THE EFFECT OF ACUTE PAIN ON PERFORMANCE IN THE SUSTAINED ATTENTION TO RESPONSE TASK

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Abstract

Whilst chronic pain has been consistently shown to exert negative effects on cognition, the effect of acute pain on cognitive function in healthy humans is unclear. The most prominent suggestion has been that pain, by its very nature, demands attention and thus automatically disrupts performance on cognitive tasks requiring attention. However, despite having significant implications for daily-living, the exact influence of acute pain on human cognition is as yet poorly understood. The current study investigated the effect of cold pressor-induced acute pain on performance in the Sustained Attention to Response Task (SART) in healthy individuals (N = 74). In a between-subjects design, participants completed the SART whilst having their hand immersed in cold water (painful condition) or warm water (control condition) and provided subjective measures of arousal, task workload, and thoughts. Different studies have argued that the SART measures either lapses in attention or motor response inhibition. The results suggested that acute pain did not significantly affect SART performance. Errors of commission were associated with response times rather than off-task thoughts in line with the response inhibition perspective of the SART. No associations between SART performance and subjective measures were found. We argue that the cognitive resources on which SART performance depends were not shared with pain processing. Further explanations and implications of this are discussed.

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1. Introduction

1.1. Chronic pain and human cognition

Chronic pain that lasts a long period of time and is often resistant to medical treatments (International Association for the Study of Pain, 1986) has been consistently shown to have wide reaching negative effects on executive function (for a review see Moriarty, McGuire, & Finn, 2011). However, the effect of acute pain which usually lasts a short period of time, serving as a warning signal or an indication of illness or injury (Carr & Goudas, 1999; Apkarian et al., 2009) is currently unclear. Executive function is an umbrella term that covers a broad set of cognitive processes such as attention, planning, and decision making that allow us to engage in coordinated, goal-directed activities, and react to novel situations in an adaptable and effective manner (Banich, 2009; Funahashi, 2001). Evidence from recent meta-analyses concerned with the effect of chronic pain on executive function in humans suggests that four distinguishable cognitive components - response inhibition, complex executive function (e.g., planning, visuo-construction, sustained attention, problem solving and decision-making), set shifting and updating - are negatively impacted by chronic pain (Berryman et al., 2013; Berryman et al., 2014). Cognitive impairment in chronic pain patients is argued to result from chemical, functional and structural changes within both the brain and central nervous system, and is thought to be caused by the prolonged experience of pain (Apkarian, Baliki, & Geha, 2009; Farmer et al., 2011; Moseley & Flor, 2012, Wand et al., 2011). Indeed, evidence from brain imaging research showed that relative to healthy controls, chronic pain patients show less activity in cortical structures involved in motor preparation/response selection which are part of the brain's inhibition network during a simple response inhibition task (Go/No-Go) (Glass et al., 2011). In addition, alterations have also been observed in neural circuits linked to both pain and executive control processes, resulting in maladaptive changes in behaviour (Seminowicz & Davis, 2007; Simons, Elman,

& Borsook, 2014). For example, research has shown that chronic pain or fear of pain often results in automatic dysfunctional withdrawal or inhibitory responses in order to avoid increased pain (e.g., Vlaeyen & Linton, 2000; Vlaeyen & Linton, 2012). Thus, chronic pain patients tend to report reduced physical activity, goal attainment and positive social experiences (Crombez et al., 2012).

1.2. Acute pain and human cognition

Unlike chronic pain that has been consistently shown to exert negative effects on cognitive function, the effect of acute pain on cognitive function in healthy humans is unclear. Studies using healthy volunteers and different methods of experimentally induced acute pain have yielded mixed results. Pain has been found to exert either disruptive (Crombez, Eccleston, Baeyens, & Eelen, 1996, 1998; Van Damme, Crombez, Eccleston, 2004) or somewhat facilitative (Patil, Apfelbaum, Zacny, 1995) effects on cognitive task performance in some studies, yet other studies found no pain-related effects at all (Houlihan, McGrath, Connolly, Stroink, Finley, Dick, & Phi, 2004; Veldhuijzen, Kenemans, de Bruin, Olivier, & Volkerts, 2006). For example, Crombez et al. (1996) tested the effect of acute pain induced by painful electric shocks on participants' ability to distinguish between high pitch and low pitch tones in a tone discrimination task. The introduction of a painful stimulus disrupted participants' performance on the tone discrimination task, resulting in longer reaction times and reduced accuracy when compared to the no-pain control group. Explanations for such findings were mostly drawn from theories of attention (Bradley, Cuthbert, & Lang, 1993; Siddle, 1991), suggesting that by its very nature, acute pain is disruptive and automatically demands attention. Thus, the introduction of a higher priority stimulus (i.e., acute pain) into the attentional system resulted in the reduced amount of attention paid to the processing of auditory stimuli in the tone discrimination task.

Interestingly, one study concerned with the effect of a painful cold-water stimulus on cognitive functioning found an elevated threshold in the cold group on the Critical Flicker Frequency (CFF) alertness task (Patil, Apfelbaum, Zacny, 1995), during which participants had to discriminate a flickering light from a slow flicker rate to a fast flicker rate (i.e., fusion-from-flicker) and vice versa (i.e., flicker-from-fusion), indicating increased alertness. This finding is difficult to reconcile with Crombez and colleagues' (1996) results. It seems reasonable to suggest that the relationship between acute pain and cognitive performance as reported in the literature is perhaps dependent on the tests and painful stimuli used. For example, the cold pressor test (CPT) used in Patil and colleagues' (1995) study is thought to induce tonic pain that lasts a short time but is continuous in nature as opposed to phasic pain that comes and goes as in Crombez and colleagues' (1996) study using electric shocks. Thus, the CPT induced pain is, arguably, a more accurate experimental representation of real-life acute pain (Sinke, Schmidt, Forkmann, & Bingel, 2015).

In contrast to the research discussed above that found either detrimental or somewhat facilitative effects of acute pain on cognitive performance, the results of other studies showed that acute pain did not have a significant effect on cognitive task performance (Houlihan, McGrath, Connolly, Stroink, Finley, Dick, & Phi, 2004; Veldhuijzen, Kenemans, de Bruin, Olivier, & Volkerts, 2006). For example, Houlihan et al. (2004) tested the effect of the cold pressor induced acute pain on the Sternberg memory-scanning task performance (Stenberg, 1969). Participants were asked to memorise a set of consonants presented to them on the computer screen, followed by a series of probes, presented one at a time, which participants had to identify as belonging to the previous memory set or not. The reaction time (RT) and accuracy data revealed that the cold pressor induced acute pain had no significant effect on participants' performance. Another study investigated the effect of cold pressor induced acute pain on participants' performance on the visual search task (VST), during which participants

had to respond to 1 of the 2 target letters displayed on the computer screen by pressing a corresponding key (Veldhuijzen et al., 2006). There was no significant effect of acute pain on participants' visual search performance.

Considering that several authors have proposed that pain and cognitive task performance rely on the same limited attentional resources (e.g., Crombez, Eccleston, Baeyens, & Eelen, 1996, 1998; Eccleston and Crombez, 1999; Van Damme, Crombez, Eccleston, 2004), results from the aforementioned studies are somewhat surprising. However, from a multiple resource perspective (Wickens, 1984), it is possible that the cognitive resources required for the successful performance on the memory-scanning and visual search tasks were not claimed by acute pain processing. The multiple resource perspective suggests that the degree to which two tasks can be performed concurrently depends on the type of resources each task demands. For example, it could be that visual search primarily requires perceptual resources rather than the more central attentional resources that are utilised during pain processing (Veldhuijzen et al., 2005; Villemure, & Bushnell, 2002), thus resulting in visual search performance being unaffected by pain.

1.3. Cognitive performance in the Sustained Attention to Response Task

In addition to the more explicit investigations of the effect of acute pain on cognitive performance discussed above, some indirect evidence from studies investigating the effect of anxiety induced by unpredictable electric shocks on cognitive performance appears to suggest that acute pain in healthy individuals may improve cognitive performance (Robinson, Krimsky, and Grillon, 2013; Wilson, de Joux, Finkbeiner, Russell, and Helton, 2016). More specifically, these studies examined the effect of induced anxiety on performance on the Sustained Attention to Response Task (SART; Robertson et al., 1997). The SART is a Go/No-Go type task that was originally developed to measure failures in vigilance or sustained attention (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). In the SART,

around 90% of the trials require participants to respond to Go type stimuli and approximately 10% of the trials require participants to inhibit or withhold their motor responses to No-Go type stimuli (the Go and No-Go stimuli in the original SART are represented by numbers 1-9 with one number being the No-Go stimulus) (Robertson et al., 1997). It has been proposed that such repetitive responding to more frequent Go stimuli in the SART promotes either "mindlessness" (i.e., complete loss of attention and awareness, leading to a "blank" mind) (Manly, Robertson, Galloway, & Hawkins, 1999) or "mind-wandering" (i.e., increase in task-unrelated thoughts) (Smallwood, 2013; Smallwood, McSpadden, & Schooler, 2007; Smallwood & Schooler, 2006), resulting in failures to inhibit motor responses to infrequent No-Go stimuli (i.e., commission errors). Over the years, the SART has become one of the most popular measures of sustained attention in research investigating both normal and clinical populations (Bonnefond et al., 2010; Carter et al., 2013; Greene et al., 2009; Helton and Head, 2012; Wilson et al., 2013). The use of the SART has also been expanded to studies concerned with response inhibition (e.g., Robinson, Krimsky, and Grillon, 2013; Wilson et al., 2015; Wilson et al., 2016) which prompted an ongoing debate regarding the usefulness and accuracy of the SART as a sustained attention measure (Helton et al., 2009). Researchers have shown that frequent and fast presentation of Go stimuli leads to a greater amount of commission errors (i.e., failures to withhold responses to No-Go stimuli), indicating that the repetitive and speeded responses to Go stimuli impair participants' ability to inhibit their motor responses to No-Go stimuli (Head & Helton, 2013, 2014; Seli, Cheyne, & Smilek, 2012). Thus, it has been suggested that commission errors in the SART may be a better measure of response inhibition failures rather than lapses in attention (Finkbeiner et al., 2015; Wilson et al., 2015, Wilson et al., 2016). An acknowledgment of this methodological debate seems relevant here as the present study aimed to contribute towards addressing the SART controversy.

Robinson, Krimsky, and Grillon (2013) demonstrated that unpredictable electrical shocks on the wrist during the SART resulted in participants making significantly less commission errors when compared to those whose performance on the SART was examined in a safe (i.e., no electrical shocks) condition. The authors suggested that anxiety induced by threat or anticipation of shock improved performance on the SART. Studies using the SART have demonstrated that typically, any change in commission errors coincides with change in response speed (e.g., Seli et al., 2013; Wilson et al., 2016; Wilson, Finkbeiner, de Joux, & Russel, 2016). For example, slower RTs are usually associated with reduced errors of commission and vice versa which is known as a speed-accuracy trade-off (SATO). However, what is especially interesting is that in Robinson and colleagues' (2013) study the electrical shock (anxious) condition demonstrated improved No-Go accuracy without any significant changes in response speed (i.e., the improvement in accuracy was not merely due to SATO). The authors of the study provided several possible explanations drawn from multiple lines of research for such unexpected novel findings. First, a number of EEG studies have discovered an association between higher levels of trait anxiety and improved motor response inhibition in the SART during No-Go trials (e.g., Righi et al., 2009; Sehlmeyer et al., 2010). Findings from these studies offer some support for the idea that higher levels of anxiety due to electric shocks may have enhanced performance on the SART. Second, some studies have shown that induced anxiety facilitates inhibition of a startle motor response following a weaker (prepulse) stimulus (Grillon & Davis, 2007; Cornwell et al., 2008). This suggests that higher levels of anxiety may enhance one's ability to inhibit habitual responding. In the case of a real-life threat enhanced inhibition acts as a protector from unnecessary and inappropriate motor and social responses, thus, indicating its clear adaptive value. Indeed, such findings and explanations from the aforementioned studies could potentially account for reduced commission errors in the electrical shock (anxious) condition at no cost to response speed.

Essentially, induced anxiety may facilitate the transition from the habitual responding caused by the frequent Go trials to the cancellation of an initiated prepotent response (Robinson, et al., 2013) during the less frequent No-Go trials in the SART. A third explanation provided by the authors suggested that anxiety may improve participants' detection of the No-Go stimuli by enhancing perception and or focused attention which is based on research showing that induced anxiety results in better perceptual processing (e.g., Hu et al., 2012).

Alternatively, considering that unpredictable electrical shocks have also been used as a method of acute pain induction in studies examining the effect of pain on attention (e.g., Crombez, Eccleston, Baeyens, & Eelen, 1996, 1998; Van Damme, Crombez, Eccleston, 2004), it seems reasonable to suggest that reduced commission errors in Robinson and colleagues' (2013) study could be more related to the acute pain induced by the electrical shocks rather than anxiety. More specifically, it is possible that acute pain induced by electrical shocks caused a surge in vigilance, which exerted facilitative effects on the SART. From an evolutionary point of view, heightened vigilance in the case of a sudden acute pain plays a protective role against threats in the environment and allows correct responding in life-threatening situations (Millan, 1999; Oken et al., 2006; Price, 2000). This notion is further supported by some human brain imaging studies (Peyron et al., 1999, 2000) in which the experience of acute pain resulted in increased activations of bilateral thalamus and upper brainstem which are important components of the brain's sleep-wake system involved in the maintenance of alertness and sustained attention to external sensory inputs (Peyron et al., 2000). Studies have shown that cortical processing of non-nociceptive sensory information is highly sensitive and reactive to changes in vigilance/arousal levels (Davis and Whalen, 2001; Mackworth, 1968; Oken et al., 2006), with enhanced processing occurring at an increased vigilance level (Shackman et al., 2011; van Marle et al., 2009).

Other studies using different methods of anxiety induction to examine the novel finding of enhanced performance in the SART under the threat of electrical shock found conflicting results (e.g., Wilson, de Joux, Finkbeiner, Russell, and Helton, 2016). Findings from these studies offer further support for the idea that improved performance in the SART in Robinson and colleagues' (2013) study occurred due to the acute pain caused by electrical shocks rather than anxiety. For example, Wilson, de Joux, Finkbeiner, Russell, and Helton (2016) examined the impact of anxiety-inducing stimuli on performance in the SART by using affect-provoking pictures (e.g., a mortally injured person) and neutral pictures (e.g., a towel). Surprisingly, the researchers found that the introduction of negative (affect-inducing) pictures resulted in participants making more commission errors rather than fewer as hypothesised. Consequently, Robinson's findings that induced negative affect (or more specifically, anxiety) enhanced participants' performance in the SART are difficult to reconcile with more recent findings, casting some doubts regarding the possibility that anxiety per se causes such improvement.

1.4. The effect of acute pain on cognition in animal model studies

The most explicit investigations of the effect of acute pain on executive function have mostly been confined to studies using animal models of acute pain (e.g., Boyette-Davis, 2008; Guo et al., 2016; Freitas et al., 2015). Findings from these studies appear to be mixed and inconclusive, however, they offer some valuable insight into how acute pain might affect human cognition. Boyette-Davis, Thompson and Fuchs (2008) examined the effect of acute inflammatory pain caused by a formalin injection in male Sprague-Dawley rats on attentional processing using the 5-choice serial reaction time task (5CSRTT; Robbins, 2002). The 5CSRTT involves a random exposure to a light in one of the five nose poke holes for a fixed amount of time during which an animal must respond to the light by placing its nose inside the hole, followed by the presentation of a food pellet if the animal responds before the light

extinguishes (Boyette-Davis et al., 2008). The amount of time the animal takes to respond to the light and retrieve the food pellet (latency to reward) and incorrect responses or failed responses to the light are recorded in the 5CSRTT. The results of this study showed that formalin-induced acute pain had a significant disruptive effect on attentional processing in male Sprague-Dawley rats, resulting in more failures to respond to the light stimulus during the 5CSRTT when compared to the saline-treated rats. Interestingly, even though formalin-treated rats showed an increased number of omissions, neither of the groups showed increases in latency, providing further support for the idea of attentional impairment in formalin-treated rats (Boyette-Davis et al., 2008; Robbins, 2002).

Freitas, Millhouse, Leitl and Negus (2015) also examined the effect of acute pain on attention in rats. The effects of three acute noxious stimuli (i.e., injections of pain inducing chemical substances) on male Sprague-Dawley rats' performance on the Visual-Signal Detection Task (VSDT) were tested. In the VSDT animals are required to respond to a "blank" lever when there is no change in the intensity of the signal light in their chamber and to a "signal" lever when the signal light intensity in their chamber lever increases. Similarly, to the 5CSRTT, correct responses are followed by the delivery of a food pellet. The findings of the study showed that two out of three noxious stimuli – caused significantly impaired performance on the VSDT as measured by the amount of failures to respond to the stimulus. Overall, results from the two studies appear to suggest that noxious, acute pain inducing stimuli disrupt attention in rats. Such findings are in line with research concerned with the effect of chronic pain on attention in humans (for a review see Berryman et al., 2014), as well as the Neurocognitive Model of Attention to Pain (NMAP), where pain, by its very nature requires attention, thus reducing the amount of attention paid to peripheral input and disrupting overall executive functioning, and the brain's capability of goal-directed activity (Legrain, Van Damme, Eccleston et al., 2009).

In contrast to the studies discussed above, a recent study concerned with the effect of pain on cortical processing of non-nociceptive sensory information in rats found that formalin-induced acute pain enhanced auditory information processing when compared to no-pain controls (Guo, Wang, Sun, & Wang, 2016). Unlike acute pain, chronic pain was found to exert an inhibitory effect. The authors of the study proposed that such contrasting effects of acute and chronic pain on cortical processing of auditory stimuli in rats could be explained by different vigilance states, resulting from acute and chronic pain. One of the most common complaints of chronic pain patients is sleep disturbance and resulting fatigue (Ashburn and Staats, 1999; Hart et al., 2000; Smith and Haythornthwaite, 2004) which impairs vigilance-related cognitive performance (Belyavin and Wright, 1987; Cajochen et al., 1995, 1999; Cote et al., 2003; Lim and Dinges, 2008; Ziino and Ponsford, 2006). In addition, chronic pain has been shown to cause excessive attention to the internal somatic signals and changes in relation to pain (Crombez et al., 2005; Eccleston and Crombez, 1999, 2007). Thus, the hypervigilance to pain in chronic pain patients results in the reduction of attention paid to the external environment, leading to impaired processing of non-nociceptive external sensory inputs irrelevant to pain (Crombez, Van Damme, Eccleston, 2005; Peters, Vlaeyen, Kunnen, 2002). Contrary to chronic pain, acute pain acts as a warning signal and enhances one's attention to changes and threats in the environment by increasing general arousal and the amount of attention paid to the external environment. From an evolutionary perspective, a surge in vigilance in the case of acute pain allows correct responding and recuperation in life-threatening situations (Guo, Wang, Sun, & Wang, 2016).

1.5. Hypotheses and principal goals

Based on the literature reviewed, it is evident that the impact of acute pain on cognitive task performance is unclear. The present study aimed to examine the effect of acute pain on participant performance in the traditional digit version of the SART using the cold

pressor task (CPT; Kyle and McNeil, 2014) as a method of temporary pain induction. Multiple lines of research suggest that acute pain could potentially have a wide range of influences on cognition (Boyette-Davis, Thompson, & Fuchs, 2008; Guo et al., 2016; Freitas et al., 2015; Robinson et al., 2013), leading to conflicting hypotheses regarding the effect of acute pain on the SART. On one hand, cold pressor induced acute pain could impair performance on the SART because attention and pain are believed to rely on the same limited attentional resources, resulting in conflicting demands and interference with cognitive task performance (Eccleston and Crombez, 1999; Eccleston, 1994). This hypothesis is supported by reports from both human (Crombez, Eccleston, Baeyens, & Eelen, 1996, 1998; Van Damme, Crombez, Eccleston, 2004) and animal model studies (Boyette-Davis, Thompson, & Fuchs, 2008; Freitas et al., 2015), showing that acute pain impaired performance on cognitive tasks.

However, evidence from other research points to the opposite hypothesis; that acute pain could enhance performance in the SART (Guo, Wang, Sun, & Wang, 2016; Robinson, Krimsky, & Grillon, 2013). First, acute pain induced by the cold pressor has been found to increase alertness during the flicker-from-fusion task (Patil, Apfelbaum, Zacny, 1995) which is in line with animal model studies, showing that acute pain improved the processing of sensory stimuli in rats by triggering a surge in vigilance (Guo, Wang, Sun, & Wang, 2016). Based on these findings, the cold-water stimulus in the present study could potentially lead to enhanced perception of the SART stimuli which would facilitate the detection of infrequent No-Go stimuli. Early detection of No-Go stimuli would allow more time for the participant to withhold prepotent responses, resulting in reduced commission errors. Second, if reduced commission errors in Robinson and colleagues' (2013) study were more related to acute pain caused by electric shocks rather than anxiety, it is possible that cold pressor induced acute pain could also enhance participants' inhibitory control during the SART in the present study.

From an evolutionary perspective, the countermanding of automatic or prepotent behaviours in the case of acute pain is especially important as it helps to avoid impulsive and incorrect responding in dangerous or life-threatening situations (Millan, 1999; Oken et al., 2006; Price, 2000).

Therefore, the primary objective in this study was to distinguish between the two conflicting possibilities and examine the effect of acute pain on the SART, using the cold pressor pain paradigm. More specifically, participants performed the SART in one of the two different conditions: while having their hand immersed in cold water (experimental condition), or while having their hand immersed in warm water (control). The analysis of the behavioural findings from the SART such as participant reaction times (RT's) to Go stimuli presented in the SART and errors of commission were of main interest and importance, as they directly reflected either facilitative or detrimental effects of acute pain on the SART.

We also acknowledged the on-going debate regarding whether commission errors better represent lapses in sustained attention or failures of response inhibition, and sought to clarify this by examining self-reports of on- and off-task thoughts (Helton, 2014, Wilson et al., 2016). In addition, considering that some evidence suggests that anxiety may improve participants' performance on the SART, and the CPT could potentially increase state anxiety/stress (Deuter et al., 2012; Schwabe, Wolf, 2010), we controlled for state anxiety prior to and during the SART.

2. Method

2.1. Participants

Seventy-four (53 female, 21 male) undergraduate students from the University of Huddersfield in Huddersfield, United Kingdom, participated as part of a course research participation requirement. They ranged in age between 18 and 42 years (M = 21.88, SD = 4.66). All participants had normal or corrected-to-normal vision. Inclusion criteria were: (1)

no consumption of alcohol for at least 12 hours before the test session, (2) no intake of illicit drugs for at least five days before the test session, (3) no current use of anti-depressant medication, (4) no heart or circulation problems (e.g., Reynaud's syndrome), blood pressure problems, diabetes, epilepsy, and recent serious injury. All participants gave written informed consent approved by the School Research Ethics Panel.

2.2. Design

The study employed an independent groups design. Participants were randomly assigned to complete the SART in either a cold temperature condition (5°C) (Mitchell, MacDonald & Brodie, 2004) or a warm (no-pain) temperature condition (36°C). Both conditions had an equal number of participants.

2.3. Materials and procedure

Participants were tested in a university laboratory cubicle containing the cold pressor equipment, computer and a designated area for completing subjective reports. The cold pressor apparatus used was RW-2025G (RS-232 interface) from Medline Scientific Limited. It had a built-in cooling and warming circulating water system that was used for the two experimental conditions. The computer task was a modified version of the SART (Robertson et al., 1997) with stimuli presentation, timing, and response accuracy accomplished using E-prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002).

Participants were seated approximately 50 cm in front of a computer screen (head movements were not restrained). They were instructed to focus their attention on the computer screen and respond to frequently-occurring Go stimuli (the digits 1-9, excluding 3) by pressing the spacebar on the computer keyboard, and withhold responses to rare No-Go stimuli (the digit 3). Equal importance of both speed and accuracy was emphasised to

participants (see Appendix A1 for the exact instructions given to participants). The SART consisted of 18 practise trials (16 Go trials, 2 No-Go trials) during which participants received feedback on their responses (i.e., "correct", or "incorrect" displayed on the monitor) and 216 test trials (192 Go trials, 24 No-Go trials adding up to 11.1% of total trials) which were distributed across 4 blocks. Each of the four continuous blocks consisted of 48 Go trials and 6 No-Go trials. The order of the stimuli was randomised across all four blocks. The digit stimuli were presented for 250 ms and were all of Arial font but varied in size which was randomly selected from point sizes 48, 72, 94, 100, and 120. Responses were recorded up until 1000 ms following stimulus onset. A fixation cross appeared on the computer screen immediately after each digit stimulus, presented for 900 ms. The onset to onset interval was 1150 ms. The duration of the SART was approximately 4.30 minutes.

First, all participants completed 18 practise trials, and the cold pressor was not used during these trials. Then participants completed the experimental trials whilst having their left hand immersed up to the wrist in the cold pressor basin, containing either cold (5°C) or warm (36°C) water. They were instructed not to form a fist or move their fingers (Grant, Redden, & Chamberlain, 2017) and made aware that they could remove their hand if they felt too uncomfortable to continue. Left-handed participants were excluded from the study due to the positioning of the cold pressor equipment, allowing the immersion of a left hand only. Immersion time (in seconds) was recorded by the experimenter with a stop-watch. The experimental task finished when either the participant completed the 216 SART trials, or withdrew their hand from the water. Yoked-control comparisons were used to account for the time differences in participants who withdrew their hand from the cold water before the SART ended.

Subjective self-report measures were also used. A State-Trait Anxiety Inventory (STAI; Spielberger, 1989) was administered to participants before the practise trials of the

SART (see Appendix 1). This consisted of 40 self-report items rated on a 1 to 4 Likert scale, and concerned with measuring and differentiating between state and trait anxiety. Immediately after the completion of the CPT, participants were asked to rate their pain on a 1 ("not painful") to 7 ("very painful") Likert scale (see Appendix 2). This was followed by a question regarding pain intensity at different stages of the task (first half of the task versus second half; for the exact question used please see Appendix 3). Participants were also asked to complete a self-report stress scale (Blakely, 2014; Sellers, Helton, Näswall, Funke, & Knott, 2014; Wilson et al., 2016), consisting of 11 items related to current stress, arousal, and mind-wandering (i.e., on- and off-task thoughts), which were rated on a 0 ("low") to 10 ("high") Likert scale (see Appendix 4). Items in the stress scale were based on the Dundee Stress State Questionnaire (DSSQ; Matthews et al. 2002), however, the stress scale contained different questions to the ones found in the DSSQ. For example, in contrast to the DSSQ, the questionnaire used in the present study was not concerned with measuring a mix of highly specific task-unrelated thoughts (TUTs). Instead, it contained one more general question aimed at measuring TUTs: "How much did you think about something other than the task?" Other items included in the stress scale were physical fatigue, mental fatigue, tense, unhappy, motivation, task interest, self-related thoughts, concentration, confidence, and task-related thoughts (TRTs).

The self-report stress scale was followed by the completion of a modified version of the NASA Task Load Index (NASA - TLX) scale (Hart & Staveland, 1988), which was concerned with measuring perceived workload during the task, and consisted of six items that were rated on a 0 ("low") to 10 ("high") Likert scale (see Appendix 5). The modified version of the NASA–TLX scale used in the study consisted of six items which measured mental demand, physical demand, temporal demand, performance monitoring demand, effort, and emotional demand (see Blakely 2014; Sellers 2014). Prior factor analyses (see Bailey and

Thompson, 2001; Ramiro et al. 2010) helped determine this version of the scale. Each item was ranked on a 1 (“very low”) to 10 (“very high”) Likert scale. The combined average of the responses to the six NASA-TLX factors was also calculated to gauge a global workload measure for each participant.

3. Results

Results from six participants were excluded from all statistical analyses. First, results from two participants were not included in the statistical analyses, as they made an unusually large amount of commission and omission errors during the SART, indicating a potential failure to follow task instructions (Wilson, et al., 2016). In addition, data from four participants who removed their hand from the cold water before the first SART block ended (approximately 1 min 8 secs into the SART) were also excluded from the data analysis. Results from six participants were excluded from all statistical analyses.

3.1. Acute pain induced by cold pressor stimulus

The subjective ratings of pain were examined to check whether the cold pressor stimulus successfully induced pain in participants. Pain ratings were significantly higher in the cold condition ($M = 4.97$, $SD = 1.48$) than in the warm (control) condition ($M = 1.03$, $SD = .16$), $F(1, 72) = 259.42$, $p < .001$, $\eta 2 = .78$. As expected, these findings supported the idea that the cold pressor induced acute pain in participants.

3.2. SART performance

The proportion of commission errors, omission errors, and mean correct response times to Go stimuli were computed for each subject. Participants in the cold condition tended to make slightly more errors of commission and errors of omission. Mean reaction time was slower in the cold condition. These data are presented in table 1.

To examine the differences between the two conditions a one-way ANOVA was performed on each of the three performance measures. No significant differences in mean commission errors, $F(1, 72) = .19$, $p = .663$, $\eta 2 = .003$; omission errors, $F(1, 72) = 1.35$, $p = .249$, $\eta 2 = .018$; or reaction times (RTs), $F(1, 72) = .72$, $p = .40$, $\eta 2 = .010$, were found between the two experimental conditions. In order to better evaluate the support for and against the null and alternative hypotheses, JZS Bayes factors were computed by performing a JZS Bayes factor t-test (Rouder et al., 2009; Rouder et al., 2012), as provided by JASP (Marsman & Wagenmakers, 2017). The resulting BF was approximately 3.74 in favour of the null for RT's, 3.07 in favour of the null for errors of commission, and 2.12 in favour of the null for errors of omission, indicating moderate support (Matthews , 2011; Raftery, 1995) for no between-group difference in the three behavioural measures.

In order to explore the possibility that the cold pressor stimulus was not painful enough to affect performance on the SART, or that participants experienced habituation to pain throughout the task, a one-way ANOVA was performed on a dataset ($N = 16$) from participants who removed their hand from the cold water before the SART ended, and rated their pain as 6 and above on a 1 to 7 Likert scale. No significant differences in mean commission errors, $F(1, 14) = .229$, $p = .640$, $\eta 2 = .016$; omission errors, $F(1, 14) = .037$, $p = .851$, $\eta 2 = .003$; or RTs $F(1, 14) = .009$, $p = .927$, $\eta 2 = .001$ were found between the two conditions. A more in-depth evaluation of the support for and against the null and alternative hypotheses was achieved by calculating JZS Bayes factors. The resulting BF's were approximately 2 in favour of the null for RT's, errors of commission, and errors of omission, indicating some evidence for no between-group difference. The exact Bayes factors as well as means and standard deviations for each of the three performance measures can be found in table 1.

Table 1. Full time and early removal SART performance's means and standard deviations.

	Full time		Early removal		Full time	Early removal
	Cold	Warm	Cold	Warm	Bayes factors	
RT (ms)	310.62 (64.55)	298.20 (61.61)	286.99 (27.98)	284.89 (57.31)	3.74, null	2.33, null
EC (%)	55.19 (22.60)	52.93 (21.75)	56.31 (22.19)	62.52 (29.32)	3.07, null	2.16, null
EO (%)	2.33 (2.46)	1.68 (2.38)	3.50 (3.28)	3.15 (3.95)	2.12, null	2.31, null

Values within parentheses represent standard deviations. Alt = in favour of alternative hypothesis, null = in favour of null hypothesis.

3.3. Block by block analysis of SART performance

In order to gain more insight into participants' performance in each block of the SART, a one-way between-subjects ANOVA was conducted on each of the four SART blocks. No significant differences in the mean scores of the three measures of the SART between the two conditions were found in block 1 (commission errors, $F(1, 72) = 2.664$, $p = .107$, $\eta 2 = .026$; omission errors, $F(1, 72) = 1.667$, $p = .201$, $\eta 2 = .020$; RT, $F(1, 72) = .445$, $p = .507$, $\eta 2 = .007$), block 2 (commission errors, $F(1, 58) = .056$, $p = .814$, $\eta 2 = .002$; omission errors, $F(1, 58) = 1.390$, $p = .243$, $\eta 2 = .026$; RT, $F(1, 58) = .485$, $p = .489$, $\eta 2 = .008$), block 3 (commission errors, $F(1, 56) = .046$, $p = .832$, $\eta 2 = .001$; omission errors, $F(1, 56) = .987$, $p = .325$, $\eta 2 = .017$; RT, $F(1, 56) = 1.350$, $p = .250$, $\eta 2 = .024$), or block 4 (commission errors, $F(1, 56) = .052$, $p = .820$, $\eta 2 = .001$, omission errors, $F(1, 56) = .319$, $p = .574$, $\eta 2 = .006$, RT, $F(1, 56) = .558$, $p = .458$, $\eta 2 = .010$). A more in-depth evaluation of the support for and against the null and alternative hypotheses was achieved by calculating JZS Bayes factors. The resulting BF's indicated some evidence for the lack of between group differences in all

three SART measures in all four blocks. Bayes factors as well as means and standard deviations for SART performance in each block are presented in table 2.

Table 2. SART performance's means and standard deviations for each block.

	Cold	Warm	Bayes factors
Block 1			
EC (%)	68.47 (27.44)	58.56 (24.73)	1.33, null
EO (%)	2.31 (3.06)	1.46 (2.55)	2.04, null
RT (ms)	293.58 (43.63)	286.52 (47.35)	3.44, null
Block 2			
EC (%)	54.44 (29.34)	52.78 (25.18)	3.72, null
EO (%)	1.74 (2.58)	1.04 (1.95)	2.13, null
RT (ms)	304.57 (68.27)	292.62 (64.60)	3.11, null
Block 3			
EC (%)	46.55 (30.01)	44.83 (31.53)	3.69, null
EO (%)	1.87 (2.51)	1.15 (2.98)	2.49, null
RT (ms)	333.48 (105.20)	304.62 (82.64)	2.14, null
Block 4			
EC (%)	48.85 (30.51)	50.58 (26.90)	3.68, null
EO (%)	2.44 (3.82)	1.94 (2.89)	3.29, null
RT (ms)	332.59 (93.56)	313.14 (104.59)	2.98, null

Values within parentheses represent standard deviations. alt = in favour of alternative hypothesis, null = in favour of null hypothesis.

3.4. Subjective state

The average scores for state anxiety (see Table 3), as measured by the STAI, and for the stress scale (see Table 3) and NASA-TLX (see Table 4) items were calculated for each subject. A one-way ANOVA was performed on each of the subjective items. There were no

significant differences in mean pre-task state anxiety scores, $F(1, 72) = .312$, $p = .578$, $\eta 2 = .004$) between the two conditions. Nor were there differences in ratings of tension $F(1, 72) = 3.60$, $p = .062$, $\eta 2 = .048$ (i.e., "How tense did you feel during the task?"), measured by the post-task stress scale, suggesting the CPT was indeed pain rather than anxiety inducing for participants. Bayes factors were 3.64 in favour of the null for state anxiety, providing moderate support for no between-group difference in state anxiety prior to completing the SART, and 0.9 in favour of the null for tension, indicating weak evidence for no between-group difference.

There were also no significant differences in mean TRTs, $F(1, 72) = 1.032$, $p = .313$, $\eta 2 = .014$, TUTs, $F(1, 72) = 1.219$, $p = .273$, $\eta 2 = .017$, or self-related thoughts (SRT) $F(1, 72) = .171$, $p = .680$, $\eta 2 = .002$ between the two conditions. The remaining items of physical fatigue, mental fatigue, motivation, task interest, concentration, and confidence showed no significant differences in mean scores between the two groups, $p > .05$, except for unhappiness which had a significantly higher score in the cold group when compared to the warm group, $F(1, 72) = 4.313$, $p = .041$, $\eta 2 = .057$.

Table 3. Means and standard deviations for state anxiety (STAI) and stress scale items.

	Cold	Warm	Bayes factors
State anxiety (STAI)	34.49 (9.91)	33.14 (10.87)	3.64, null
Physical fatigue	3.43 (2.29)	2.70 (2.30)	1.87, null
Mental fatigue	4.08 (2.47)	4.16 (2.73)	4.13, null
Tense	4.68 (2.36)	3.49 (3.00)	0.90, null
Unhappy*	3.24 (2.66)	2.05 (2.25)	0.67, alt
Motivation	7.57 (1.82)	7.76(1.95)	3.84, null
Task interest	7.08 (2.30)	6.81 (2.57)	3.77, null
Self-related thoughts	4.65 (2.96)	4.38 (2.66)	3.87, null
Concentration	6.84 (2.15)	7.70 (1.66)	0.85, null
Confidence	5.84 (1.79)	5.59 (1.98)	2.67, null
Task-related thoughts	7.24 (1.95)	7.70 (1.94)	3.65, null

Values within parentheses represent standard deviations. * $p < .05$. alt = in favour of alternative hypothesis, null = in favour of null hypothesis.

Ratings for physical demand, $F(1, 72) = 53.25$, $p < .001$, $\eta 2 = .425$, emotional demand, $F(1, 72) = 9.109$, $p = .004$, $\eta 2 = .112$, and global workload, $F(1, 72) = 13.186$, $p = .001$, $\eta 2 = .155$, as measured by the NASA-TLX, were significantly higher in the cold condition. There were no significant differences in the scores of the remaining items of mental demand, temporal demand, performance monitoring, and effort, $p > .05$. Bayes factors as well as means and standard deviations for these measures can be found in table 4.

Table 4. Means and standard deviations for NASA-TLX items.

	Cold	Warm	Bayes factors
Mental demand	6.79 (2.06)	6.16 (2.65)	2.41, null
Physical demand*	5.73 (2.63)	1.86 (1.86)	4.11e -8, alt
Temporal demand	7.19 (1.66)	7.70 (1.81)	2.08, null
Emotional demand*	4.05 (2.31)	2.38 (2.46)	0.09, alt
Performance monitoring	4.84 (2.49)	4.73 (2.28)	4.10, null
Effort	7.59 (1.76)	7.41 (1.82)	3.81, null
Global workload*	6.05 (1.19)	5.05 (1.19)	0.02, alt

Values within parentheses represent standard deviations. * $p < .05$.

alt = in favour of the alternative hypothesis, null = in favour of null hypothesis.

3.5. Correlations

Correlations between RT and errors of commission.

In order to analyse the relationships between errors of commission and RT for each of the conditions (N = 37 in each condition), Pearson product correlation coefficients were used. There was a significant negative correlation between errors of commission and RT in both the cold group, $r = -.612$, $p < .001$ and the warm group, $r = -.634$, $p < .001$, suggesting medium to strong speed-accuracy trade-offs in both groups.

Correlations between subjective state and SART performance.

Correlations between the three SART performance measures and state anxiety, tension, unhappiness, concentration, TUTs, and TRTs were examined. Overall, there was a significant negative correlation between RT and tension, $r = -.242$, $p = .038$, indicating that participants who had faster reaction times to SART stimuli tended to report feeling more

tense. No significant correlations were found between the three SART performance measures and state anxiety, unhappiness, concentration, TUTs, or TRTs.

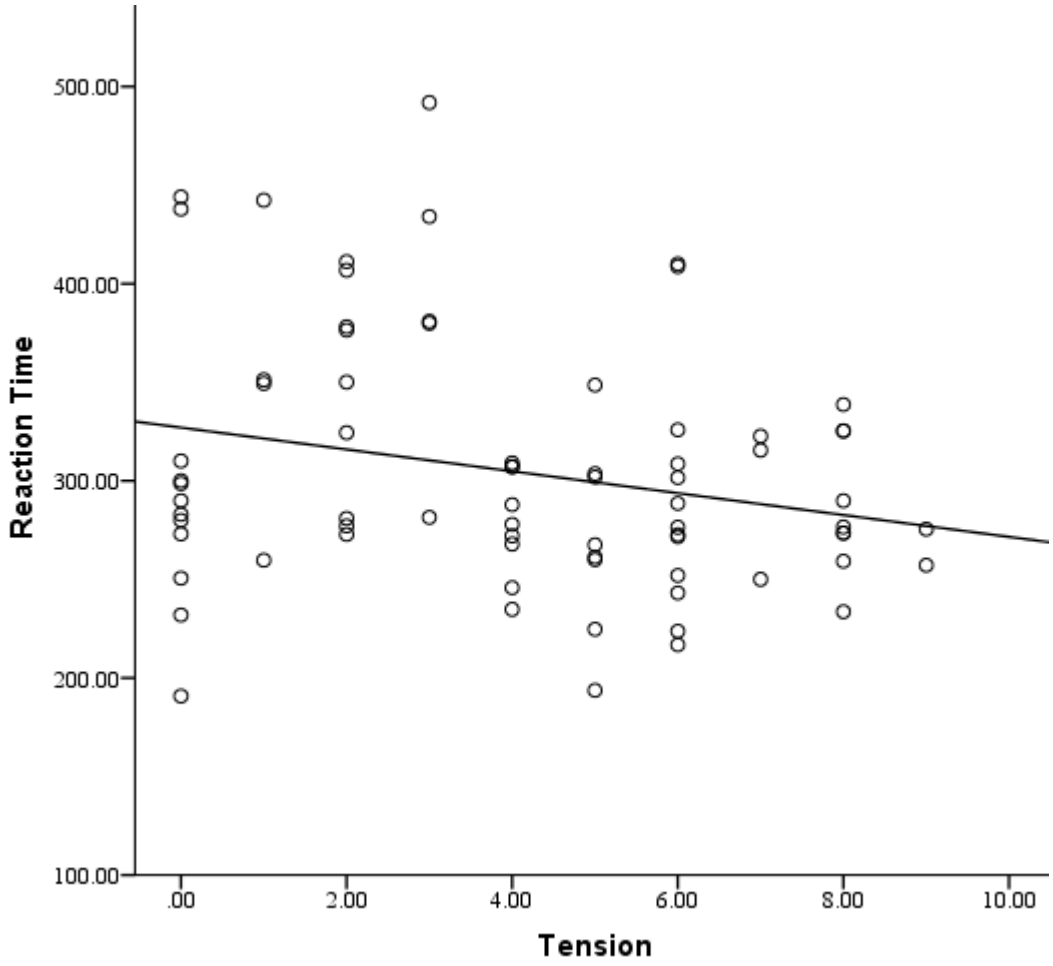

Figure 1. Relationship between reaction times and tension, as measured by the stress scale.

4. Discussion

The primary objective of this experiment was to investigate the effects of acute pain on SART performance. If the CPT induced pain improves performance on the SART, then a significantly reduced number of commission errors (i.e., improved response accuracy), with no cost to response speed, made by participants in the cold condition would be found. Alternatively, if acute pain induced by the CPT disrupts performance on the SART, participants in the cold condition would be found to make significantly more errors of

commission when compared to those in the warm condition. However, performance on the SART was found to be unaffected by the CPT induced pain. More specifically, no significant differences in the three performance measures of the SART (i.e., errors of commission, errors of omission and RT) were found between the two conditions despite reports of acute pain increases in the cold condition. The Bayesian analysis for the difference between the two conditions was in favour of the null hypothesis for all three behavioural measures of the SART. In addition, faster RTs were associated with more commission errors in both cold and warm conditions, indicating a speed-accuracy trade-off.

Subjective ratings of TUTs and TRTs did not differ between the two conditions. The Bayesian analysis for the difference between the two conditions was in favour of the null hypothesis for TUTs, and TRTs. Unsurprisingly, self-reported ratings revealed that unhappiness (measured by the stress scale) and physical demand, emotional demand and global workload (measured by the NASA-TLX) were perceived to be significantly higher in the cold condition.

Several authors have suggested that pain, by its very nature, demands attention (Crombez, Eccleston, Baeyens, & Eelen, 1996, 1998; Eccleston and Crombez, 1999; Van Damme, Crombez, Eccleston, 2004; Wickens, 1984). Considering that pain serves as a warning signal of a bodily threat, it makes sense for pain related sensations to have a much higher processing priority than other competing sources of information. Indeed, the involuntary capture of attention by pain has been demonstrated in behavioural studies in which healthy participants perform an attention demanding cognitive task while experiencing task-irrelevant, experimentally induced pain, resulting in significantly impaired cognitive task performance (Crombez, Eccleston, Baeyens, & Eelen, 1996, 1998; Van Damme, Crombez, Eccleston, 2004). Findings from the present study, indicating that performance on the SART

was not affected by the CPT induced acute pain are difficult to reconcile with this view of pain as inherently interruptive.

Given the unexpected results of the present study, the effectiveness of the experimental manipulation used in the study requires some consideration. Some researchers have proposed that in order to find a disruptive effect of pain on cognitive task performance, the pain inducing stimulus should be intense and the cognitive task should be difficult (Eccleston and Crombez, 1999). With respect to pain intensity, 70.3% of participants in the cold group rated their pain as 5 or above on a 1 to 7 Likert scale. In addition, analysis of behavioural data from a small group of participants (8 in each condition) who chose to remove their hand from the cold water early (i.e., before the SART ended) due to the cold pressor stimulus causing too much discomfort revealed no significant differences in SART performance between the two groups. Following Bayesian analysis for the difference between the two conditions was in favour of the null hypothesis for errors of commission, errors of omission and RTs, lending further support for the finding that the CPT induced acute pain did not affect performance in the SART. Concerning task difficulty, measures of mental and temporal demand in relation to the SART had an average rating of approximately 7 out 10, indicating fairly high mental and temporal demand, and a measure of effort (i.e., "How hard did you have to work to accomplish your level of performance?") had an average rating of approximately 7.6 in the cold group and 7.4 in the warm group, suggesting that participants found the task difficult. This was further supported by high rates of commission errors, indicating that participants found it difficult to withhold their responses to the No-Go stimuli in the SART.

It could be argued that that the application of continuous cold pressor induced pain resulted in habituation (i.e., participants got used to the pain after a while) or suppression of pain related sensations, which could have improved focusing on the SART. Indeed, 34 out of

37 participants in the cold condition reported that the CPT induced pain was worse during the first half of the SART rather than the second half of the SART. Based on this, it would be reasonable to expect significantly different performance in the SART during the first block of trials when compared to the last block of trials, or during the first two blocks when compared to the last two blocks. However, block by block analysis of the SART performance, did not reveal any significant differences between the two conditions. These findings were further supported by the Bayesian analysis for the difference in the mean scores of the three behavioural measures between the four SART blocks, which was in favour of the null hypothesis, ruling out the possibility that differences in the three behavioural measures of SART performance could be more pronounced in the first block of the SART due to habituation. The CPT induced tonic pain that lasts a short time but is continuous in nature as opposed to phasic pain that comes and goes is, arguably, a more accurate experimental representation of real-life acute pain (Sinke, Schmidt, Forkmann, & Bingel, 2015). Indeed, the cold pressor paradigm is a well-established and widely accepted method of pain induction that has been used in numerous studies investigating both normal (e.g., Houlihan, et al., 2004; Van Damme, Crombez, Nieuwenborgh-De Wever, & Goubert, 2008; Veldhuijhzen et al., 2006; Wang, Jackson, Cai, 2016) and clinical (for a review see Birnie et al., 2012) populations.

The question remains, however, as to the exact nature of the relationship between the SART and acute pain. It is possible that an additional mechanism of "switching" (Eccleston, 1995) attentional resources from the processing of pain related sensations to SART-related processing during pain resulted in performance unaffected by pain (in comparison to no pain). However, such continuous reallocation or switching of attention from pain to task in order to reduce the interruptive effects of pain and maintain an optimal level of SART performance is, itself, demanding of attentional control resources (Crombez, Eccleston,

Baeyens, Eelen, 1996; Eccleston, 1995; Norman, & Shallice, 1980). Thus, even though the coping based mechanism of switching cognitive resources from pain-related processing to task-related processing remains plausible, the impact of the attention demanding nature of this mechanism on cognitive task performance is unclear and requires further investigation.

Even though multiple studies (e.g., Crombez, Eccleston, Baeyens, & Eelen, 1996, 1998; Van Damme, Crombez, Eccleston, 2004) found that a painful stimulus disrupts cognitive task performance due to its inherently high attention demands, the present study found that SART performance was unaffected by pain. It is possible that different approaches in relation to the way experimental pain was induced, used to examine the effect of pain on attention-demanding cognitive tasks, and anticipatory fearfulness toward the pain stimulus could account for different outcomes (Crombez, Eccleston, Baeyens, & Eelen, 1998; Ogden, Moore, Redfern, & McGlone, 2014; Veldhuijzen, 2006). For example, Crombez et al. (1996) used unpredictable intermittently occurring electrical shocks to induce pain in healthy participants and test its effect on attention. Thus, unpredictable electrical shocks in the study of Crombez et al. (1996) could have induced anticipatory fearfulness toward the pain stimulus in-between intermittently occurring trials. The implications are that focal attention will be placed automatically on the painful stimulus (i.e., the object of fear) due to its high threat value, resulting in the deterioration of cognitive task performance (Crombez et al., 1998). Indeed, some authors have shown that fearful anticipation of pain or "catastrophic thinking" (Crombez et al., 1998, p. 188) about pain enhances attentional disruption during attention requiring cognitive task performance (Crombez et al., 1998; Van Damme, Crombez, Eccleston, 2002; 2003). Thus, it is possible that pain and arousal or emotional response (i.e., anticipatory fearfulness) to painful stimuli work together to produce interruptive effects of pain on attention. In contrast, the present study used a continuous pain-inducing stimulus (i.e., the cold pressor task) which had no threat value and therefore, arguably, no arousal or

anticipatory fearfulness inducing properties. Indeed, subjective measures of state anxiety or tension did not significantly differ between the two conditions in the present study, providing some evidence for the view of the CPT as a pain only inducing stimulus. Even though pain per se has been demonstrated to exert disruptive effects on cognitive task performance due to its attention demanding properties, its effects are somewhat dependent on individual differences (i.e., tolerance to pain) (Coghill, 2010; Fillingim, 2005). Thus, it is highly plausible that pain will affect cognitive performance to a lesser extent in some individuals than others, making it harder to detect interruptive effects of pain on cognition.

Interestingly, other authors have suggested that fearful anticipation of a painful stimulus may facilitate attentional processing by activating parts of specialised neural circuitries located in the amygdala and responsible for increased "emotional attention" (Bornhövd, Quante, Glauche, Bromm, Weiller, & Büchel, 2002; Vuilleumier, 2005). Thus, the predominant goal of the short phasic pain such as electric shocks may be to serve as an arousal-inducing signal that urges the recipient to pay close attention to the environment (Sinke at al., 2015). This is in line with Robinson and colleagues' (2013) finding that unpredictable electrical shocks enhanced performance in the SART. Overall, it appears that the method of experimental pain induction could be responsible for the different outcomes from the different studies. In addition, it is important to disentangle other factors (e.g., threat value, individual differences in relation to pain perception) that could work together with or alongside pain to produce disruptive or facilitative effects of pain on cognitive performance.

Another and, arguably, more likely explanation for findings showing SART performance unaffected by acute pain is that cognitive resources on which performance in the SART depends were perhaps not utilised by pain processing. More specifically, considering that an important element of the SART is the suppression of prepotent motor responses to No-Go stimuli, it could be that SART performance was unaffected by pain due to the SART

relying predominantly on the motor cortex rather than the more central attentional resources that are shared with pain processing (Veldhuijzen et al., 2005; Villemure, & Bushnell, 2002). Indeed, brain imaging studies have shown that successful inhibition of motor responses in response inhibition tasks (e.g., Go/No-Go) relies heavily on the motor cortex (Burle et al., 2016; Fonken et al., 2016; Glass et al., 2011). Thus, considering that pain processing has been demonstrated to recruit more central attentional resources, it makes sense to find SART performance unaffected by pain. This is line with the multiple resource perspective (Wickens, 1984), suggesting that the degree to which two tasks can be performed concurrently depends on the type of resources each task demands. For example, if the two tasks rely predominantly on the same attentional resources, then the joint demand for attention is likely to exceed the limited available supply, resulting in impaired performance on one of the tasks. In contrast, if the two tasks rely on different resources, then performance on either of the tasks should not normally be disrupted. More direct evidence in support of such line of thought comes from Veldhuijzen and colleagues' (2006) study that examined the effect of the CPT induced pain on attention capacity during a visual search task (VST) in low task load and high task load conditions whilst simultaneously recording event-related potentials (ERPs). Performance on the VST was found to be unaffected by pain and no significant interactions between pain and task load were observed. What is especially interesting is that further analysis of topographic maps of ERP data showed that scalp potentials representing the effects of pain and task load were distributed in a topographically different manner. More specifically, the task load effect was predominantly distributed in parietal regions of the brain whilst the pain effect used more central resources and had a more widespread distribution, suggesting that the resources on which the VST depends where not shared by pain processing.

Even though the SART was originally developed to measure failures in sustained attention by inducing mindlessness or mind-wandering due to its repetitive nature which

results in less attention being paid to the task (Robertson et al., 1997; Smallwood, 2013; Smallwood, McSpadden, & Schooler, 2007; Smallwood & Schooler, 2006), the results from the present experiment are in line with a number of other studies (Finkbeiner et al., 2015; Wilson et al., 2015, Wilson et al., 2016), questioning the nature of the task and what commission errors in the SART truly represent – lapses in attention or failures in response inhibition. The results from the present study did not allow the differentiation between the two theories (mindlessness and/or mind-wandering vs. response inhibition). However, considering that conscious thoughts (i.e., TUTs and TRTs), as measured by the stress scale did not differ between the two conditions and were found to have no impact on SART performance measures, the findings from the present study are especially difficult to reconcile with the view of the SART as an attention task aimed at inducing mind-wandering in order to identify lapses in sustained attention.

In conclusion, the present study aimed to investigate the effect of the CPT induced acute pain on SART performance. Previous research has mostly demonstrated that acute pain is likely to disrupt performance on cognitive tasks requiring attention (Crombez, Eccleston, Baeyens, & Eelen, 1996, 1998; Van Damme, Crombez, Eccleston, 2004), and there is some indirect evidence suggesting somewhat improved performance on cognitive tasks (Robinson et al., 2013; Patil, Apfelbaum, Zacny, 1995). Surprisingly, results from the present experiment showed that acute pain did not have an effect on participants' performance in the SART. Thus, the two possibilities that had been originally proposed were not supported. From a multiple resource perspective, it is possible that SART performance was unaffected by pain because SART and pain draw on resources located in different cortical areas. Future studies investigating this possibility are required as incorrect use of the SART as a measure of sustained attention has serious implications for the interpretation of findings from various studies employing this task.

Appendices

Appendix 1

State-trait Anxiety Inventory (STAI)

State-trait Anxiety Inventory

Please read each statement and then circle the appropriate number to the right of the statement to indicate how you feel *right now,* that is, *at this moment.* There are no right or wrong answers. Do not spend too much time on any statement but give the answer that seems to describe your present feelings best.

		NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1.	I feel calm	1	2	3	4
2.	I feel secure	1	2	3	4
3.	I am tense	1	2	3	4
4.	I feel strained	1	2	3	4
5.	I feel at ease	1	2	3	4
6.	I feel upset	1	2	3	4
7.	I am presently worrying over possible misfortunes	1	2	3	4
8.	I feel satisfied	1	2	3	4
9.	I feel frightened	1	2	3	4
10.	I feel comfortable	1	2	3	4

11.	I feel self-confident	1	2	3	4
12.	I feel nervous	1	2	3	4
13.	I am jittery	1	2	3	4
14.	I feel indecisive	1	2	3	4
15.	I am relaxed	1	2	3	4
16.	I feel content	1	2	3	4
17.	I am worried	1	2	3	4
18.	I feel confused	1	2	3	4
19.	I feel steady	1	2	3	4
20.	I feel pleasant	1	2	3	4

Please read each statement and then circle the appropriate number to indicate how you ***GENERALLY FEEL.***

		ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
21.	I feel pleasant	1	2	3	4
22.	I feel nervous and restless	1	2	3	4
23.	I feel satisfied with myself	1	2	3	4
24.	I wish I could be as happy as others seem to be	1	2	3	4
25.	I feel like a failure	1	2	3	4
26.	I feel rested	1	2	3	4
27.	I am “calm, cool, and collected”	1	2	3	4
28.	I feel that difficulties are piling up so that I cannot overcome them	1	2	3	4
29.	I worry too much about something that really doesn’t matter	1	2	3	4
30.	I am happy	1	2	3	4
31.	I have disturbing thoughts	1	2	3	4
32.	I lack self-confidence	1	2	3	4
33.	I feel secure	1	2	3	4
34.	I make decisions easily	1	2	3	4
35.	I feel inadequate	1	2	3	4
36.	I am content	1	2	3	4
37.	Some unimportant thought runs through my mind and bothers me	1	2	3	4
38.	I take disappointments so keenly that I can’t put them out of my mind	1	2	3	4

39.	I am a steady person	1	2	3	4
40.	I get in a state of tension as I think over my recent concerns and interests	1	2	3	4

Appendix 2

Pain Scale

Please rate the level of pain experienced during the cold pressor task on a 1 ("not painful") to 7 ("very painful") scale below by circling an appropriate number.

1	**2**	**3**	**4**	**5**	**6**	**7**

Appendix 3

Pain Intensity during Different Stages of the SART

Was the pain worse during the first half of the task or the second half of the task? Please tick.

1. First half
2. Second half

Appendix 4

Self-report Stress Scale

Self-report Stress Scale

11 item	*rate on a 0-10 scale, from low to high*	
1	PHYSICAL FATIGUE - How physically exhausted and tired did you feel?	

2	MENTAL FATIGUE - How mentally exhausted and tired did you feel?	
3	TENSE - How tense or anxious did you feel?	
4	UNHAPPY - How unhappy did you feel?	
5	MOTIVATION - How motivated were you to do well?	
6	TASK INTEREST - How interesting was the task?	
7	SELF-RELATED THOUGHTS - How much did you think about yourself?	
8	CONCENTRATION - How focused on the task were you?	
9	CONFIDENCE - How confident were you during the task?	
10	TASK-RELATED THOUGHTS - How much did you think about the task?	
11	TASK-UNRELATED THOUGHTS - How much did you think about something other than the task?	

Appendix 5

NASA-TLX Questionnaire

NASA-TLX (modified)

6 item, rated on a 0-10 scale, from low to high

1	mental demand	*how mentally demanding was the task?*
2	physical demand	*how physically demanding was the task?*
3	temporal demand	*how hurried or rushed was the pace of the task?*
4	emotional demand	*overall how emotionally demanding was the task?*
5	performance monitoring	*how successful were you in accomplishing what you were asked to do?*
6	effort	*how hard did you have to work to accomplish your level of performance?*

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