixation duration" (1000-2000 ms). Each index is calculated by summing the total duration of each trial for each period.

Self-Report Measures

Demographics and pain history questionnaire. Participants were asked basic demographic questions and questions about their pain history and current pain complaints, including the duration, location, frequency, and cause of any pain. They were also asked to describe the pain intensity associated with several common types of pain (tooth ache, paper cut, stubbed toe, biting your tongue, sunburn, and ear ache) on a scale from 0-10, where 0 = no pain and 10 = the highest pain intensity.

Pain disability. The Pain Disability Index (PDI; Pollard, 1984) is a 7-item scale that assesses the degree of daily disability due to pain. Items are scored on an 11-point Likert scale with a total scale score range is 0-70, where higher scores reflect a greater degree of pain disability. The PDI has good internal consistency (Cronbach's alpha = .86), good test-retest reliability (r = .44 over a two-month period), and it has good concurrent validity with measures of psychological distress, pain severity, and other items measuring pain-related disability (Tait, Chibnall, & Krause, 1990). The internal consistency of the PDI in the present study was good (Cronbach's alpha = .89).

Pain catastrophizing. The Pain Catastrophizing Scale (PCS; Sullivan, Bishop, & Pivik, 1995) is a 13-item scale that measures the degree to which individuals catastrophize, i.e., ruminate/worry about, magnify, and feel helpless in the face of painful experiences. Items are

scored on a 5-point Likert scale and the total score range is 0-52. Higher scores reflect more pain catastrophizing. Internal consistency is high (coefficient alpha is .87) and test-retest reliability is good (r = .75 over a six week period; Sullivan et al., 1995) The internal consistency of the PCS in the present study was excellent (Cronbach's alpha = .94).

Pain vigilance. The Pain Vigilance and Awareness Questionnaire (PVAQ; McCracken, 1997) is a 16-item scale that assesses an individual's daily preoccupation with pain. Each item is scored on a 5-point Likert scale and the total score range is 0-64. Higher scores indicate greater awareness, consciousness, vigilance, and observation of pain. The PVAQ has good internal consistency (Cronbach's alpha = .86), good test-retest reliability (r = .80 when retaken an average of 4 days later), and good convergent validity with private body consciousness (r = .58) and a negative correlation to the ignoring pain subscale of the Coping Strategies Questionnaire (r = -.24; McCracken, 1997). The internal consistency of the PVAQ in the present study was good (Cronbach's alpha = .87).

Pain anxiety. The Pain Anxiety Symptoms Scale - Short Form (PASS-SF; McCracken & Dhingra, 2002) is a 20-item scale that assesses anxiety regarding pain and pain sensations. Each item is scored on a 5-point Likert scale and the total score range is 0-100. Higher scores reflect a tendency to be anxious about the experience of pain. The short form correlates highly with the original 40-item scale (r = .97). The PASS-SF has excellent internal consistency (alpha = .91), reliability, and validity (Cronbach's alpha = 0.81; McCracken & Dhingra, 2002). The internal consistency of the PASS-SF in the present study was excellent (Cronbach's alpha = .93).

Chronic pain acceptance. The Chronic Pain Acceptance Questionnaire (CPAQ; Vowles, McCracken, McLeod, & Eccleston, 2008) is a 20-item scale that measures the tendency to accept the experience of pain and to engage in daily activities despite feeling pain. All items

are scored on a 7-point Likert scale and the total score range is 0-120. Greater acceptance of chronic pain is reflected in higher scores. It has good internal consistency (Cronbach's alpha = .85), adequate reliability, and good convergent validity with related psychosocial distress and physical functioning questionnaires (McCracken, Vowles, & Eccleston, 2004). The internal consistency of the CPAQ in the present study was acceptable (Cronbach's alpha = .74).

State anxiety. The state version of the State-Trait Anxiety Inventory (STAI-S; Spielberger, 1983) is a 20-item scale that assesses current feelings of anxiety. Each item is rated on a 4-point Likert scale and the total score range is 20-80. High scores are reflective of higher levels of state anxiety. Internal consistency is high (ranges from .86-.95). Test-retest reliability is fairly low (ranges from .16 to .62) since state levels of anxiety are expected to change with time (Spielberger, 1972). The STAI-T has well-established construct and concurrent validity (Spielberger, 1989). The internal consistency of the STAI-S in the present study was excellent (Cronbach's alpha = .94).

Anxiety sensitivity. The Anxiety Sensitivity Index-3 (ASI-3; Taylor et al., 2007) is an 18-item questionnaire designed to assess beliefs and fear associated with anxiety-related sensations (specifically, that the symptoms of anxiety have harmful consequences). Items are scored on a 5-point Likert scale and the total score range is 0-72. Higher scores reflect a greater tendency to be fearful of the experience of anxiety symptoms. The internal consistency for the subscales ranges from good to excellent (alpha ranges from .80-.90). The ASI-3 also has good reliability (alpha = .93; Wheaton, Deacon, McGrath, Berman, & Abramowitz, 2012) The internal consistency of the ASI-3 in the present study was good (Cronbach's alpha = .89).

Illness sensitivity. The Illness Sensitivity Index- Short Version (ISI-SF; Taylor, 1993) is an 11-item scale that assesses the fear of experiencing illness. Items are scored on a 5-point

Likert scale and the total score range is 0-44. Higher scores indicate a higher level of fear. The ISI has good internal consistency (alpha > .80; Taylor, 1993) and total scale reliability (r = 0.89). The internal consistency of the ISI-SF in the present study was excellent (Cronbach's alpha = .91).

Sensitivity to pain traumatization. The Sensitivity to Pain Traumatization Scale (STPS; Kleiman et al., 2011) is a 20-item that measures anxiety-related cognitive, emotional, and behavioral reactions to pain that resemble symptoms of posttraumatic stress disorder. Items are scored on a 5-point Likert scale and the total score range is 0-80. The scale was developed with an exploratory factor analysis on the items of the PASS-SF, PCS, and ASI-3. The STPS has good psychometric properties: the concurrent validity was established by comparing people with chronic pain and without chronic pain and it shows good convergent validity with related measures (Kleiman et al., 2011). The internal consistency of the SPTS in the present study was excellent (Cronbach's alpha = .91).

Procedure

After arriving at the lab and providing informed consent, participants completed a computer-administered survey consisting of the ten questionnaires described above. The demographic and pain history questions appeared at the beginning of the survey for all participants. The order of the remaining questionnaires was randomized within participants using an online survey manager (Sona Systems, Bethesda, MD, USA). Participants were led to a windowless room to complete the dot-probe task. They were positioned approximately 60 cm in front of the screen with eyes level with the center of the screen. Five-point eye calibration was performed with Tobii Studio software to customize the eye-tracking specifications to each participant. The computer input was adjusted to run E-Prime from a second computer

whereupon a second eye calibration was performed. Next, the dot-probe task was introduced and described. Participants were told that they were to fix their gaze at the central fixation cross, that a pair of words would appear briefly on the screen and that a dot would be presented in the location of one of the words. Their task was to identify the location of the dot as quickly and accurately as possible. Participants then completed 12 practice trials to familiarize themselves with the task.

The protocol for each trial consisted of three parts: (1) a fixation cross ("+") appeared at the center of the screen for 500 ms; (2) two words in bold, Arial font in size 24 (sensory pain-neutral or neutral-neutral) were presented simultaneously, one on the left, and the other on the right side of the screen for 2000 ms; and (3) immediately after the offset of the words, a dot-probe ("●") appeared on the left or right side of the screen (in the prior location of the word) for 2000 ms or until the participant responded by pressing one of two keyboard keys. Participants were told to press the "P" with their right index finger if the dot-probe was on the right side of the screen and the "Q" with their left index finger if the dot-probe was on the left. All text and symbols appeared in black on a white background. Word pairs were counter-balanced, controlling for word type location and dot-probe location, so that each word pair was presented four times (see Figure 1). In total, participants completed 120 trials (4 trials each of the 15 sensory pain-neutral word pairs and 4 trials each of the 15 neutral-neutral word pairs). Following the trials, participants repeated the same procedure using pictorial stimuli instead of words, although these data will not be reported here. The presentation order of trials was randomly generated by E-Prime (i.e., the order selection was set to "random") for each participant.

Statistical Analysis

Comparisons of nominal data categories, such as participants in the chronic pain group in comparison to pain-free participants, were made with chi-square tests of independence. The reaction time indexes were analyzed using a mixed design 2 x 3 analysis of variance (ANOVA) using Group (chronic pain, pain-free) as the independent samples factor and Congruency (congruent, incongruent, and neutral comparison indexes) as the within-subjects factor. Number of fixations, average fixation duration, number of visits, average visit duration, early phase total fixation duration, middle phase total fixation duration, and late phase total fixation duration were analyzed by a series of 2 x 2 mixed-design ANOVAs using Group (chronic pain, pain-free) as the between-subjects factor and Word Type (sensory pain, neutral) as the within-subjects factor. Significant interactions were proceeded with simple main effects analyses with the alpha criterion adjusted to $\alpha = .01$ to account for the number of comparisons (Bonferroni, 1936). Correlation analyses were used to examine the strength of the linear relationships between total questionnaire scores and group, reaction time, and visual attention.

Chapter Three: Results

Data Preparation

Reaction time measures. On the dot-probe task, incorrect trials or trials that had reaction times >2000 ms. were excluded from the calculation of the mean reaction time scores (Koster et al., 2004). Reaction times for these trials do not indicate a bias towards the measured variables and therefore may artificially skew the data. According to these criteria, 1.02% trials were excluded from the calculation of the mean reaction time scores. Missing reaction times scores were pro-rated if 80% or more of trials were available (Heckman, 1979; Rubin, 1976). One participant with insufficient data was excluded from the analysis of the reaction time data.

Visual attention measures. Eye-tracking recordings were screened for the quality of visual gaze capture. Only participants whose gaze capture exceeded 75% were included, consistent with previous eye-tracking research (Vervoort et al., 2013). Lower gaze capture may be related to compromised attention, consistently lowered/closed eyelids, or reflections off of glasses that obscure the visual recording (Duchowski, 2007). This led to the exclusion of 20 participants with poor capture ($M_{capture}$ = 60.90%, $SD_{capture}$ = 12.52%) and 2 participants who were unable to be calibrated. The mean eye capture for included participants was 88.44%, *SD* = 5.34%.

Questionnaires. Reverse-scored items on the STAI-S, PVAQ, and CPAQ were reverse coded. Total scores were calculated by adding all item scores on each questionnaire. Missing questionnaire items were pro-rated if 80% or more of trials were available (Heckman, 1979; Rubin, 1976). One participant responded to fewer than 80% of the questions on the ASI, STAI-S, and SPTS, and was consequently excluded from the analysis of these questionnaires.

Participants

A total of 113 participants were included for analysis. The age range of the sample was 18-44 years, $M_{age} = 21.32$, $SD_{age} = 4.35$. Eighty-four participants were female (74.30%) and 29 were male (25.70%). The sample was ethnically diverse, with participants self-identifying as Caucasian (32.54%), South Asian (28.57%), African (10.32%), East Asian (9.53%), Middle Eastern (8.73%), Hispanic/Latino (4.76%), Caribbean (3.97%), Aboriginal (0.79%), or undisclosed (0.79%). Forty-nine participants wore vision-correction aids during testing, with 16 (14.2%) using contact lenses and 33 (29.2%) using glasses.

For the purpose of the present study, chronic pain was defined as the presence of ongoing pain that had persisted for three months or longer (Merskey & Bogduk, 1994). According to this criterion, 51 (45.13%) participants reported experiencing chronic pain. Of these, seven (13.70%) participants reported experiencing pain for 3-6 months, five (9.80%) for 6-12 months, and 39 (76.50%) for 12 months or longer. Participants reported pain in 1-5 body locations ($M_{location} = 2.16$, $SD_{location} = 1.08$): 30 reported neck and/or back pain, 22 reported headache/migraine pain, 21 reported ankle and/or knee pain, 15 reported shoulder pain, 12 reported stomach pain, 5 reported hip(s) pain, 2 reported arm pain, 1 reported eye pain, 1 reported jaw pain, and 1 declined to respond to this question. Most participants reported that the pain commenced after an injury (47.10%) or that they were unsure how the pain started (35.30%), while for 7.80% of participants stated it started to due overuse and/or stress, 5.9% due to an illness, and one (0.79%) due to a hereditary predisposition. Frequency of pain was reported as daily (64.70%), weekly (33.30%), or other (2.00%) with the average intensity as mild (15.70%), moderate (74.50%), or severe (9.80%). When completing the questionnaires, 30 participants reported their present pain intensity as mild (73.30%) or moderate (26.60%) pain. Approximately half (52.90%) of chronic

pain participants used painkillers on a regular basis, most notably NSAIDs (63.00%) and acetaminophen (59.30%), as well as aspirin (25.90%), opioids (7.40%), and others (29.60%).

Participants included in the final analysis did not differ significantly from those with insufficient gaze data ($N = 22$) on age, $t(133) = .71$, $p = .481$, use of contact lenses, $\chi^2(2, N = 135) = 5.50$, $p = .064$, glasses, $\chi^2(2, N = 135) = .45$, $p = .504$, or presence of chronic pain, $\chi^2 (2, N = 135) = .58$, $p = .448$. There was a significantly greater proportion of males, $\chi^2 (2, N = 135) = 11.84$, $p = .003$, and participants self-identifying as Caucasian, $\chi^2 (2, N = 135) = 8.29$, $p = .004$ among those with sufficient gaze data and significantly greater proportion of participants self-identifying as African, $\chi^2 (2, N = 135) = 5.15$, $p = .023$, among those with insufficient gaze data.

Normality

There was no evidence that assumptions of normality were violated in the present data set: sphericity was not violated according to Box's Test of Equality of Covariance Matrices and Mauchly's Test of Sphericity. Levene's Test of Equality of Error Variances did not show evidence that homogeneity of variance was violated. Shapiro-Wilk Test of Normality and an examination of skewness and kurtosis according to a test statistic adapted from Cramer (sample skewness divided by the standard error of skewness; 1997, p. 85), did not suggest violations in normality. Exceptions for any tests are discussed in conjunction with the specific analysis below.

Hypothesis 1: Dot-Probe Task Reaction Time Measures

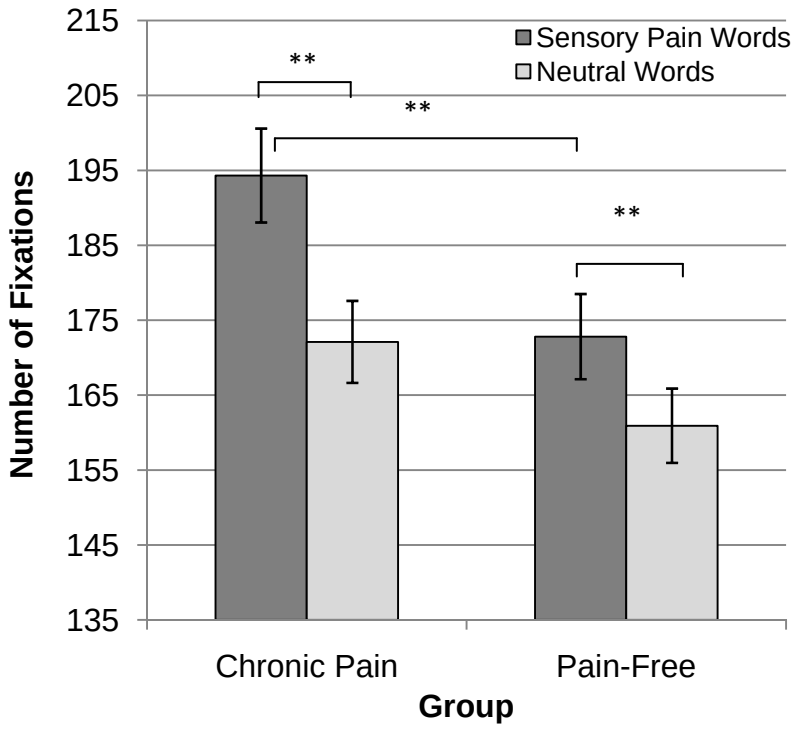
Table 2 shows the mean reaction times for the congruency, incongruency, and neutral indexes according to chronic pain and pain-free participants. A mixed-design ANOVA evaluated the relationship between group and index type (congruency, incongruency, and neutral comparison index). Mauchly's Test of Sphericity was significant, $X^2(2) = 9.30$, $p = .010$ which

Table 2: Hypothesis 1: Reaction time index scores (in ms.) for each group.

	Chronic Pain Group *Mean* (*SD*)	Pain-Free Group *Mean* (*SD*)
Congruency index	532.18 (93.58)	548.15 (88.80)
Incongruency index	526.76 (84.96)	539.28 (79.12)
Neutral comparison index	532.69 (85.82)	540.37 (86.78)

necessitated a Huynh-Feldt correction (Huynh & Feldt, 1976). Significant effects were not found for group, $F(1, 110) = .59$, $p = .451$, $\eta_p^2 = .012$, index type, $F(1.90, 208.57) = 2.27$, $p = .113$, $\eta_p^2 = .021$, or the group by index type interaction, $F(1.90, 208.57) = .70$, $p = .490$, $\eta_p^2 = .006$.

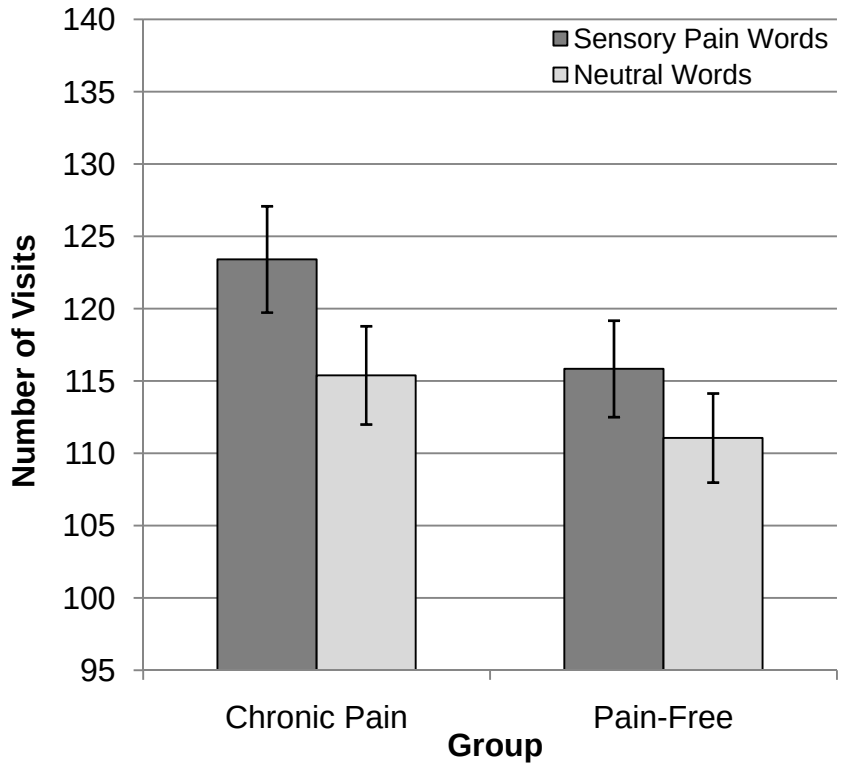
Figure 2: Frequency of fixations for each group. Error bars display the standard error. ** $p < .01$



Hypothesis 2: Frequency Measures of Visual Attention using Eye-Tracking

Table 3 shows the means and standard deviations for the visual attention measures by group. Mixed-design ANOVAs evaluated differences between group (chronic pain vs. pain-free) and word type (sensory pain vs. neutral) for all visual attention measures. For number of fixations, the main effect of group, $F(1, 111) = 4.55$, $p = .035$, $\eta_p^2 = .039$, word type, $F(1, 111) = 66.03$, $p = .000$, $\eta_p^2 = .373$, and the group by word type interaction were significant, $F(1, 111) = 6.06$, $p = .015$, $\eta_p^2 = .052$. Simple main effects showed that the number of fixations on threat words was greater for participants with chronic pain than for pain-free participants, $F(1,111) = 6.46$, $p = .012$, $\eta_p^2 = .055$, and the number of fixations on sensory pain words was significantly greater than that for neutral words among pain-free participants, $F(1, 111) = 17.77$, $p = .000$, $\eta_p^2 = .138$, and for chronic pain participants, $F(1, 111) = 51.07$, $p = .000$, $\eta_p^2 = .315$ (see Figure 2).

Figure 3: Frequency of visits for each group. Error bars display the standard error. ** $p < .01$



For number of visits (see Figure 3), only the main effect of word type was significant, $F(1, 111) = 34.37$, $p = .000$, $\eta_p^2 = .236$ [group: $F(1, 111) = 1.64$, $p = .204$, $\eta_p^2 = .015$, group by word type interaction: $F(1, 111) = 2.21$, $p = .140$, $\eta_p^2 = .020$].

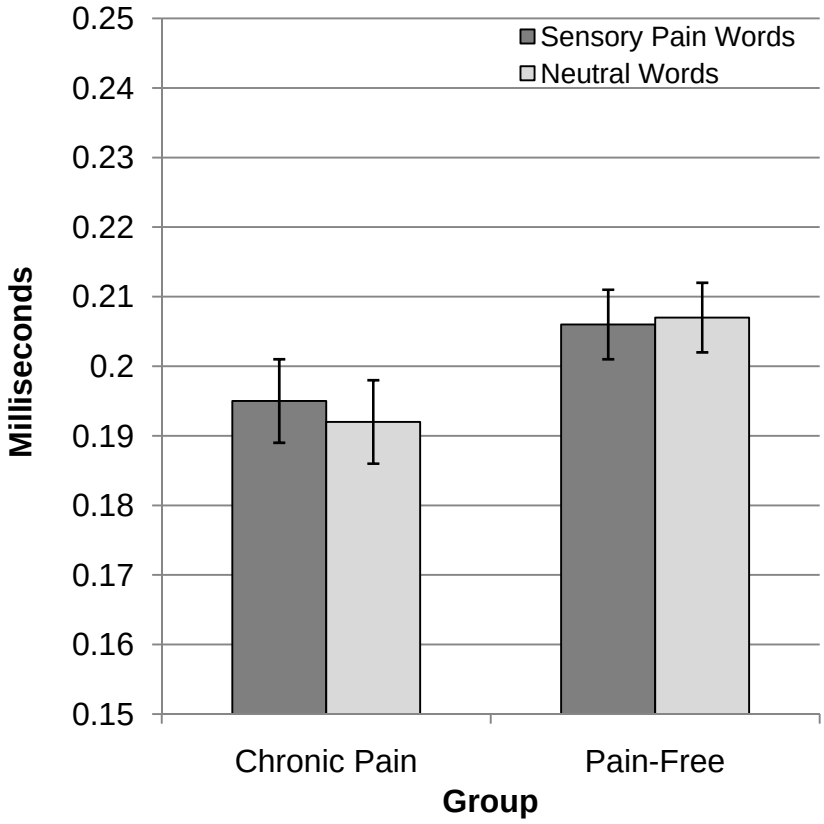
Table 3: Hypotheses 2-4: Frequency and duration of eye-tracking dependent variables for each group.

	Chronic Pain Group		Pain-Free Group	
	Sensory pain words *Mean* (*SD*)	Neutral words *Mean* (*SD*)	Sensory pain words *Mean* (*SD*)	Neutral words *Mean* (*SD*)
Hypothesis 2: Frequency of visual attention				
Number of fixations	194.31 (40.37)	172.10 (34.75)	172.81 (48.06)	160.92 (42.27)
Number of visits	123.41 (22.41)	115.39 (21.05)	115.84 (22.58)	111.06 (26.62)
Hypothesis 3: Sustained visual attention				
Average fixation duration (ms.)	.195 (.04)	.192 (.04)	.206 (.04)	.207 (.04)
Average visit duration (ms.)	.334 (.06)	.310 (.06)	.329 (.06)	.319 (.06)
Hypothesis 4: Presentation phase				
Early phase total fixation duration (0-500 ms.)	6.27 (2.02)	5.89 (1.93)	5.56 (2.14)	5.30 (1.73)
Middle phase total fixation duration (500-1000 ms.)	10.31 (2.67)	8.78 (2.40)	9.90 (2.82)	8.86 (2.51)
Late phase total fixation duration (1000-2000 ms.)	21.46 (7.09)	18.37 (5.37)	19.53 (6.06)	18.91 (6.34)

Hypothesis 3: Measures of Sustained Visual Attention using Eye-Tracking

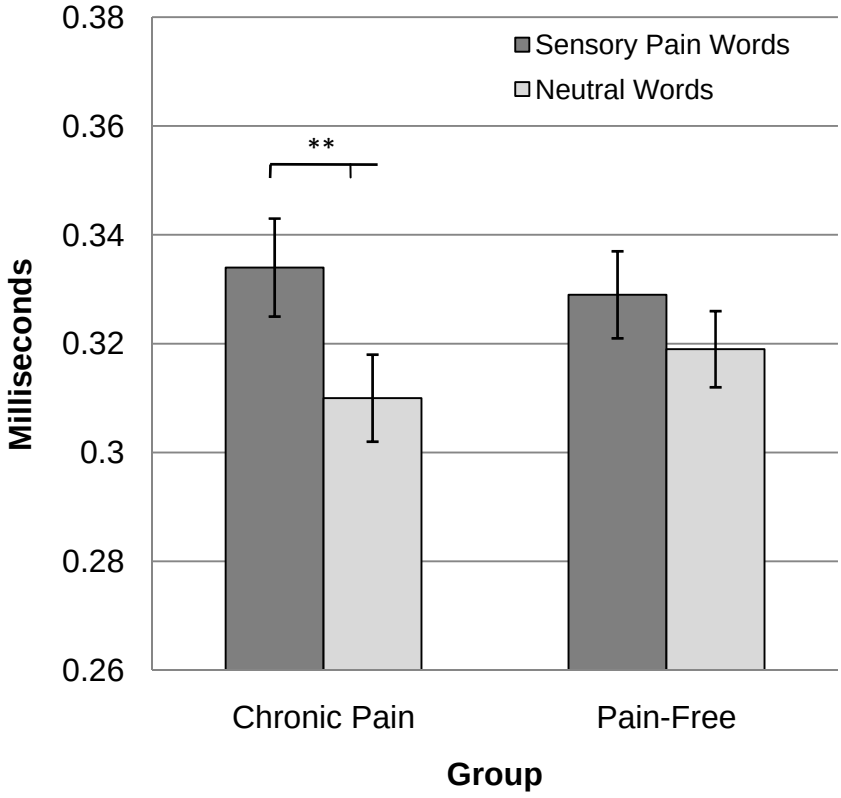
For average fixation duration (see Figure 4), none of the effects was significant [group: $F(1, 111) = 2.93$, $p = .090$, $\eta_p^2 = .026$, word type: $F(1, 111) = .41$, $p = .523$, $\eta_p^2 = .004$, group by word type interaction: $F(1, 111) = 1.16$, $p = .283$, $\eta_p^2 = .010$].

Figure 4: Average fixation duration for each group. Error bars display the standard error. ** $p < .01$



For average visit duration, the main effect of word type, $F(1, 111) = 22.34$, $p = .000$, $\eta_p^2 = .168$, and the group by word type interaction were significant, $F(1, 111) = 4.15$, $p = .044$, $\eta_p^2 = .036$ [group: $F(1, 111) = .03$, $p = .876$, $\eta_p^2 = .000$]. Simple main effects showed that the average visit duration for sensory pain words was significantly longer than that for neutral words among participants with chronic pain, $F(1,111) = 20.839$, $p = .000$, $\eta_p^2 = .158$ (see Figure 5).

Figure 5: Average visit duration for each group. Error bars display the standard error. ** $p < .01$



Hypothesis 4: Measures of Visual Attention according to Presentation Phase

The pattern of results was the same for the early and middle phase total fixation duration (see Figures 6 & 7). For early phase total fixation duration, only the main effect of word type was significant, $F(1, 111) = 8.24$, $p = .005$, $\eta_p^2 = .069$ [group: $F(1, 111) = 3.42$, $p = .067$, $\eta_p^2 = .030$, group by word type interaction: $F(1, 111) = .28$, $p = .599$, $\eta_p^2 = .002$]. Similarly, for middle phase total fixation duration only the main effect of word type was significant, $F(1, 111) = 44.10$, $p = .000$, $\eta_p^2 = .284$ [group: $F(1, 111) = .13$, $p = .721$, $\eta_p^2 = .001$, group by word type interaction: $F(1, 111) = 1.58$, $p = .211$, $\eta_p^2 = .014$].

Figure 6: Early phase total fixation duration for each group. Error bars display the standard error. ** $p < .01$

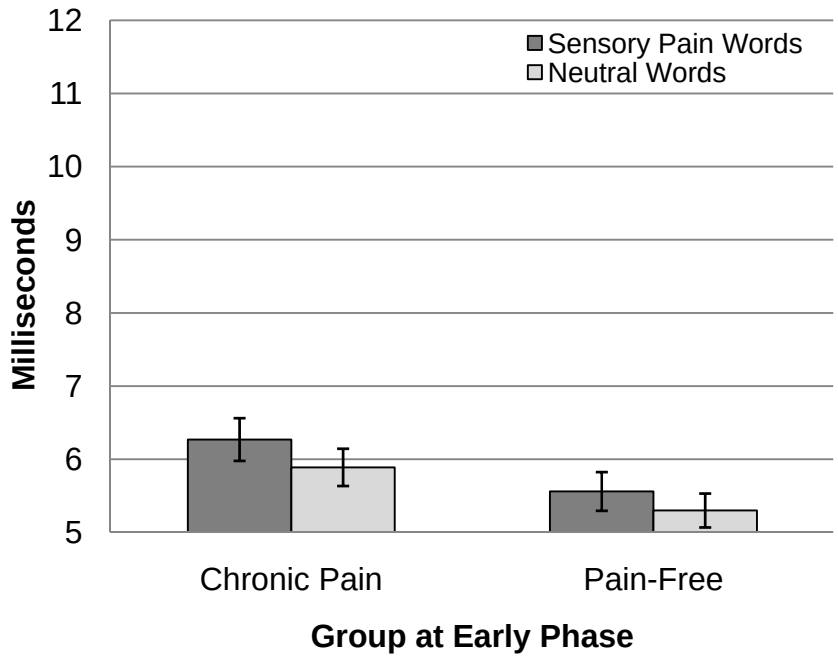
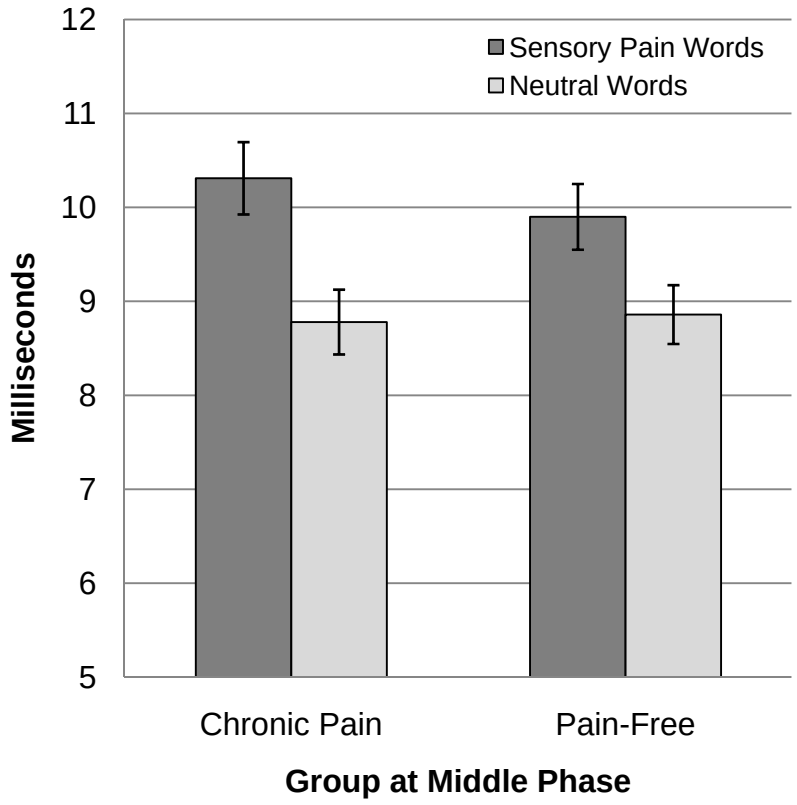
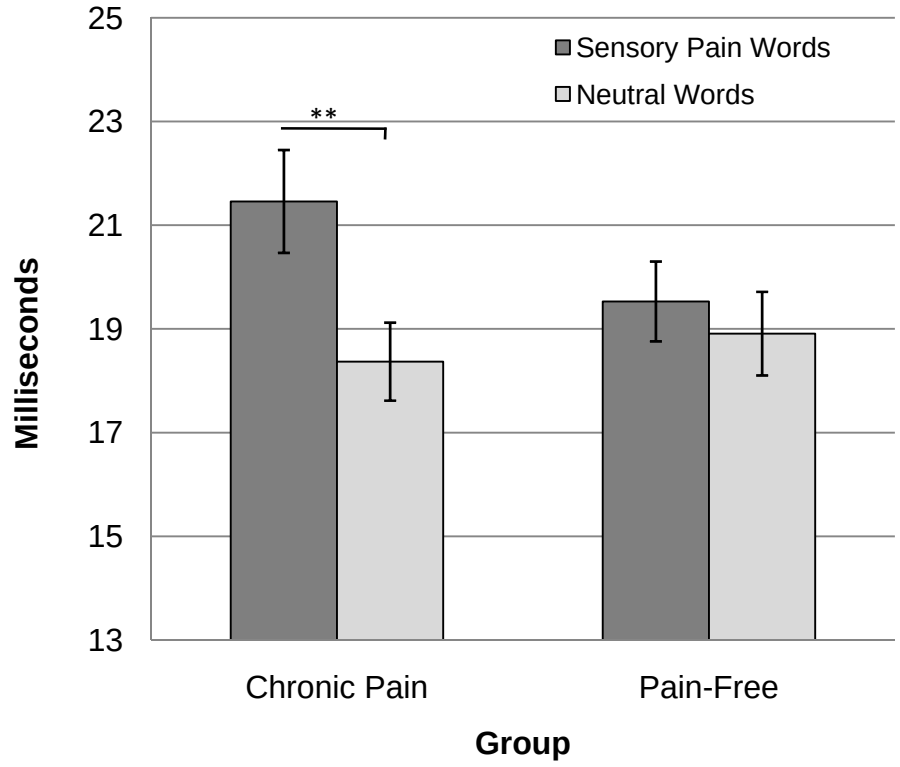


Figure 7: Middle phase total fixation duration for each group. Error bars display the standard error. ** $p < .01$



In contrast, for late phase total fixation duration, the main effect of word type, $F(1, 111) = 12.59$, $p = .001$, $\eta_p^2 = .102$, and the group by word type interaction were significant, $F(1, 111) = 5.594$, $p = .020$, $\eta_p^2 = .048$ [group: $F(1, 111) = .436$, $p = .510$, $\eta_p^2 = .004$]. Simple main effects showed that the total late phase fixation duration for sensory pain words was significantly longer than that for neutral words among participants with chronic pain, $F(1,111) = 15.94$, $p = .000$, $\eta_p^2 = .126$ (see Figure 8).

Figure 8: Late phase total fixation duration for each group. Error bars display the standard error. ** $p < .01$



Hypothesis 5: Relationship between Questionnaires and Behavioral Measures

Group effects. Table 4 shows the means and standard deviations for the questionnaire total scores for participants with and without chronic pain. Groups were compared with *t*-tests

and the Type I error rate was adjusted to $p = .006$ using a Bonferroni correction to adjust for alpha error rate inflation (Bonferroni, 1936). Chronic pain participants reported significantly higher levels of pain disability and chronic pain acceptance.

Correlations among reaction time and visual attention measures. Pearson correlations evaluated the relationship between questionnaires and behavioral measures. Only correlations with sensory pain words were examined. The Type I error rate was adjusted to

Table 4: Hypothesis 5: Comparisons between the chronic pain and pain-free group according to questionnaire data.

	Chronic Pain Group *Mean* (*SD*)	Pain-Free Group *Mean* (*SD*)	*t* (*df*)	*p*
PDI	20.18 (12.00)	5.37 (9.21)	-7.42 (92.41)[a]	.000*
PCS	19.22 (11.69)	16.14 (12.00)	-1.36 (111)	.176
PVAQ	46.18 (10.69)	41.23 (9.64)	-2.59 (111)	.011
PASS-SF	37.72 (17.61)	36.03 (19.94)	-.474 (111)	.637
CPAQ	77.57 (14.74)	66.57 (14.74)	-4.15 (111)	.000*
STAI-S	39.53 (12.39)	34.01 (11.14)	-2.49 (110)	.014
ASI-3	21.49 (12.86)	22.36 (13.33)	.349 (110)	.728
ISI-SF	16.71 (8.64)	16.23 (9.55))	-.277 (111)	.782
SPTS	27.91 (13.48)	26.93 (15.39)	-.356 (110)	.722

Note. [a] = Adjusted *t*-test score reported due to a violation in Levene's Test of Equality of Variance, $F(2, 108) = 5.75$, $p = .018$. * = Indicates a significant difference in scores at an adjusted $p = .006$ to correct for multiple comparisons (Bonferroni, 1936). PDI - Pain Disability Index, PCS - Pain Catastrophizing Scale, PVAQ - Pain Vigilance and Awareness Questionnaire, PASS-SF - Pain Anxiety Symptoms Scale - Short Form, CPAQ - Chronic Pain Acceptance Questionnaire, STAI-S - State-Trait Anxiety Inventory (state version), ASI-3 - Anxiety Sensitivity Index-3, ISI-SF - Illness Sensitivity Index- Short Version, STPS - Sensitivity to Pain Traumatization Scale.

$p = .003$ for reaction time measures and to $p = .001$ for visual attention measures with a Bonferroni correction to control error associated with the large number of comparisons (Bonferroni, 1936). One-tailed tests were used consistent with predicted outcomes. Five correlations were significant for participants with chronic pain: PCS total score and incongruency index, $r(51) = .38$, $p = .003$, CPAQ total score and congruency index, $r(51) = -.39$, $p = .002$, CPAQ total score and incongruency index, $r(51) = -.38$, $p = .003$, and ISI total score and late phase total fixation duration, $r(51) = .482$, $p = .0002$. Only the correlation the STAI-S total score and early phase total fixation duration was significant for pain-free participants, $r(61) = -.38$, $p = .001$.

Chapter Four: Discussion

The present study used eye-tracking technology to compare attentional biases to threat versus neutral words in individuals with and without chronic pain using a dot-probe task. Significant differences were not found for reaction time. In contrast, significant group by word type interaction effects were found for several eye-tracking measures: number of fixations, average visit duration, and late phase total fixation duration. These findings indicate that individuals with chronic pain, but not those who are pain-free, display a bias toward sensory pain words (Figures 3 and 4) and that individuals with chronic pain differ from those who are pain-free in terms of how frequently they attend to sensory pain words (Figure 2). Taken together these findings suggest that eye-tracking technology provides more sensitive measures of a bias than does the dot-probe task.

As noted above, dot-probe reaction times did not show evidence of an attentional bias contrary to the expectations of our first hypothesis (see Table 2). There are several possible explanations for the absence of an effect. The most likely one is the limitation associated with using reaction time as the sole measure of attention (Schmukle, 2005; Sharpe, 2013). Reaction time is an indirect indicator of visual attention where faster congruent reaction times suggest that the participant's gaze is on the threat word before the dot appeared on the screen (MacLeod et al., 1986), creating a substantial margin of error since there is a delay between what the participant sees and the reaction of pressing the computer key, which introduces opportunities for error. For example, the participant may look at the center of the screen and indicate the location of the dot by seeing it in their peripheral vision, press the wrong key by accident, look down to adjust hand(s)s, or remove hand(s) for a moment. Taken together, this margin of error reduces the sensitivity of detecting an effect

Another possibility is that the exposure duration used in the present study was longer than that in other studies (Schoth et al., 2012). To our knowledge, only one other study has used an exposure duration of 2000 ms. in a sample of people with pain and the results also failed to find significant differences (Yang et al., 2013). However, this explanation does not appear to account for the lack of differences in reaction time, since a recent meta-analysis (Crombez et al., 2013) of dot-probe studies showed larger effect sizes associated with exposure durations longer than 1000 ms. in comparison to exposure durations between 0-500 ms. and 500-1000 ms., suggesting that the longer exposure duration used in the present study did not reduce the likelihood of finding an effect.

The nature of the sample used in the present study may have led to insignificant differences according to reaction time; namely, students that self-reported experiencing chronic pain. Attentional biases have been more consistently identified with reaction times using the dot-probe task in individuals recruited from clinical settings (Dehghani, Sharpe, & Nicholas, 2003; Khatibi et al., 2009; Roelofs et al., 2005). Individuals seeking treatment for pain likely experience greater distress and preoccupation with painful sensations, leading to greater attentional biases that then become detectable with the dot-probe task. The present sample exhibited low disability (Sandborgh, Lindberg, & Denison, 2008). This suggests that only substantial attentional biases can be identified with reaction time as the outcome measure, whereas more subtle biases can be identified with eye-tracking as in the present study. This is consistent with the finding that attentional biases are not present in populations that experience procedural pain, acute pain, and experimental pain (Crombez et al., 2013).

In contrast to the lack of findings using reaction time as the bias measure, number of fixations, average visit duration, and late phase total fixation duration all showed evidence for a

bias towards pain-related stimuli in individuals with chronic pain, supporting hypotheses 2-4. Of particular interest is the finding that a bias to sensory pain words, as measured by fixation duration, was only evident in the later stage of attentional processing and not the early or middle stages (see Figure 4). Since later stages of attentional processing are associated with more top-down, conscious processes, such as avoidance and re-engagement (Heeren et al., 2011; Hermans et al., 1999), this supports the proposition that increased attention toward pain-related stimuli reflects more of an explicit, cognitive bias rather than an automatic, preattentive bias (Crombez et al., 2013; Schoth et al., 2012). That is, the bias becomes evident only once the threat has been identified and its meaning and relevance have become apparent. The late phase findings are consistent with the work of Pincus and Morley (2001) who proposed the presence of an explicit cognitive-processing bias in chronic pain.

In contrast, number of fixations and average visit duration (Figures 2-3) were calculated across the course of each trial (i.e., 0-2000 ms.) so that the significant interactions may reflect a bias in any one or more of the following phases of attention: initial orientation and engagement, maintenance, or re-engagement (Bradley et al., 2000; Heeren et al., 2011; Koster et al., 2004; Koster et al., 2005; Schoth et al., 2012). Although there is not an agreed upon definition of what constitutes automatic processing (Allport & Meyer, 1993; Keogh et al., 2003), it is generally accepted that it is effortless, mostly unconscious, fairly fast, and requires little attentional capacity or cognitive processing (Beck & Clark, 1997). Given the simplicity of the dot-probe task, it may be that the associated attentional processing required by participants was not sufficiently intentional and conscious to be considered controlled, but the present results do not permit a conclusion regarding the stage(s) of processing that underlie the present effects. Nevertheless, the results clearly show that participants with chronic pain fixated more frequently

on pain words than did pain-free participants (Figure 2) and the average visit duration for sensory pain words was significantly longer than that for neutral words among participants with chronic pain (Figure 3). Future research might consider a finer-grained analysis to determine the extent to which these significant effects are guided by early (e.g., bottom-up, pre-attentive) or later (top-down, cognitive) processes.

Eye-tracking measures also detected significant word type and group by word type interaction effects (see Table 3) independent of pain status. Word type effects showed that all participants looked more frequently at (i.e., had a higher number of fixations) and for longer durations (i.e., during early and middle presentation phases) on sensory pain words than neutral words. This supports the idea that humans are evolutionary predisposed to attend to threats in the environment: automatic processing provides information regarding the threat to prepare for a behavioral response such as escape or confrontation (Öhman, 2005; Öhman & Wiens, 2004; Pratto & John, 1991). Since sensory pain words have a higher threat value than neutral words, this may have led to increased attention by all participants.

We expected to find significant correlations among reaction time scores, visual attention measures, and self-reported pain-related psychological factors. For participants with chronic pain, only five correlations were significant, providing provisional support for hypothesis 5. We found that higher pain catastrophizing scores were related to higher incongruency scores. Since high incongruency scores reflect longer response times to trials in which the dot appears behind the neutral words, this suggests that participants high in catastrophizing have a bias away from neutral words. This is consistent with the increased level of vigilance proposed in individuals that catastrophize (Sullivan et al., 1995; Sullivan et al., 2001). Both the congruency and incongruency indexes were negatively related to chronic pain acceptance scores, suggesting that

participants higher in chronic pain acceptance respond faster on all trials, regardless of the location of the dot. Since pain has been linked to diminished performance on cognitive tasks (McCracken & Iverson, 2001; Roth, Geisser, Theisen-Goodvich, & Dixon, 2005) as a form of interruption (Eccleston & Crombez, 1999) it is possible that greater levels of acceptance of the pain experience increased the level of performance in the dot-probe task. The finding that participants with higher illness sensitivity scores spent more time looking at threat words during the late phase for total fixation duration shows that the more fearful a participant is of experiencing illness, the more likely they are to attend to pain-related stimuli. Overall, there is some evidence to support the hypothesis of a relationship between pain-related psychological factors and attentional patterns among participants with chronic pain.

Few differences were identified between participants with and without chronic pain according to psychological constructs. Participants with chronic pain reported higher levels of pain disability and chronic pain acceptance, but no differences according to anxiety related constructs pain catastrophizing, pain vigilance, pain anxiety sensitivity, state anxiety, anxiety sensitivity, illness sensitivity, or sensitivity to pain traumatization. The absence of differences may reflect lower levels of impairment of an undergraduate sample with pain in comparison to a clinical sample actively seeking treatment. Additionally, since attentional biases towards threatening stimuli are evident in individuals with high levels of fear of pain or other anxieties (Asmundson & Hadjistavropoulos, 2007; Asmundson et al., 1997; Yang et al., 2012), the lack of differences between the chronic pain and control groups may increase the likelihood that the significant findings are related to pain status rather than related psychological dimensions.

For control participants, high scores for state anxiety were related to longer early phase total fixation durations, with attention away from pain-related stimuli. This may reflect a pattern

of avoidance in early attentional processing for participants without pain. Interestingly, we did not find an effect for some psychological constructs that we expected to be related to behavioral measures. For example, the pain vigilance scale was not significantly correlated with any behavioral measure despite measuring conscious preoccupation with pain in daily life (McCracken, 1997): it would expected that participants high in hypervigilance would attend to pain-related words more throughout the exposure duration (Roelofs et al., 2005). However, it is possible that the large number of comparisons reduced the statistical power to detect an effect. Taken together, these findings show that there is some support for a relationship between behavioral measures and psychological constructs

Clinical Implications

The present study has important clinical implications regarding the development and course of chronic pain. According to the Fear-Avoidance Model, increased attention towards pain sensations can exacerbate symptoms, leading to avoidance of activities that produce pain, physical deconditioning, and consequently more pain (Vlaeyen & Linton, 2000). In the Misdirected Problem-Solving Model, increasing attention to pain-related stimuli disrupts routine cognitive functioning and promotes worry, motivating the individual with pain to engage in problem-solving behavior (e.g., taking medication, seeing the doctor; Eccleston & Crombez, 2007). However, if the pain persists following problem-solving behavior, the attentional activation continues to contribute to the cycle of worry, hypervigilance, and pain interruption, thereby worsening outcomes. This model suggests that acceptance of chronic pain, therefore, can reduce psychological symptoms such as distress, anxiety, and depression, as well as physical symptoms such as pain and disability (McCracken & Eccleston, 2003). This is supported by the finding that increased levels of chronic pain acceptance are associated with a reduced attentional bias towards pain-related information (Viane, Crombez, Eccleston, Devulder, & De Corte,

2004). Similarly, an attentional bias towards pain may reflect an ongoing goal to achieve an unattainable pain-related goal, such as elimination of pain in an intractable chronic pain condition, as implicated in the Motivational Account of Pain Attention (Van Damme et al., 2010). Therefore, if attentional biases causally contribute to the development and maintenance of chronic pain as has been proposed, then eye-tracking technology can be used to monitor progress and efficacy of pain management interventions.

Limitations

The present study had several limitations. First, due to programming limitations, we were unable to collect data related to the direction of first fixation and first fixation duration for each trial, an index used in previous research (Yang et al., 2013; Yang et al., 2012). This would have captured early attention more effectively (Vervoort et al., 2013). Second, the present study used words related to the sensory aspects of pain to detect attentional biases. Words reflect a semantic understanding of threat and may not adequately capture automatic processing responses that people with chronic pain experience (Asmundson et al., 2005a; Eccleston & Crombez, 1999). Future studies should consider using pictures related to pain (e.g., images of others experiencing pain, injuries, or objects that may cause pain) to increase the ecological validity of the visual stimuli. Third, the chronic pain group was heterogeneous: pain was experienced in a wide variety of body locations (most notably the neck/back and headache/migraine pain) and the frequency and severity of pain was varied. It is possible the presence and direction of attentional biases may differ according to these qualities. This is consistent with the finding that attentional biases, at least as measured by the traditional dot-probe task, are not found in populations that experience procedural pain, acute pain, and experimental pain (Crombez et al., 2013).

A final relevant issue is related to the processing of threat-related material. Most studies using the dot-probe investigate attentional biases towards pain-related information. However, it

is possible that some people display a bias away from pain-related stimuli, as predicted by the fear-avoidance model of chronic pain (Crombez, Eccleston, Van Damme, Vlaeyen, & Karoly, 2012). If this were the case, it is possible that the absence of an overall effect of an attentional bias reported in many studies actually reflects a bias toward pain-related stimuli in some individuals and a bias away from pain-related stimuli in others. This pattern of results would mask the effects of the two biases that operate in opposite directions and would produce an overall non-significant finding. Future studies should evaluate whether, in whom, and under what circumstances biases are evident toward and away from pain-related stimuli.

Conclusion

In summary, the present study used eye-tracking methodology to investigate attentional biases toward sensory pain words in individuals with and without chronic pain. The results showed that all participants attended to stimuli related to pain more than to neutral stimuli and that this effect was more pronounced among participants with chronic pain as measured by number of fixations, average visit duration, and late phase total fixation duration. As well, a larger effect was present in later stages of attentional processing, suggesting the presence of a top-down cognitive bias toward sensory pain words. In contrast, the traditional dot-probe reaction time measures did not show evidence for an attentional bias. Taken together, these findings suggest that eye-tracking technology provides a more accurate and sensitive measure of selective visual attentional biases than reaction time.

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