2013

RELATIONSHIPS AMONG PAIN THRESHOLD, SELF-REGULATION, EXECUTIVE FUNCTIONING, AND AUTONOMIC ACTIVITY: A GENERAL INHIBITORY SYSTEM PERSPECTIVE

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THESIS

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A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Arts and Sciences at the University of Kentucky

By

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2013

ABSTRACT OF THESIS

RELATIONSHIPS AMONG PAIN THRESHOLD, SELF-REGULATION,
EXECUTIVE FUNCTIONING, AND AUTONOMIC ACTIVITY: A GENERAL
INHIBITORY SYSTEM PERSPECTIVE

Chronic pain patients have poorer pain inhibition, self-regulatory ability, executive functioning and autonomic inhibition than those without pain, supporting the view that suppressing pain is mentally taxing. In the current study, an alternate explanation was proposed; namely, that pain inhibition, self-regulation, executive functions, and heart rate variability (HRV) are all controlled by the same general inhibitory system. To test this hypothesis, participants came into the laboratory for three sessions. At the first session, individual differences in pain thresholds, self-regulatory strength, executive functioning, and HRV were measured. At the second and third sessions, self-regulatory persistence and within-session changes in pain thresholds were measured under conditions of high and low self-regulatory fatigue. Results revealed that those low in inhibitory strength, operationalized as the aggregate of pain inhibition, self-regulation, executive functioning, and HRV, became more sensitive to pain under conditions of self-regulatory fatigue, whereas no significant changes in pain threshold were found for those high in inhibitory strength. Additional analyses revealed that high baseline pain threshold marginally protected against the effects of self-regulatory fatigue. The findings provide some support for a general inhibitory system and suggest that physiological inhibition of pain and autonomic activity may be influenced by phasic self-regulatory fatigue.

KEYWORDS: Pain Threshold, Self-Regulation, Autonomic Inhibition, Executive
Functioning, Fatigue

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 09/04/2013_____

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Chapter One: Introduction

"I assess the power of a will by how much resistance, pain, torture it endures…"

- Friedrich Nietzsche

The famous philosopher Friedrich Nietzsche realized that enduring pain requires some form of willpower, or ability to self-regulate. Self-regulation refers to one's fundamental ability to alter dominant responses including emotions, behaviors, and thoughts. It is characterized as both a trait and a state, such that there is individual variability in overall level of self-regulatory strength, while at the same time the ability to regulate is affected by a number of situational and environmental demands. Self-regulation is thought to rely on a limited resource that, like energy in a muscle, becomes fatigued with use (Muraven & Baumeister, 2000). When two self-regulation tasks are presented consecutively, performance on the second task is impaired because self-regulatory resources become fatigued during the first (e.g., Baumiester, Bratslavsky, Muraven & Tice, 1998; for a review of fatiguing tasks, see Hagger, Wood, Stiff, & Chatzisarantis, 2010). Because experiencing pain requires self-regulation, it may impair subsequent self-regulatory attempts.

The Effect of Pain on Self-Regulation and Executive Functions

Several studies support the idea that experiencing pain taxes self-regulatory ability. In one study, participants were randomly assigned to complete either a high-fatigue or a low-fatigue self-regulatory task (Vohs, Baumeister, Schmeichel, Twenge, Nelson, & Tice, 2008). After the self-regulatory task, they underwent a cold-pressor task requiring them to submerge their hand in ice water and keep it there for as long as possible. Participants in the high fatigue condition removed their hand from the water

significantly sooner than participants in the low fatigue condition, presumably because the mental energy required to tolerate the pain became partially fatigued during the first task. In another study, participants again underwent a fatiguing task prior to the cold-pressor task, but before starting the cold-pressor half the participants were told they would need to engage in a third difficult task, while a control group was told the third task would be easy. In reality, there was no third task. However, those participants who expected the third task to be difficult attempted to conserve their self-regulatory resources by removing their hand from the ice water sooner than the control group, suggesting they were influenced by the expectation that enduring pain would tax their self-regulatory capability (Muraven, Shmueli, & Burkley, 2006). If enduring pain fatigues self-regulatory ability, then individuals with chronic pain should exhibit chronic self-regulatory deficits. Women without chronic pain persisted less at an unsolvable anagram task under conditions of high fatigue than low fatigue. Women with fibromyalgia or temporomandibular disorder had low levels of persistence regardless of level of fatigue, suggesting that chronic pain is characterized by chronic self-regulatory failure (Solberg Nes, Carlson, Crofford, de Leeuw, & Segerstrom, 2010).

Additional evidence that people who experience chronic pain also experience chronic fatigue comes from evidence that, compared with normal controls, chronic pain patients have more trouble regulating thoughts and emotions (Burns, Quartana, & Bruehl, 2008; Kane et al., 2007), coping with stress (Arango & Cano, 1998), navigating social interactions (Affleck et al., 1997), and engaging in behaviors that require mental flexibility (Karp et al., 2006). Self-regulatory fatigue may manifest as poorer executive cognitive functioning (Heatherton & Wagner, 2011; Schmeichel, 2007; Small, Zatorre,

Dagher, Evans, & Jones-Gotman, 2001). Executive functions are defined as a set of "interrelated abilities that enable people to modify their thoughts and action" (Schmeichel, 2007, p. 10), and include planning, inhibition, task switching, processing speed, and working memory, among others. Individuals experiencing acute pain or chronic pain experience impairments in verbal fluency, free recall, working memory, and other tasks requiring the use of executive functions (Katz, 2004; Landro, Stiles, Sletvold, 1997; Park, Glass, Minear, & Crofford, 2001; Schoofs, Wolf, & Smeets, 2009; for a detailed review of how pain affects self-regulation and executive functions, see Solberg Nes, Roach, & Segerstrom, 2009).

Taken together, these findings provide compelling evidence that pain impairs one's ability to self-regulate and that experiencing chronic pain results in chronic self-regulatory deficits. This relationship between chronic pain and self-regulatory ability may not be unidirectional. When self-regulatory ability is fatigued, emotions and urges actually feel more intense, raising the possibility that the state of self-regulatory fatigue in chronic pain patients exacerbates the pain experience (Vohs, Baumeister, Mead, Ramanathan, & Schmeichel, 2012).

A General Inhibitory Explanation

The relationship between pain and self-regulatory fatigue might also be influenced by a third variable: inhibitory strength. In other words, there might be a system which undermines both the ability to centrally inhibit pain and to self-regulate. Such a general inhibitory system may not only affect dominant response inhibition (i.e., self-regulation) and pain inhibition, but also autonomic inhibition, as these outcomes are all influenced by overlapping brain areas.

Self-Regulation. Preliminary evidence suggests that a general inhibitory system model could explain the relationships between self-regulation and pain inhibition. In a study to assess how pain affects self-regulatory persistence, Hardy (2012) compared anagram persistence among people experiencing chronic physical pain or chronic social pain and healthy controls. There are strong theoretical, psychological, and physiological correlates between physical and social pain, so performance on self-regulatory tasks should be similarly impaired in both groups (see McDonald & Leary, 2005 for a review). As expected, those in chronic pain (both physical and social) persisted less than healthy controls. Interestingly, the findings held even when the people in the pain groups were not in pain at the time of the experiment. In other words, despite current pain ratings being similarly low for all three groups immediately prior to performing the persistence task, the two chronic pain groups performed worse than the control group. These findings suggest that the relationship between chronic pain and poor self-regulatory persistence cannot be explained solely by the experience of immediate pain.

Related to self-regulatory ability is one's ability to regulate emotions. Pain is conceptualized as having a somatosensory component which determines the physical sensation of pain and an affective component which determines how people emotionally react to pain (Melzack & Casey, 1968; Price, 1999). Experiencing pain activates neural mechanisms also implicated in emotion regulation, including activation in structures such as the insula, amygdala, and anterior cingulate cortex (Fullbright, Troche, Skudlarski, Gore, & Wexler, 2001; Hofbauer, Rainville, Duncan, & Bushnell, 2001; Price, 2000) In a study of patients with juvenile arthritis, emotion regulation ability predicted pain levels and functioning, suggesting that the affective components of the pain experience

contribute to important outcomes (Connelly et al., 2012). As such, it is important to test how emotion regulation ability influences sensitivity to experiencing pain.

     Pain Inhibition. The same brain regions implicated in self-regulation and autonomic inhibition are also implicated in pain inhibition. Pain inhibition refers to automatic descending neural signals that reduce pain. Whereas sensory neurons from all over the body are constantly sending signals to the brain, the majority of these signals are inhibited by endogenous inhibitory mechanisms. Pain threshold, which is defined as the amount of noxious stimulation required before pain is felt, is thought to measure how effective these endogenous inhibitory mechanisms are at quieting the ascending pain signals and has been shown to be relatively stable within people across time (Brennum, Kjeldsen, Jensen, & Jensen, 1989). Magnetically stimulating the dorsolateral prefrontal cortex, an area also strongly implicated in self-regulation, leads to the reduction of both acute and chronic pain (Lefaucher, 2008; Rosen, Ramkumar, Nguyen, & Hoeft, 2009; Taylor, Borckardt, & George, 2012). Additionally, stimulation of the dorsolateral prefrontal cortex also leads to increased pain thresholds in healthy volunteers (Boggio, Zagni, Lopes, & Fregni, 2008; Nahmias, Debes, de Andrade, Mhalla, & Bouhassira, 2009). One possible explanation for these findings is that the prefrontal cortex is responsible for initiating descending pain-inhibitory signals. Studies using fMRI and PET methodologies have found that placebo analgesia is induced by top-down inhibitory analgesic pathways initiating in higher brain areas. For instance, cognitive behavioral therapy for chronic pain has been shown to increase activation in the ventrolateral prefrontal cortex, which is also the area implicated in processes requiring cognitive executive control (Jensen et al., 2012). These findings suggest that the prefrontal cortex

"likely represents the pivotal source of modulation that, at least within one conceivable pathway, initiates downstream analgesic activity" (Bingel & Tracey, 2008, p.373; Kong et al., 2006).

Further evidence for a general inhibitory system influencing the pain experience comes from studies investigating diffuse noxious inhibitory control (DNIC) responses in healthy controls and in those with chronic pain (Lorenz, Minoshima, & Casey, 2003; Oosterman, Dijkerman, Kessels, & Scherder, 2010). DNIC responses, which are mediated by endogenous pain inhibitory pathways, are at least partially influenced by prefrontal input (Edwards, Ness, Weigent, & Fillingim, 2003; Goodin et al., 2009; Lautenbacher, Prager, & Rollman, 2007; Weissman-Fogel, Sprecher, & Pud, 2008). To test DNIC responses, researchers administer a noxious stimulus in one area of the body and then concurrently add another noxious stimulus at a different location. The administration of the second stimulus reduces the pain of the first, even after controlling for distraction, effectively treating pain with pain. In a study testing the DNIC response via isometric exercise in fibromyalgia patients versus normal controls, researchers found that engaging in repeated hand exercise reduced pain of a subsequent noxious stimulus in normal controls but increased pain in fibromyalgia patients (Staud, Robinson & Price, 2005). Other studies have also found that patients with chronic pain have a weaker DNIC response (van Wijk & Veldhuijzen, 2010), suggesting altered inhibitory mechanisms.

Studies using pain threshold ratings instead of DNIC responses have found similar results. Patients with a wide variety of pain disorders including fibromyalgia (Giesecke et al., 2003) and chronic tension headaches (Schoenen, Bottin, Hardy, & Gerard, 1991) have lower pain thresholds than normal controls. Furthermore, when a

painful stimulus was administered, the pain lasted significantly longer and was maintained using lower frequency of stimulation in fibromyalgia patients than in normal controls (Staud, Price, Robinson, Mauderli, & Vierck, 2004). Taken together, the DNIC and pain threshold findings support the view that chronic pain patients experience generalized pain inhibitory failure.

      Autonomic Inhibition. The self-regulatory system involved in inhibiting dominant behavior shares overlapping brain regions with the parasympathetic nervous system pathway which inhibits autonomic activity. The pre-frontal cortex, along with the anterior cingulate, insula, amygdala, hypothalamus, and periaqueductal gray form part of the central autonomic network, which provides parasympathetic, or autonomic inhibitory, input to the heart (Ahern et al., 2001). Self-regulatory strength can be indexed by measuring parasympathetic nervous system activity via heart-rate variability (HRV), defined as the variability between heartbeats. In a study using HRV to predict self-regulatory strength and persistence, participants were randomly assigned to a high fatigue or low fatigue manipulation and were then asked to solve an unsolvable anagram (Segerstrom & Solberg Nes, 2007). Resting levels of HRV predicted increased persistence on the anagram task, suggesting that it could serve as a physiological biomarker of trait, or tonic, self-regulatory strength. HRV was greater in moments when participants were exerting self-regulatory effort, thus also serving to index phasic, or state, self-regulatory effort (Segerstrom & Solberg Nes, 2007). Evidence from other studies also supports the relationship between self-regulatory ability and HRV. For example, pharmacological deactivation of the prefrontal cortex leads to decreases in HRV, and engagement of the prefrontal cortex during self-regulatory tasks increases

HRV (Ahem et al., 2001; Matthews, Paulus, Simmons, Nelesen, & Dimsdale, 2004; Wong, Masse, Kimmerly, Menon, & Shoemaker, 2007; for a review of the relationship between self-regulation and HRV, see Segerstrom, Hardy, Evans, and Winters, 2011).

Autonomic tone has been shown to influence how people experience pain. One study found that low-frequency HRV, which is thought to reflect both sympathetic and parasympathetic autonomic activity, has been associated with lower ratings of pain unpleasantness and lower pain sensitivity to thermal pain (Appelhans & Luecken, 2008). The relationship between high frequency HRV and pain threshold remains unknown; however, programs designed to increase parasympathetic tone have been successfully used to treat chronic pain in patients with orofacial pain (Carlson, Bertrand, Ehrlich, Maxwell, & Burton, 2001), suggesting that high frequency HRV may influence pain thresholds.

Summary of the Literature on Self-Regulation and Pain

Nietzsche thought that a person's ability to endure pain was a testament to that person's self-regulatory strength. The aforementioned research has established that there is indeed a connection between self-regulation and pain. Evidence from both the acute and chronic pain literature has demonstrated that people whose self-regulatory capacity has been fatigued are less able to tolerate pain, and those who are experiencing pain are less able to self-regulate. Further, chronic pain patients show diminished self-regulatory abilities, impaired executive functions, and reduced HRV (Cohen et al., 2000; Martinez-Lavin, Hermosillo, Rosas, & Soto, 1998; Schmidt & Carlson, 2009). A common interpretation of the literature has been that experiencing pain is fatiguing, and that fatigue then leads to impairment in subsequent self-regulatory tasks, executive

functioning, and autonomic inhibition.

I propose an alternative model explaining the relationship between self-regulation and pain. Because of the neurological overlap between brain regions involved in pain inhibition, self-regulation, executive functioning, and autonomic inhibition, failures in all four domains can be indicative of poor general inhibitory control. If there is, as I argue, a more generalized inhibitory system, and if there is individual variability in the strength of this generalized system, then people with poor general inhibitory control would experience the same self-regulatory failures seen in the extant chronic and acute pain literature. Evidence for a generalized inhibitory system has some support. HRV studies show that autonomic inhibitory control is predictive of self-regulatory strength (for a review, see Segerstrom et al. 2007). Self-regulation, executive functioning, and HRV are impaired in chronic pain patients even when they are not experiencing pain, suggesting that there is something above and beyond the experience of pain that is undermining their inhibitory capabilities (Hardy, 2012). Finally, pain inhibition is impaired in chronic pain patients, and chronic pain patients have lower pain thresholds than normal controls (Staud et al., 2004; Staud, Robinson, & Price, 2005).

The Current Study

Despite the existing support that a general inhibitory system underlies pain inhibition, self-regulatory strength, executive functioning, and autonomic inhibition, the model has not been tested directly. In the current study, the model was tested by comparing pain threshold ratings before and after participants completed a high fatigue and low fatigue task. If the same inhibitory system underlies the ability to inhibit pain and the ability to inhibit dominant responses, and if self-regulatory tasks temporarily fatigue

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that system, then individuals should be more sensitive to pain following self-regulatory fatigue. Although scarce, preliminary research shows that pain threshold may be positively correlated with the ability to inhibit a dominant response (Oosterman et al., 2010).

Based on the extant literature, the following predictions are made:

1. Individual differences in pain threshold, self-regulatory ability, executive functioning, and autonomic inhibition will significantly and positively correlate with one another, presumably because they are all related to a general inhibitory system.

2. There will be a main effect of fatigue condition in predicting persistence in the anagram task and within-session changes in pain thresholds, with more fatigue leading to reduced persistence and larger decreases in pain thresholds within the session.

3. There will be a main effect of each of the four inhibitory strength variables (baseline pain threshold, self-regulatory ability, executive functioning, and HRV) in predicting persistence and within-session changes in pain thresholds. Specifically, higher levels of the inhibitory strength variables should predict increased persistence and reduced within-session decreases in pain threshold, supporting the view that those with better baseline inhibitory tone will be better able to inhibit behavioral (persistence) and physiological (pain threshold) processes.

4. The four inhibitory strength variables will each moderate the relationships between fatigue condition and persistence and between fatigue condition and within-session changes in pain thresholds. Specifically, higher levels of baseline pain threshold, self-regulatory ability, executive functioning, and HRV are predicted to protect against the effect of regulatory fatigue in predicting persistence and within-session changes in pain

thresholds. Under conditions of low fatigue, it was expected that there would be a positive relationship between persistence and each of the four inhibitory strength variables. Because it was expected that there would be no within-session changes in pain thresholds under conditions of low fatigue (there is no reason for it to change), no relations were expected with the inhibitory strength variables in this condition. If a general inhibitory system exists, then fatiguing this system should predict impaired outcomes. Thus, under conditions of high fatigue, it was expected that higher levels of the inhibitory strength variables would protect against the effects of self-regulatory fatigue. In other words, under high fatigue, participants with higher baseline pain threshold, self-regulatory strength, executive functioning, and HRV were expected to be protected against subsequent impairment in performance compared to those with lower general inhibitory ability.

5. A composite inhibitory strength variable consisting of an aggregate of baseline pain threshold, self-regulatory ability, executive functioning, and HRV will more strongly moderate the relationships between fatigue condition and persistence and between fatigue condition and within-session changes in pain thresholds than any of the inhibitory strength variables entered independently, supporting the view that a general inhibitory system is responsible, and that it is composed of the four aforementioned components.

6. Based on existing evidence of gender differences in inhibitory ability (e.g., Fillingim & Maixnert, 1995), the interactions described above are predicted to be stronger in females than in males.

Chapter Two: Methods

Participants

One hundred eighteen students at the University of Kentucky (60 male; 58 female) agreed to participate in the study to fulfill a requirement for an introductory psychology course. Eligibility criteria for the study included: 18 years of age or older; no history of chronic pain disorders; no neurodegenerative, stroke, psychiatric, or neurological disorder; no current alcohol or substance use; no current psychotropic, statin, blood pressure or current pain medications (including over-the-counter pain medications in the past 24 hours); and no current pain (an answer of 0 on a 0-5 scale to the question of "What is your current, average level of daily pain?"). Participants were asked not to smoke or drink coffee/alcohol for two hours prior to the experiment to ensure that HRV or pain threshold measures were not influenced by these substances. Self-reported race of the sample was 78.0% White, 10.2% African American, 6.8% Asian, and 5.0% other/mixed race. Of those 118 participants, the first 40 were asked to return for sessions 2 and 3 (see below). One participant was unable to complete the experiment on time and had an activity scheduled immediately after; two other participants did not return for the final session. The session 2 and 3 data from these participants were not included in subsequent analyses.

Design and Procedures

All participants signed an informed consent form prior to beginning the experiment. Participants completed one or three sessions as explained below, and experimenters were matched to the sex of the participant for all sessions to diminish the effects of social desirability in pain reporting (Levine & Simone, 1991). The first session

was used to obtain individual difference measures, and the next two sessions included self-regulatory fatigue manipulations. Order was counterbalanced between the second and third session, and each participant experienced both levels of the manipulation (high and low fatigue). The first 40 participants were asked to complete all three sessions; the next 80 only completed session one. At the beginning of each session, the experimenter asked the participant several questions to ensure that eligibility criteria were met (described above). If participants endorsed being on pain medication or drinking coffee/alcohol in the past two hours, they were asked to reschedule for a later date.

At the first session, participants were fitted to electrocardiogram (ECG) monitoring equipment and asked to sit quietly throughout an acclimatization and baseline recording period. Afterward, their blood pressure was measured and their pain threshold was assessed on three consecutive trials using a pressure algometer. Following pain threshold testing, participants were asked to complete several executive function tasks assessing task-switching, working memory, and inhibition in the same order. These tasks were interspersed with a number of self-report questionnaires assessing self-regulatory strength, mood, and demographic information (all tasks and measures are described below). At the end of the first session, participants were detached from the HRV equipment and either debriefed (if they were only completing session one) or schedule for an appointment within two weeks of the first session (if they were completing sessions two and three).

At the start of the second session, participants were again fitted to the ECG monitoring equipment, underwent an acclimatization and baseline recording period, provided a blood pressure reading, and provided three consecutive pre-fatigue pain

threshold trials. They were then randomly assigned to undergo either a high- or low-fatiguing task. In the high-fatigue condition, participants watched a video of a woman's face. During the video, words flashed on the bottom of a screen. Participants were instructed to ignore the words and remain focused on the woman's face. This visual attention task has been widely used as a self-regulatory fatigue manipulation; because the dominant response is to shift attention to new stimuli in the visual field, inhibiting that response draws on self-regulatory resources (Hagger et al., 2010). In the low-fatigue condition, participants watched the same video but were not given specific instructions to ignore the words. As a measure of self-regulatory persistence, participants from both groups were asked to solve an unsolvable anagram. They were given two practice items to ensure they understood the task. An experimenter using a stopwatch measured how long it took the participants to complete or give up on each anagram. Following the anagram task, post-fatigue pain threshold was assessed on three consecutive trials. Immediately after completing each task, participants were asked to rate the difficulty of the task and their mood.

The third session was identical to the second session, with the exception that participants underwent the opposite fatigue manipulation from the second session. At the end of sessions three, participants were detached from the ECG equipment, debriefed, and thanked for their participation. Figure 1 shows a graphical depiction of the procedures and materials across all three sessions.

Figure 1

Graphical Representation of Study Procedures across Sessions

SESSION 3

Fitted to HRV equipment

Acclimatization and baseline HRV recording

Pre-fatigue pain threshold testing (PANAS-X)

Low fatigue task (PANAS-X) (Task Appraisal)

High fatigue task (PANAS-X) (Task Appraisal)

Unsolvable anagram task (PANAS-X) (Task Appraisal)

Post-fatigue pain threshold testing (PANAS-X) (Task Appraisal)

Debriefing

SESSION 2

Fitted to HRV equipment

Acclimatization and baseline HRV recording

Pre-fatigue pain threshold testing (PANAS-X)

Low fatigue task (PANAS-X) (Task Appraisal)

High fatigue task (PANAS-X) (Task Appraisal)

Unsolvable anagram task (PANAS-X) (Task Appraisal)

Post-fatigue pain threshold testing (PANAS-X) (Task Appraisal)

SESSION 1

Informed consent

Fitted to HRV equipment

Acclimatization and baseline HRV recording

Pain threshold testing

Test session (in order)
PANAS-X
Demographics
SCS
Digit Span Task
BRIEF
Trails A and B
Random Number Generation

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Materials

Physiological measures

Heart rate variability. HRV was operationalized as log power in the high-frequency (0.15-0.40 Hz) spectrum of the interbeat interval series derived from the ECG. Our HRV sampling procedures were based on those used in other studies of self-regulatory persistence (Hardy, 2012; Segerstrom & Solberg Nes, 2007; Solberg Nes et al., 2010). Participants were asked to sit quietly for a period of 7 minutes. The first two minutes served as an acclimatization period, and the data for that period were discarded. The data from the following five minutes were analyzed to provide baseline HRV. The ECG was sampled at 1000 samples/sec. To obtain the ECG, three Ag/AgCl electrodes with shielded leads were attached in Type II configuration. These leads were connected to an ECG150C Electrocardiogram Amplifier. Acqknowledge software (Biopac, Santa Barbara, CA) was used for storage, and data was analyzed using the MindWare analysis system (MindWare, Cahana, OH). To create individual difference measures of HRV, baseline HRV across all three sessions were averaged to enhance reliability. Internal consistency for the HRV measure was $\alpha = .78$.

Pain threshold. Pain threshold was measured via a pressure algometer with a rubber tip 1 cm in diameter. The algometer was placed on the intermediate phalange of the ring finger on the participant's non-dominant hand, with pressure gradually increased by 30 kPA/sec (e.g., Staud et al., 2005). Participants were instructed to press a stop-button with their dominant hand at the moment when the sensation changed from pressure to pain. The algometer produced a reading of the amount of pressure being applied when the stop-button was pressed. To increase reliability, an average of three

consecutive trials were obtained at each of the five test occasions (session 1, session 2 pre-fatigue, session 2 post-fatigue, session 3 pre-fatigue, and session 3 post-fatigue). Past research has shown that pain threshold measured via a pressure algometer is stable over time, with test/retest reliabilities over several days ranging from $\alpha = .81 - .94$ (Brennum et al., 1989). In the current study, internal consistency of all three trials on each of the five test occasions ranged from $\alpha = .86 - .98$.

To obtain individual differences in baseline pain thresholds, an average of the three session-one trials and the six pre-fatigue trials (three from session 2, three from session 3) was calculated. In all analyses including baseline pain thresholds, models were run with and without BMI and systolic blood pressure (see below) as covariates to control for the fact that some people have more fat on their fingers than others and that systolic blood pressure is related to pain threshold (Bruehl, Carlson, & McCubbin, 1992). When inclusion of the covariates influenced the results, both models are reported; when they did not, only the model without covariates is reported to enhance interpretability.

Pre-fatigue and post-fatigue pain threshold for each session was obtained by averaging the three respective trials. Within-session changes in pain thresholds were calculated by subtracting post-fatigue pain ratings from pre-fatigue pain ratings. Negative numbers indicate that pain thresholds decreased after experiencing self-regulatory fatigue (i.e., people became more sensitive to pain), whereas positive numbers mean that pain threshold increased (i.e., people became less sensitive to pain).

Blood pressure. Blood pressure and heart rate were measured using an OMRON Premium blood pressure monitor. A cuff was placed on the participant's left upper arm, and participants were instructed to rest their arm on the table while data were being

collected. To create individual difference measures of blood pressure, systolic and diastolic blood pressure ratings were averaged across all three sessions to enhance reliability. Internal consistencies for the systolic and diastolic composite variables were α =.83, and .84, respectively.

Psychological measures

Self-regulatory persistence. Participants were asked to solve four anagrams. Unbeknownst to the participants, the first of these four was unsolvable. The remaining three were difficult but solvable. Participants were allowed 5 min to solve or skip the first anagram, and 2 min for each of the other three. As they were solving the anagrams, an experimenter was timing how long it took before the participants completed or decided to skip each of the anagrams. Different sets of anagrams were used for sessions two and three. This task has been successfully used in numerous other studies to index self-regulatory persistence and correlates with trait self-regulatory strength. Longer time spent working on the anagrams reflects greater persistence (e.g., Baumeister et al., 1998; Hardy, 2012; Solberg Nes et al., 2005). Time spent on all four anagrams (unsolvable + three solvable but difficult) was used as a measure of persistence. Covarying the number of anagrams solved did not change any results, and therefore was not entered as a covariate in subsequent analyses.

Executive functions. Participants were asked to undergo tasks assessing several executive functions including psychomotor speed, task-switching, working memory, and inhibition.

Psychomotor speed and task-switching. Participants completed the Trail Making Tasks A and B. In Task A, participants drew lines connecting numbers in sequential order

from smallest to largest while being timed. Quicker performance is associated with better psychomotor speed (Reitan, 1958). In Task B, participants did the same task, with the added challenge of alternating between numbers and letters. The difference in completion time between Task B and Task A is widely used to assess executive dysfunction in the areas of task-switching and updating, and is thought to be a better measure than the ratio of A to B (see Giovagnoli et al., 1996; Salthouse, Atkinson, & Berish, 2003).

Working memory. The Digit Span portion of the Wechsler Adult Intelligence Scale, 4th Edition was used to assess working memory. This task is composed of three components: Digit Span Forward (DSF), Digit Span Backwards (DSB) and Digit Span Sequencing (DSS). In DSF, experimenters read a string of numbers and participants were asked to recite them back to the experimenter in the order they were read. In DSB, participants recited the numbers in opposite order, beginning with last number read and working backward to the first. In DSS, participants recited the numbers in order from smallest to largest. For each of the three components, one point was given for each correct answer. When two mistakes were made on the same-length digit-string, the component was discontinued. This task is widely used to measure executive functioning and is believed to have good construct validity (Schroeder, Twumasi-Ankrah, Baade, & Marshall, 2012). Higher scores are indicative of better working memory.

Inhibition. Participants completed the Random Number Generation task. In this task, a metronome produced a beep every 800 ms. Each time the metronome beeped, participants were asked to say a random number between 1-9 (with replacement), as if they were drawing a number out of a hat, putting it back in, and then drawing another number. This requires inhibition in that it forces participants to alter their dominant

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response of reciting non-random sequences. Participants were stopped after 120 sec. Computer software was used to calculate 13 different indices of randomness for each participant (Towse & Neil, 2008). These different indices were combined into three components: Component 1 reflects mental inhibition ability, Component reflects updating ability, and Component 3 is thought to reflect several executive functions simultaneously (Miyake et al., 2000).

Questionnaire measures. Prior to analyses, all self-report questionnaire data were checked for data entry errors, and all appropriate items were reverse-scored. Scores on all measures were obtained by averaging across all items on the respective scales.

Demographics. Participants reported their age, sex, height, weight, race, and relationship status. Height and weight information was used to calculate body mass index (BMI).

Self-regulatory strength. The Self-Control Scale Short Form (SCS) is a widely-used scale composed of 13 items that measures an individual's trait level of self-regulatory strength (Tangney, Baumeister, & Boone, 2004). Each item has 5 response options ranging from 1 "Not at all" to 5 "Very much." It has been shown to have high internal consistency ($\alpha = .89$), good test-retest reliabilities over 3 weeks ($\alpha = .89$), and has been shown to predict a number of self-regulatory behaviors in an undergraduate sample (Tangney et al., 2004; for a review, see de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012). Sample items include "I am good at resisting temptations" and "I keep everything neat," with higher scores reflecting greater self-regulatory strength. In the current sample, the scale had internal consistency of $\alpha = .84$.

Behavioral inhibition. The Behavior Rating Inventory of Executive Functions-

Adult Version (BRIEF) is a measure that captures individuals' views of their own self-regulatory capabilities as they occur in everyday environments (Roth, Isquith, & Gioia, 2005). For the current study, three subscales of the BRIEF were used. The Inhibit scale assesses lack of behavioral inhibition (e.g., "I have problems waiting my turn"), the Self-Monitor scale assesses lack of social inhibition (e.g., "I talk at the wrong times), and the Emotion Regulation scale assesses lack of emotional inhibition (e.g., I have angry outbursts"). Participants are asked to rate how often each item has been a problem within the last month, with response options ranging from 1 "Never" to 3 "Often." Scores were reverse coded so that higher scores indicated greater self-regulatory ability. These subscales have high internal consistency (α = .73 - .90) and good validity based on a large non-clinical adult sample (Gioia, Isquith, & Kenealy, 2008; Roth et al., 2005). In the current sample, internal consistency scores for the Inhibit, Self-Monitor, and Emotion Regulation scales were α = .70, .69, and .86, respectively.

Emotion Regulation. The Emotion Regulation Scale (ERQ) is a 10-item scale that measures the extent to which people use two different emotion regulation strategies: reappraisal and suppression (Gross & John, 2003). Reappraisal refers to changing the way one thinks about things (e.g., "When I want to feel less negative emotions, I change what I am thinking about") whereas suppression refers to trying to stop thinking or feeling certain emotions (e.g. "I keep my emotions to myself"). Each of the items are rated on a 7-point scale ranging from "Strongly disagree" to "Strongly agree," with higher scores reflecting greater endorsement of that strategy. Research shows that these two strategies differentially predict affect, relationship success, and physical well-being (Gross & John, 2003). In undergraduate samples the scales have adequate internal

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consistency (α = .73 - .79) and test-retest reliability over a 3 month period (α = .69; Gross & John, 2003). In the current sample, the reappraisal and suppression scales had internal consistencies of α = .63 and .76, respectively.

Mood. The Positive and Negative Affect Schedule Expanded version (PANAS-X) has been shown to effectively detect momentary fluctuations in affect (Watson & Clark, 1999; Watson, Clark, & Tellegen, 1988). While the original PANAS-X contains 60 items, a subset of 26 of those items were used in the present study to measure four facets: positive affect, negative affect, fatigue, and attentiveness. Participants rated 26 adjectives based on how they felt "right now, at the present moment" using a five-point scale ranging from 1 "Very slightly or not at all" to 5 "extremely." Example items include "interested" and "irritable." Each of the four included facets has good internal consistency (α = .72 - .88) in undergraduate samples (Watson & Clark, 1999). In the current sample, the average internal consistencies for the positive affect, negative affect, fatigue, and attentiveness subscales across all measurement occasions were α = .85, .80, .87, and .70, respectively.

Task appraisal. Following the fatigue task, the anagram task, and all pain threshold testing occasions, participants were asked to complete a seven-item questionnaire assessing the perceived difficulty of the task (e.g., "It was difficult"). Each of the seven questions was rated on a seven point scale ranging from 1 "Not at all" to 7 "Very much." Similar scales have been successfully used as a manipulation check in other self-regulation studies (Solberg Nes et al., 2010). The task appraisal questionnaire had an average internal consistency of α = .94 across all measurement occasions.

Composite measures

Self-Regulation Composite. Factor analysis was conducted to extract a latent self-regulation variable from the SCS, the three BRIEF subscales, and the two ERQ subscales. Factor analysis was conducted using SAS 9.3, with varimax rotation. A scree plot was used to determine the appropriate number of factors. A single Self-regulation Composite factor solution was the best fit for the data, composed of the SCS and three BRIEF subscales. To create this composite, scales were first standardized and then averaged together. Due to low factor loadings, the two ERQ subscales were not included in the composite self-regulation variable (for factor loadings, see Table1). The composite self-regulatory variable had adequate internal consistency ($\alpha = .76$).

Table 1

Factor Loading of Self-Control Variables

	Factor 1	Factor 2
BRIEF Inhibition	.76912	.10767
BRIEF Self-Monitoring	.72080	-.03112
SCS	.96477	.27268
BRIEF Emotional Control	.41794	-.23012
ERQ Reappraisal	-.06762	.32020
ERQ Suppression	-.15089	-.34468

Executive Function Composite. A raw score of Trails A was subtracted from that of Trails B and then standardized, so that higher scores reflected greater executive functioning. This standardized difference variable was then averaged with participant's standardized digit span total score. The correlation between the Trails difference variable and the digit span total variable was $r = .06$. However, previous research has suggested that composites of different executive functions do a better job at capturing the universe of executive functioning than any one variable by itself (Duckworth & Kern, 2011; Mather & Knight, 2005).

Inhibitory Strength Composite. An inhibitory strength variable was created by averaging the standardized baseline HRV, baseline pain threshold, self-regulation composite, and executive function composite variables. Internal consistency for the inhibitory strength composite variable was $\alpha = .21$. Reliability analyses revealed that the internal consistency would increase to $\alpha = .27$ if the executive functioning composite, which includes working memory and updating variables, were removed. However, because executive functioning is controlled by similar brain areas as are self-regulations, HRV, and pain inhibition, it was retained so that the composite inhibitory strength variable could capture a wider array of inhibitory capacities.

Chapter Three: Results

Remedial Actions

Prior to analysis, data were screened for violations of regression, including normality of residuals, homoscedasticity, kurtosis, and multicollinearity. High frequency HRV was log transformed to correct for skew. All of the other variables met the necessary assumptions for regression and ANOVA.

Manipulation Checks

Mood. To rule out the explanation that mood accounted for any of the effects, repeated measures ANOVAs were conducted on the four PANAS-X scores between the two conditions (high fatigue vs. low fatigue) following all tasks (see Figure 1). Neither positive affect, negative affect, attention, nor fatigue were significantly different within people across different fatigue conditions at any of the four measurement occasions (baseline, following the video task, following the anagram task, or following the final pain sensitivity rating; ps > .05).

Fatigue Manipulation. Prior to analyses, data from 4 participants were removed for all analyses of fatigue condition because experimenter notes taken during the session revealed that the participants were not following directions. Three participants fell asleep during the video task and another one fidgeted and looked around the room rather than watch the video. Repeated measures ANOVAs were conducted to test whether participants rated the video task and anagram task differently under conditions of high or low self-regulatory fatigue. The video task was rated as significantly more fatiguing following the high fatigue ($M = 3.51$, $SD = 1.43$) than the low fatigue ($M = 3.15$, $SD = 1.33$) instructions, $F(1,36) = 4.96$, $p = .03$. There were no significant differences in

participant's ratings of difficulty for the anagram task following the high fatigue ($M =$
4.50, $SD = 1.24$) versus low fatigue ($M = 4.49$, $SD = 1.10$) manipulation, $F(1,36) = 0.01$,
$p > .05$.

Order

Repeated measures ANOVA were conducted to test if order of session (low
fatigue –high fatigue vs. high fatigue – low fatigue) influenced persistence or within-
session changes in pain thresholds. For these analyses, order was coded as 0 or 1 and was
entered as a between-subject factor in the model. Results revealed that order significantly
influenced persistence ($F(1,31) = 8.30$, $p = .01$), such that participants persisted
significantly longer in the low fatigue condition when it came after the high fatigue
condition ($M = 187.79$) than when it came before the high fatigue condition ($M =$
147.15). Order did not influence persistence in the high fatigue condition. As such, all
models using fatigue condition to predict persistence were run with and without an order
term and an order by fatigue condition interaction term. Including these variables did not
significantly influence any of the models (including p-values), so only those without the
order and order by condition interaction terms are included below. Order did not
influence within-session changes in pain thresholds ($F(1,31) = 0.72$, $p = .40$).

Correlations

The first hypothesis was that baseline pain threshold, self-regulatory ability,
executive functioning, and HRV would positively correlate with each other. In general,
these correlations were non-significant, with the exception of pain threshold significantly
correlating with HRV (see Table 2).

Table 2

Bivariate Correlations among Study Variables and Descriptive Statistics

Variable	1	2	3	4	5	6	7
1. Female Gender		-.36**	-.04	-.13	-.16	-.07	-.25**
2. Pain Threshold (kPa)			.00	.09	.19*	.12	.00
3. SR Composite				-.02	.12	-.04	-.13
4. EF Composite					-.08	.08	.17
5. HRV (HF Power)†						.00	-.07
6 ERQ Reappraisal							-.06
7. ERQ Suppression							
Mean	49%	259.58	0.00	0.00	6.45	4.95	3.85
(SD)		(80.32)	(0.76)	(0.74)	(0.98)	(0.91)	(1.27)

Main Effects of Self-Regulatory Fatigue

The second hypothesis was that there would be a main effect of self-regulatory fatigue condition in predicting persistence and within-session changes in pain threshold. A within-subjects ANOVA was conducted. Results revealed that participants did not persist differently after low fatigue ($M = 169.32$, $SD = 89.81$) than after high fatigue ($M = 159.59$, $SD = 85.77$), $F(1,32) = 0.57$, $p = .46$, $\eta^2 = 0.02$. Additionally, participants did not have lower pain thresholds after low fatigue ($M = 9.04$, $SD = 37.56$) than after high fatigue ($M = .748$, $SD = 31.41$), $F(1,32) = 0.72$, $p = .40$, $\eta^2 = 0.02$.

Main Effects of Inhibitory Strength Variables

The third set of hypotheses predicted that there would be main effects of the four measures of inhibitory strength on persistence and within-session changes in pain threshold. To test these effects, persistence and within-session changes in pain thresholds were averaged between low and high fatigue for each person. Linear regression was used to test these predictions. Results revealed that there were no main effects of any of the inhibitory strength variables on either persistence or within-session changes in pain thresholds (all *p*s >.10; see Table 3).

Table 3

Main Effects of Inhibitory Strength Variables on Persistence and Within-Session Changes in Pain Thresholds

| Predictor	Dependent Variable	R^2	β	$F(1,37)$	P
Baseline pain threshold					
	Persistence (sec)	.02	0.16	0.90	.35
	Within-session changes (kPa)	.01	0.08	0.24	.64
Self-regulatory ability					
	Persistence (sec)	.06	0.24	2.25	.14
	Within-session changes (kPa)	.01	-0.08	0.22	.64
Executive functioning					
	Persistence (sec)	.00	0.03	0.03	.86
	Within-session changes (kPa)	.04	0.20	1.42	.24
HRV					
	Persistence (sec)	.02	-0.14	0.76	.39
	Within-session changes (kPa)	.01	0.07	0.20	.66

Next, the main effects of the composite inhibitory strength variable were tested. Results revealed no significant main effects of composite inhibitory strength on persistence ($R^2 = .06$, $\beta = 0.23$, $F(1,37) = 2.08$, $p = .16$) or within-session changes in pain threshold ($R^2 = .00$, $\beta = 0.02$, $F(1,37) = 0.01$, $p = .91$).

Interaction of Fatigue Condition by Inhibitory Strength Variables

Using repeated measures ANCOVA, the next set of analyses tested whether measures of inhibitory strength moderated the relationships between fatigue condition and persistence or within-session change in pain threshold.
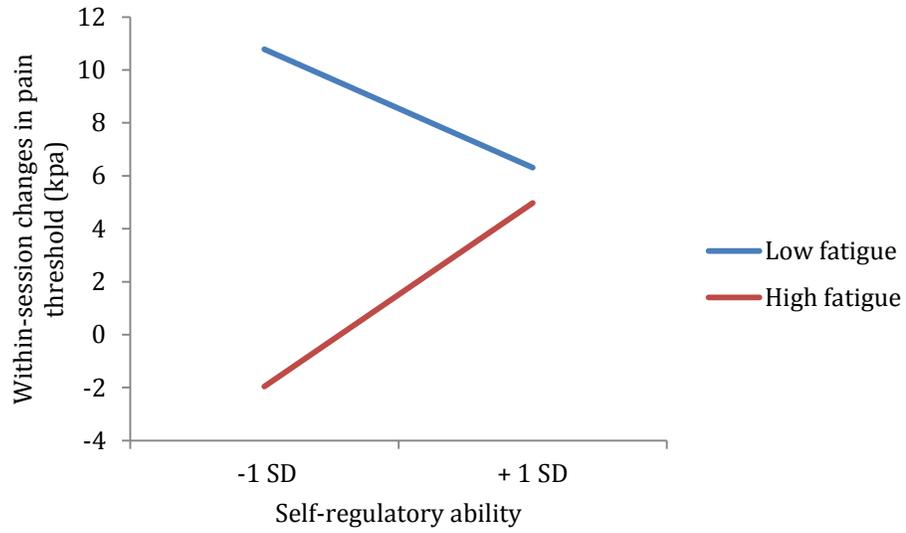
Individual differences in pain threshold tended to moderate the relationship between fatigue condition and persistence on the anagram task, $F(1,31) = 2.92$, $p = .10$, $\eta^2 = 0.09$. At low pain thresholds (-1 *SD*), people showed evidence of self-regulatory fatigue in that they tended to persist longer in the low fatigue than the high fatigue condition, $F(1,31) = 3.39$, $p = .08$, $\eta^2 = 0.10$. When people had high pain thresholds, they tended to be resistant to self-regulatory fatigue in that there was no difference between conditions at high levels of baseline pain threshold (+1 *SD*), $F(1,31) = 0.04$, $p = .85$, $\eta^2 = 0.00$. However, as shown in Figure 2, the performance of people with high pain thresholds in both conditions was approximately equal to that of people with low pain thresholds in the high fatigue condition. Baseline pain threshold did not significantly moderate the relationship between fatigue condition and within-session changes in pain thresholds, $F(1,31) = 1.68$, $p = .21$, $\eta^2 = 0.05$.

Figure 2

Interaction between Fatigue Condition and Baseline Pain Threshold in Predicting Persistence on an Anagram Task
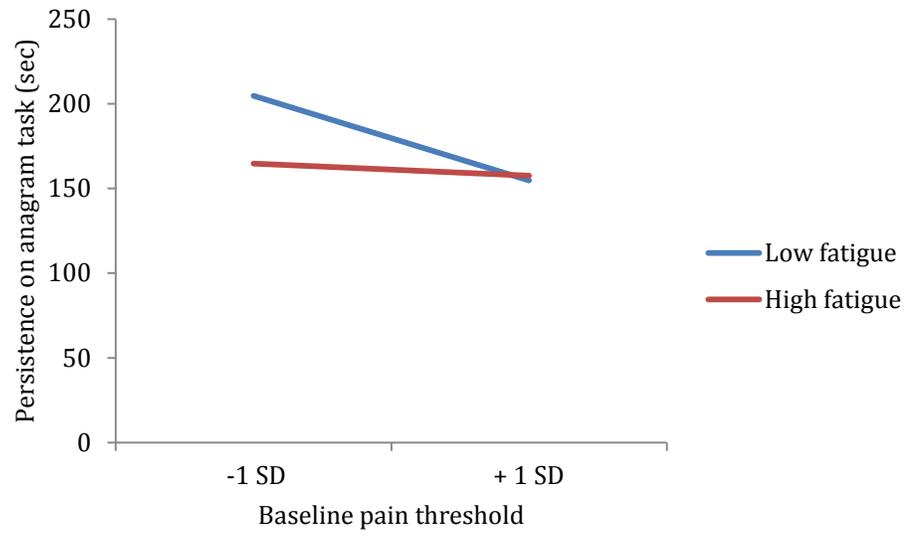
Individual differences in self-regulatory ability did not moderate the relationships between fatigue condition and persistence, $F(1,31) = 1.20$, $p = .28$, $\eta^2 = 0.04$, but tended to moderate the relationship between fatigue condition and within-session changes in pain thresholds, $F(1,31) = 2.92$, $p = .10$, $\eta^2 = 0.09$. Those with lower self-regulatory ability (-1 *SD*) experienced reductions in pain threshold as the session progressed ($F(1,31) = 1.68$, $p = .20$, $\eta^2 = 0.05$.) , whereas those with higher self-regulatory ability did not experience changes in pain threshold as a result of fatigue condition $F(1,31) = 0.02$, $p = .90$, $\eta^2 = 0.00$; see Figure 3.

Figure 3

Interaction between Fatigue Condition and Self-Regulatory Ability in Predicting Within-Session Changes in Pain Thresholds

Individual differences in executive functioning did not moderate either the relationship between fatigue condition and persistence, $F(1,31) = 1.39$, $p = .47$, $\eta^2 = 0.04$, or that between fatigue condition and within-session changes in pain thresholds $F(1,31) = 0.235$, $p = .63$, $\eta^2 = 0.01$.

Individual differences in HRV tended to moderate the relationship between fatigue condition and persistence, $F(1,31) = 2.37$, $p = .13$, $\eta^2 = 0.07$. Those with higher HRV (+1 *SD*) tended to persist more under low self-regulatory fatigue ($F(1,31) = 2.74$, $p = .11$, $\eta^2 = 0.08$), whereas those with lower HRV (-1 *SD*) persisted less regardless of fatigue condition ($F(1,31) = 0.52$, $p = .48$, $\eta^2 = 0.02$); see Figure 4. HRV did not significantly moderate the relationship between fatigue condition and within-session changes in pain thresholds, $F(1,31) = 0.00$, $p = .97$, $\eta^2 = 0.00$.

Figure 4

Interaction between Fatigue Condition and Heart Rate Variability in Predicting Persistence on an Anagram Task
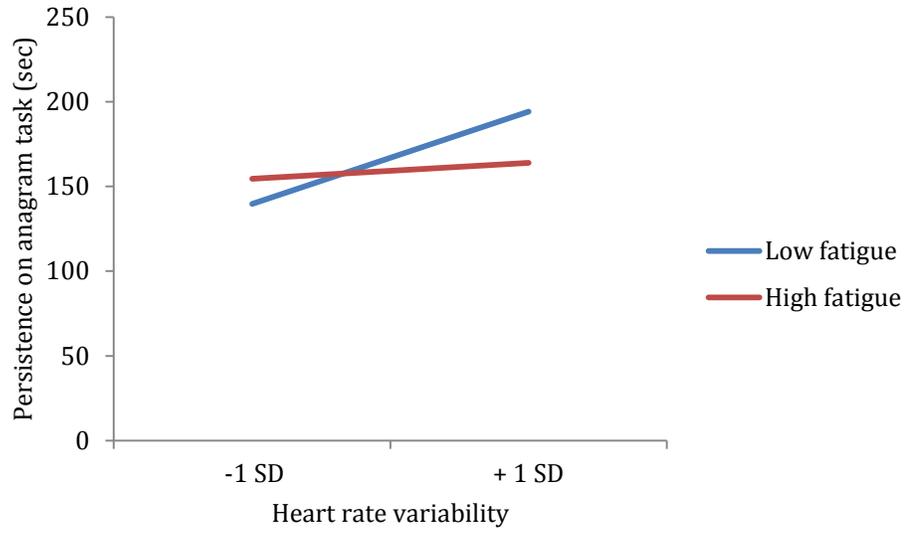
The composite inhibitory strength variable did not moderate the relationship between fatigue condition and persistence on the anagram task ($F(1,31) = 1.77$, $p = .19$, $\eta^2 = 0.05$), but significantly moderated the relationship between fatigue condition and within-session changes in pain thresholds ($F(1,31) = 4.52$, $p = .04$, $\eta^2 = 0.13$). Those low in inhibitory strength (-1 *SD*) became more sensitive to pain under conditions of self-regulatory fatigue ($F(1,31) = 5.02$, $p = .03$, $\eta^2 = 0.14$), whereas those high in inhibitory strength were protected against such decreases in pain thresholds (+1 *SD*; $F(1,31) = 1.08$, $p = .31$, $\eta^2 = 0.03$; see Figure 5).

Figure 5

Interaction between Fatigue Condition and Composite Inhibitory Strength in Predicting Within-Session Changes in Pain Thresholds
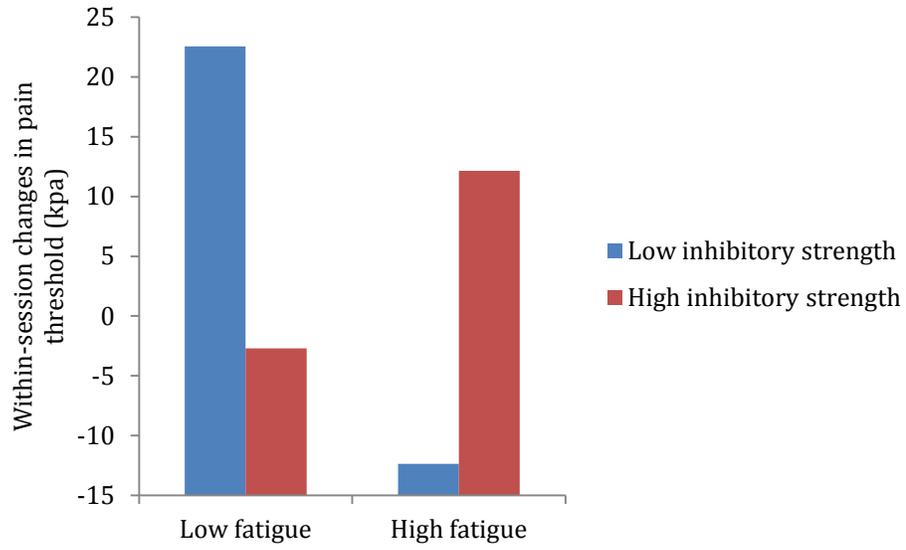
The Role of Gender as a Moderator

The final hypothesis was that gender would moderate the fatigue condition by inhibitory strength variable interactions described above in predicting persistence and within-session changes in pain thresholds.

As predicted, gender significantly moderated the fatigue condition by baseline pain threshold interaction in predicting persistence, $F(1,31) = 5.72$, $p = .02$, $\eta^2 = .16$. In males, the interaction between fatigue condition and baseline pain threshold was not significant, $F(1,12) = 0.02$, $p = .90$, $\eta^2 = 0.00$. In females, on the other hand, the relationship between fatigue condition and baseline pain threshold was marginally significant, $F(1,17) = 2.95$, $p = .10$, $\eta^2 = 0.148$. At low levels of baseline pain threshold (*-1SD*), women tended to persist longer in the anagram task under conditions of low self-regulatory fatigue ($F(1,17) = 2.10$, $p = .17$, $\eta^2 = 0.11$), whereas at high levels of baseline pain thresholds (+1*SD*) fatigue condition did not make a difference ($F(1,17) = 0.45$, $p = .51$, $\eta^2 = 0.03$). For a graphical representation of this three-way interaction, see Figure 6. No similar three-way interaction was found for within-session changes in pain thresholds, $F(1,31) = 0.76$, $p = .39$, $\eta^2 = 0.02$.

Figure 6.

Three-way Interactions between Gender, Fatigue Condition, and Baseline Pain Threshold in Predicting Persistence on an Anagram Task.
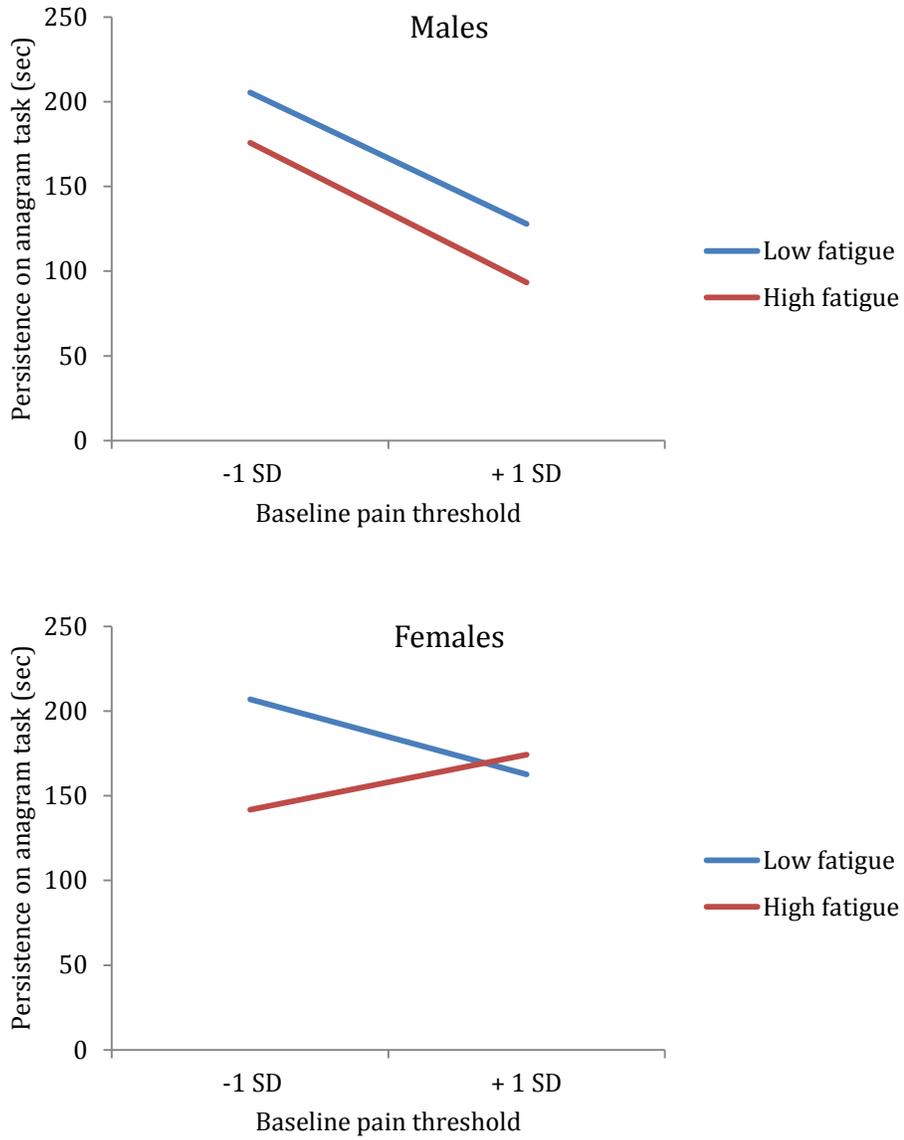
The three-way interaction between gender, self-regulatory ability, and fatigue condition was not significant in predicting persistence, $F(1,31) = 0.55$, $p = .46$, $\eta^2 = 0.00$, or within-session changes in pain thresholds, $F(1,31) = 1.19$, $p = .28$, $\eta^2 = 0.04$.

The three-way interaction of gender by fatigue condition by executive functioning in predicting persistence was not significant, $F(1,31) = 2.40$, $p = .13$, $\eta^2 = 0.07$, nor was a significant three-way interaction was found predicting within-session changes in pain thresholds, $F(1,31) = 0.05$, $p = .82$, $\eta^2 = 0.00$.

Further, there were no three way interactions of gender by HRV by fatigue condition for persistence, $F(1,31) = 0.84$, $p = .37$, $\eta^2 = 0.03$ or within-session changes in pain thresholds $F(1,31) = 0.99$, $p = .33$, $\eta^2 = .031$.

Finally, there were no significant three way interactions of gender by composite inhibitory strength by fatigue condition for persistence, $F(1,31) = 0.46$, $p = .50$, $\eta^2 = 0.02$ or within session changes in pain thresholds, $F(1,31) = 2.31$, $p = .14$, $\eta^2 = 0.07$.

Chapter Four: Discussion

Previous research has revealed that chronic pain patients, compared with normal controls, have diminished pain thresholds, self-regulatory strength, executive functioning, and autonomic inhibition. This evidence has led several authors to suggest that experiencing pain draws on psychological resources, and as such, those with chronic pain experience chronic self-regulatory fatigue. Because these four domains are controlled by overlapping brain areas, and because functioning in these domains all rely on physiological or psychological inhibition, I proposed an alternate explanation; namely, that people have a general inhibitory network and that poor functioning of such a network would manifest in reduced pain thresholds, self-regulatory strength, executive functioning, and autonomic inhibition.

Correlations among Inhibitory Strength Variables

A series of tests were conducted to test the assumptions of the general inhibitory strength framework. First, it was predicted that pain thresholds, self-regulation, executive functioning, and self-regulation would positively correlate with each other, as would be expected if the same network governed functioning across all four domains. The obtained results do not support the hypothesis. Although a significant correlation between pain threshold and HRV was obtained, there were no significant correlations among the other components of the model. The lack of correlation between self-regulation measures and executive functioning is not entirely surprising, and a recent meta-analysis of these measures revealed similar results, although the effect sizes in the current study were smaller (Duckworth & Kern, 2011).

It remains unclear whether the lack of correlations reflects shortcomings in the

constructs of self-regulation and/or executive functioning, or if they reflect shortcomings in the instruments used to assess them. In the current study, the executive functioning measures were performance-based, and a wide body of research suggests that these measures reliably assess the functions they are designed to measure (see Miyake et al., 2000, for a review). On the other hand, the self-regulation instruments used in the current study were entirely self-report; specifically, they asked participants to rate the extent to which specific behaviors have been problematic. Although previous research has validated these measures against objective outcomes such as life satisfaction, job performance, and physical health, among others (de Ridder et al., 2012), there is a dearth of research validating them for inhibitory strength. Several authors have challenged the validity of self-report measures, convincingly arguing that people have poor insight as to how or why they do things (Nisbett & Wilson, 1977). Thus, the lack of correlations could be a result of faulty constructs, faulty instruments to assess those constructs, or an inability of people to use those instruments appropriately. Those three explanations are not mutually exclusive, and future research should be geared toward helping refine- or if necessary, redefine- the construct of self-regulation.

The exception was the positive association between pain threshold and HRV. Of the four domains, these are the two that rely on physiological inhibitory strength; pain threshold indexes people's ability to inhibit ascending pain signals and HRV indexes people's ability to inhibit autonomic arousal. This relationship provides some support for the presence of a general inhibitory physiological network and is corroborated by previous research showing that interventions aimed at parasympathetic strength are beneficial to people experiencing chronic pain (Carlson et al., 2001). However, the link

between pain threshold and HRV remains equivocal. For example, Appelhans and

Luecken (2008) failed to find any correlation between high frequency HRV and pain

sensitivity to thermal pain, although they found moderate correlations between low

frequency HRV and pain. The authors speculated that low frequency HRV, which is

thought to index both sympathetic and parasympathetic activation, may be better

correlated with activity in affective brain areas involved in emotionality. The

relationships between HRV, pain threshold, and other physiological indexes in emotion

regulation- possibly by fMRI methodologies capable of detecting arousal in those brain

areas responsible for emotional arousal (i.e., the amygdala)- should be pursued in future

research.

Main Effects of Inhibitory Strength Variables

The next set of hypotheses sought to test the main effects of self-regulatory

fatigue and the four measures of inhibitory strength in predicting persistence and within-

session changes in pain thresholds. Although participants rated the video as more difficult

after the high self-regulatory fatigue condition than the low self-regulatory fatigue

condition, their persistence on the subsequent anagram task did not significantly differ

between conditions (although the means were in that direction, and the mean differences

were approximately 10 seconds). A recent meta-analysis of self-regulatory tasks revealed

that the video task used in the current experiment has some of the largest effect sizes of

any self-regulatory manipulations (Hagger et al, 2010). Despite these relatively large

effect sizes, experimental manipulations are expected to fail a substantial percentage of

the time based on chance alone (Francis, 2012).

The main effects of fatigue manipulation were also unsuccessful in generating

differences between conditions on within-session changes in pain thresholds.

Interestingly, results suggest that the means for within-session changes were in the

opposite direction than predicted; participants became *less* sensitive to pain as the session

progressed both in the high and low fatigue conditions. One possible explanation for this

effect is that the anagram task stressed participants, which potentially could have

increased tolerance to pain via a blood-pressure dependent baroreceptor reflex (Bruehl,

McCubbin, & Harden, 1999). Alternatively, participants could have been ruminating on

answers to the unsolvable anagram during the last pain threshold test, which would have

led to increased pain thresholds by way of distraction. In other words, by ruminating on

the anagrams, participants may have been paying less attention to pressing the stop button

at the precise moment when pressure first turned to pain. Results revealed no main effects

of any of the four inhibitory strength variables on persistence or within-session changes

in pain thresholds, failing to provide support for the general inhibitory hypotheses.

Particularly surprising is the lack of relationship between self-regulatory ability and

persistence, as this relationship has been found in other research (Baumeister et al.,

1998). The lack of association between HRV and persistence is also surprising given that

past research has found these effects (Segerstrom & Solberg-Nes, 2007).

Moderation by Inhibitory Strength Variables

Next, predictions were made regarding the role of the four measures of inhibitory

strength (pain threshold, self-regulatory ability, executive functioning, and HRV) in

moderating the relationships between fatigue condition and outcome variables. Under

conditions of low fatigue, it was expected that there would be a positive relationship

between persistence and each of the four inhibitory strength variables. Because it was

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expected that there would be no within-session changes in pain thresholds under conditions of low fatigue (there is no reason for it to change), no relations were expected with the inhibitory strength variables on this measure. If a general inhibitory system exists, then fatiguing this system should predict impaired outcomes. Thus, under conditions of high fatigue, it was expected that higher levels of the inhibitory strength variables would protect against the effects of self-regulatory fatigue. In other words, under high fatigue, participants with higher pain threshold, self-regulatory strength, executive functioning, and HRV were expected to be protected against subsequent impairment in performance compared to those with lower general inhibitory ability.

The obtained results provided mixed support for these hypotheses. As predicted, those low in inhibitory strength became more sensitive to pain under conditions of high self-regulatory fatigue than under conditions of low self-regulatory fatigue, whereas those higher in inhibitory strength were protected from fatigue-induced changes in pain sensitivity. These effects were only found using the composite variable, suggesting that a combination of inhibition variables better predicts changes in pain threshold variables than any one inhibitory variable alone. In fact, when measured individually, only some variables moderated the relationship between fatigue condition and persistence or within-session changes in pain thresholds.

First, baseline levels of HRV and baseline pain threshold interacted with fatigue condition to predict persistence in the anagram task. As predicted, in the low self-regulatory fatigue condition, those with higher levels of HRV predicted marginally longer than those with lower levels of HRV, although HRV did not influence persistence under conditions of high fatigue. In other words, as the general inhibitory system became taxed,

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persistence on the anagram task decreased, and these effects were seen only for those with higher levels of HRV. Those with lower levels of HRV performed as if they were under constant self-regulatory fatigue, as experiencing the fatigue manipulation did not further reduce their performance.

Alternatively, and contrary to predictions, the opposite effects were found for pain thresholds. Those with lower pain thresholds exhibited greater persistence under conditions of low self-regulatory fatigue, while those with higher pain threshold performed similarly under high and low fatigue. This effect was moderated by gender. Males persisted more under conditions of low self-regulatory fatigue, and higher pain thresholds were associated with greater persistence in under both high and low self-regulatory fatigue. In females, however, low self-regulatory fatigue was associated with greater persistence only at low levels of baseline pain thresholds. At higher pain thresholds, there were no impact of fatigue. The results suggest that pain thresholds may be partly explained by trait levels of conscientiousness, which others have found to be higher in women than in men (Costa, Terracciano, & McCrae, 2001). Those who are high in dutifulness, achievement striving, and self-discipline are more careful at following the instructions of pressing the stop button "immediately when the pressure turns to pain." Such a tendency would manifest in lower pain thresholds. However, these same characteristics probably also make people better able to persist in the anagram task. Thus, the observed results may be a function of personality differences, and may not represent a fundamental flaw in the general inhibitory strength model. To test this possibility, future research should repeat the current study while factoring out variance due to personality.

Results also showed that self-regulatory ability interacted with fatigue condition

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to predict within-session changes in pain thresholds. Under conditions of low fatigue, greater self-regulatory ability was associated with smaller within-session increases in pain thresholds. Under conditions of high fatigue, those with lower self-regulatory ability became more sensitive to pain, as predicted. These findings provide some support for the general inhibitory system framework because it shows that those with lower self-regulatory ability are less able to inhibit pain after that inhibitory system has become fatigued by self-regulatory tasks.

Limitations

The current study is not without limitations. First, the participants in the study were all undergraduate college students without a history of chronic pain, and as such, the results may not generalize to chronic pain populations who are known to have altered pain regulatory systems (Bruehl et al., 1999). Second, self-regulation required overcoming a dominant response, and no measure was taken to assess the participant's motivations to refrain from looking at the words during the video task. Finally, the self-regulation measures used to assess self-regulatory ability were self-report based and may not validly detect individual differences in behavioral inhibition.

Conclusions

In conclusion, the current study sought to test an alternative explanation of the relationships between pain threshold, self-regulatory ability, executive functioning, and autonomic inhibition by arguing that they are all reflective of the same general inhibitory system. Tests of this hypothesis, both by correlational data and experimental manipulation of self-regulatory fatigue, provide mixed support for this conclusion. Results suggest that there may be a general physiological inhibitory system which

controls pain inhibition and autonomic inhibition, and that this system is non-overlapping with a psychological inhibitory system. Our results further suggest that more work needs to be done in refining the construct of, and measurement tools used to assess, self-regulation.

Appendix A: Demographics

Age: _____

Sex: _____ Male   _____ Female

Height: _____ Feet _____ Inches

Weight: _____ Pounds

Race: _____African American

_____ Asian

_____ Alaska Native

_____ American Indian

_____ Hispanic

_____ Native Hawaiian

_____ White

Relationship Status: _____ Single
_____ In a Relationship
_____ Married
_____ Divorced
_____ Widowed

Appendix B: Positive and Negative affect Schedule

This scale consists of a number of words and phrases that describe different feelings and emotions. Read each item and then mark the appropriate answer in the space next to that word. Indicate to what extent you feel this way *right now*. Use the following scale to record your answers:

1 very slightly or not at all	2 a little	3 moderately	4 quite a bit	5 extremely

1. _____ attentive

2. _____ sluggish

3. _____ strong

4. _____ irritable

5. _____ inspired

6. _____ afraid

7. _____ tired

8. _____ alert

9. _____ upset

10. _____ active

11. _____ guilty

12. _____ nervous

13. _____ sleepy

14. _____ excited

15. _____ hostile

16. _____ proud

17. _____ jittery

18. _____ ashamed

19. _____ scared

20. _____ drowsy

21. _____ enthusiastic

22. _____ distressed

23. _____ determined

24. _____ frightened

25. _____ interested

26. _____ concentrating

References

Affleck, G., Urrows, S., Tennen, J., Higgins, P., Pav, D., & Aloisis, R. (1997). A dual pathway model of daily stressor effects on rheumatoid arthritis. *Annals of Behavioral Medicine, 19,* 161-170.

Ahern, G. L., Sollers, J. J., Lane, R. D., Labiner, D. M., Herring, A. M., Weinand, M. E., Hutzler, R., et al. (2001). Heart rate and heart rate variability changes in the intracarotid sodium amobarbital test. *Epilepsia, 42,* 912-921.

Appelhans, B. M., & Luecken, L. J. (2008). Heart rate variability and pain: Association of two interrelated homeostatic processes. *Biological Psychology, 77,* 174-182.

Arango, M. A., & Cano, P. O. (1998). A potential moderating role of stress in the association of disease activity and psychological status among patients with rheumatoid arthritis. *Psychological Reports, 83,* 147-157.

Arbuthnott, K., & Frank, J. (2000). Trail making test, part B as a measure of executive control: Validation using a set-switching paradigm. *Journal of Clinical and Experimental Neuropsychology, 22,* 518-528.

Baumeister, R. F., Bratslavsky, E., Muraven, M., & Tice, D. M. (1998). Ego depletion: Is the active self a limited resource? *Journal of Personality and Social Psychology, 74,* 1252-1265.

Bingel, U., & Tracey, I. (2008). Imaging CNS modulation of pain in humans. *Physiology, 23,* 371-380.

Boggio, P. S., Zaghi, S., Lopes, M., & Fregni, F. (2008). Modulatory effects of anodal transcranial direct current stimulation on perception and pain thresholds in healthy volunteers. *European Journal of Neurology, 15,* 1124-1130.

Brennum, J., Kjeldsen, M., Jensen, K., & Jensen, T. S. (1989). Measurement of human pressure-pain thresholds on fingers and toes. *Pain, 38,* 211-217.

Bruehl, S., Carlson, C. R., & McCubbin, J. A. (1992). The relationship between pain sensitivity and blood pressure in normotensives. *Pain, 48,* 463-467.

Bruehl, S., McCubbin, J. A., & Harden, R. N. (1999). Theoretical review: altered pain regulatory systems in chronic pain. *Neuroscience & Biobehavioral Reviews*, *23*(6), 877-890.

Burns, J. W., Quartana, P. J., & Bruehl, S. (2008). Anger inhibition and pain: Conceptualizations, evidence, and new directions. *Journal of Behavioral Medicine, 31,* 259-279.

Carlson, C. R., Bertrand, P. M., Ehrlich, A. D., Maxwell, A. W., & Burton, R. G. (2001). Physical self-regulation training for the management of temporomandibular disorders. *Journal of Orofacial Pain, 15,* 47-55.

Cohen, H., Neumann, L., Shore, M., Amir, M., Cassuto, Y., & Buskila, A. (2000). Autonomic dysfunction in patients with fibromyalgia: Application of power spectral analysis of heart rate variability. *Seminars in Arthritis and Rheumatism, 29,* 217-27.

Connelly, M., Bromberg, M. H., Anthony, K. K., Gil, K. M., Franks, L., & Schanberg, L. E. (2012). Emotion regulation predicts pain and functioning in children with juvenile idiopathic arthritis: An electronic diary study. *Journal of Pediatric Psychology, 37*, 43-52.

Costa, P. T., Terracciano, A., & McCrae, R. R. (2001). Gender differences in personality traits across cultures: Robust and surprising findings. *Journal of Personality and*

Social Psychology, 81(2), 322-331.

De Ridder, D. T. D., Lensvelt-Mulders, G., Finkenauer, C., Stok, F. M., & Baumeister, R. F. (2012). Taking stock of self-control: A meta-analysis of how train self-control relates to a wide range of behaviors. *Personality and Social Psychology Review, 16,* 76-99.

Duckworth, A. L., & Kern, M. L. (2011). A meta-analysis of the convergent validity of self-control measures. *Journal of Research in Personality, 45,* 259-268.

Edwards, R. R., Ness, T. J., Weigent, D. A., & Fillingim, R. B. (2003). Individual differences in diffuse noxious inhibitory controls (DNIC): Association with clinical variables. *Pain, 106,* 427-437.

Fillingim, R. B., & Maixnert, W. (1995). Gender differences in the responses to noxious stimuli. *Pain Forum, 4,* 209-221.

Francis, G. (2012). Publication bias and the failure of replication in experimental psychology. *Psychonomic Bulletin & Review*, *19*(6), 975-991.

Fullbright, R. K., Troche, C. J., Skudlarski, P., Gore, J. C., & Wexler, B. E. (2001). Functional MR imaging of regional brain activation associated with the affective experience of pain. *American Journal of Roentgenology, 177*(5), 1205-1210.

Giesecke, T., Williams, D. A., Harris, R. E., Cupps, T. R., Tian, X., Tian, T. X., Gracely, R. H., et al. (2003). Subgrouping of fibromyalgia patients on the basis of pressure-pain thresholds and psychological factors. *Arthritis & Rheumatism, 48,* 2916-2922.

Gioia, G. A., Isquith, P. K., & Kenealy, L. E. (2008). Assessment of behavioral aspects of executive function. In V. Anderson, R. Jacobs, & P. J. Anderson (Eds.), *Executive Functions and the Frontal Lobes: A Lifespan Perspective* (pp. 179-202), New York, NY: Taylor & Francis.

Giovagnoli, A. R., Del Pesce, M., Mascheroni, S., Simoncelli, M., Laiacona, M., & Capitani, E. (1996). Trail making test: Normative values from 287 normal adult controls. *The Italian Journal of Neurological Sciences, 17*(4), 305-309.

Goodin, B. R., McGuire, L., Allshouse, M., Stapleton, L., Haythornthwaite, J. A., Burns, N., Mayes, L. A., et al. (2009). Associations between catastrophizing and endogenous pain-inhibitory processes: Sex differences. *The Journal of Pain, 10,* 180-190.

Gross, J. J. & John, O. P. (2003). Individual differences in two emotion regulation processes: Implications for affect, relationships, and well-being. *Journal of Personality and Social Psychology, 85,* 348-362.

Hagger, M. S., Wood, C. W., Stiff, C., & Chatzisarantis, N. L. D. (2010). Ego depletion and the strength model of self-control: A meta-analysis. *Psychological Bulletin,* 136, 495-525.

Hardy, J. (2012). Examining the deficits of self-regulation in those with chronic physical pain and chronic social pain. *Unpublished dissertation.*

Heatherton, T. F., & Wagner, D. D. (2011). Cognitive neuroscience of self-regulation failure. *Trends in Cognitive Sciences, 15,* 132-139.

Hofbauer, R. K., Rainville, P., Duncan, G. H., & Bushnell, M. C. (2001). Cortical representation of the sensory dimension of pain. *Journal of Neurophysiology, 86*, 402-411.

Jensen, K. B., Kosek, E., Wicksell, R., Kemani, M., Olsson, G., Merle, J. V., Kadetoff,

D., & Ingvar, M. (2012). Cognitive behavioral therapy increases pain-evoked activation of the prefrontal cortex in patients with fibromyalgia. *Pain, 153,* 1459-1503.

Kane, M. J., Brown, L. H., McVay, J. C., Silvia, P. J., Myin-Germeys, I., & Kwapil, T. R. (2007). For whom the mind wanders, and when: An experience-sampling study of working memory and executive control in daily life. *Psychological Science, 18,* 614-621.

Karp, J. F., Reynolds, C. F., Butters, M. A., Dew, M. A., Mazumdar, S., Beglet, A. E., Lenze, E., et al. (2006). The relationship between pain and mental flexibility in older adult pain clinic patients. *Pain Medicine, 7,* 444-452.

Katz, R. S. (2004). The prevalence and clinical impact of reported cognitive difficulties (fibrofog) in patients with rheumatic disease with and without fibromyalgia. *Journal of Clinical Rheumatology, 10,* 53-58.

Kong, J., Gollub, R. L., Rosman, I. S., Webb, J. M., Vangel, M. G., Kirsch, I., & Kaptchuk, T. J. (2006). Brain activity associated with expectancy-enhanced placebo analgesia as measured by functional magnetic resonance imaging. *The Journal of Neuroscience, 26,* 381-388.

Kortte, K. B., Horner, M. D., & Windham, W. K. (2002). The trail making test, part B: Cognitive flexibility or ability to maintain a mental set? *Applied Neuropsychology, 9,* 106-109.

Landro, N. I., Stiles, T. C., & Sletvold, H. (1997). Memory functioning in patients with primary fibromyalgia and major depression and healthy controls. *Journal of Psychosomatic Research, 42,* 297-306.

Lautenbacher, S., Prager, M., & Rollman, G. B. (2007). Pain additivity, diffuse noxious inhibitory controls, and attention: A functional measurement analysis. *Somatosensory and Motor Research, 24,* 189-201.

Lefaucheur, J. P. (2008). Use of repetitive transcranial magnetic stimulation in pain relief. *Expert Review in Neurotherapeutics, 8,* 799-808.

Levine, F. M., & Simone, L. L. D. (1991). The effect of experimenter gender on pain report in male and female subjects. *Pain, 44,* 69-72.

Lorenz, J., Minoshima, S., & Casey, K. L. (2003). Keeping pain out of mind: The role of the dorsolateral prefrontal cortex in pain modulation. *Brain, 126,* 1079-1091.

MacDonald, G., & Leary, M. R. (2005). Why does social exclusion hurt? The relationship between social and physical pain. *Psychological Bulletin, 131,* 202-223.

Martinez-Lavin, M., Hermosillo, A. G., Rosas, M., & Soto, M. E. (1998). Circadian studies of autonomic nervous balance in patients with fibromyalgia: A heart rate variability analysis. *Arthritis & Rheumatism, 41,* 1966-1971.

Mather, M., & Knight, M. (2005). Goal-directed memory: The role of cognitive control in older adults' emotional memory. *Psychology and Aging, 20,* 554-570.

Matthews, S.C., Paulus, M.P., Simmons, A.N., Nelesen, R.A., & Dimsdale, J.E. (2004). Functional subdivisions within anterior cingulate cortex and their relationship to autonomic nervous system function. *Neuroimage, 22*, 1151-1156.

Melzack, R., & Casey, K. L. (1968). Sensory, motivational, and central control determinants of pain. In D. R. Kenshalo (Ed.) *The skin senses* (pp. 423-443). Springfield, IL: Charles C. Thomas Press.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49-100.

Muraven, M., & Baumeister, R. F. (2000). Self-regulation and depletion of limited resources: Does self-control resemble a muscle? *Psychological Bulletin, 126,* 247-259.

Muraven, M., Shmueli, D., & Burkley, E. (2006). Conserving self-control strength. *Journal of Personality and Social Psychology, 91,* 524-537.

Nahmias, F., Debes, C., de Andrade, D. C., Mhalla, A., & Bouhassira, D. (2009). Diffuse analgesic effects of unilateral repetitive transcranial magnetic stimulation (rTMS) in healthy volunteers. *Pain, 147,* 224-232.

Nisbett, R. E., & Wilson, T. D. (1977). Telling more than we can know: Verbal reports on mental processes. *Psychological Review, 84*(3), 231-261.

Oosterman, J. M., Dijkerman, H. C., Kessels, R. P. C., & Scherder, E. J. A. (2010). A unique association between cognitive inhibition and pain sensitivity in healthy participants. *European Journal of Pain, 14,* 1046-1050.

Park, D. C., Glass, J. M., Minear, M., & Crofford, L. J. (2001). Cognitive function in fibromyalgia patients. *Arthiritis & Rheumatism, 44,* 2125-2133.

Price, D. D. (1999). *Psychological Mechanisms of Pain and Analgesia.* Seattle, WA: I.A.S.P. Press.

Price, D. D. (2000). Psychological and neural mechanisms of the affective dimension of pain. *Science, 288,* 1769-1772.

Reitan, R. M. (1958). Validity of the trail making test as an indicator of organic brain damage. *Perceptual and Motor Skills, 8,* 271-276.

Rosen, A. C., Ramkumar, M., Nguyen, T., & Hoeft, F. (2009). Noninvasive transcranial brain stimulation and pain. *Current Pain Headache Report, 13,* 12-17.

Roth, R. M., Isquith, P. K., & Gioia, G. A. (2005). *Behavior Rating Inventory of Executive Function- Adult Version.* Lutz, FL: Psychological Assessment Resources.

Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology: General, 132*(4), 566-595.

Schmeichel, B. J. (2007). Attention control, memory updating, and emotion regulation temporarily reduce the capacity of executive control. *Journal of Experimental Psychology: General, 136,* 241-255.

Schmidt, J., & Carlson, C. R. (2009). A controlled comparison of emotional reactivity and physiological responses in masticatory muscle pain patients. *Journal of Orofacial Pain, 23,* 230-242.

Schoenen, J., Bottin, D., Hardy, F., & Gerard, P. (1991). Cephalic and extracephalic pressure pain thresholds in chronic tension-type headache. *Pain, 47,* 145-149.

Schoofs, D., Wolf, O. T., & Smeets, T. (2009). Cold pressor stress impairs performance on working memory tasks requiring executive functions in healthy young men. *Behavioral Neuroscience, 123,* 1066-1075.

Schroeder, R. W., Twumasi-Ankrah, P., Baade, L. E., & Marshall, P. S. (2012). Reliable digit span: A systematic review and cross-validation study. *Assessment, 19,* 21-30.

Segerstrom, S.C., Hardy, J.K., Evans, D.R., & Winters, N.F. (2011). "Pause and plan": Self-regulation and the heart. In G. Gendolla & R. Wright (Eds.), *Motivational Perspectives on Cardiovascular Response* (pp. 181-198). Washington, DC: American Psychological Association.

Segerstrom, S. C., & Solberg Nes, L. (2007). Heart rate variability reflects self-regulatory strength, effort, and fatigue. *Psychological Science, 18,* 275-281.

Small, D. M., Zatorre, R. J., Dagher, A. C., Evans, A. C., & Jones-Gotman, M. (2001). Changes in brain activity related to eating chocolate: From pleasure to aversion. *Brain, 124,* 1720-1733.

Solberg Nes, L., Carlson, C. R., Crofford, L. J., de Leeuw, R., & Segerstrom, S. C. (2010). Self-regulatory deficits in fibromyalgia and temporomandibular disorders. *Pain, 151,* 37-44.

Solberg Nes, L., Roach, A. R., & Segerstrom, S. C. (2009). Executive functions, self-regulation, and chronic pain: A review. *Annals of Behavioral Medicine, 37,* 173-183.

Solberg Nes, L., Segerstrom, S. C., & Sephton, S. E. (2005). Engagement and arousal: Optimism's effects during a brief stressor. *Personality and Social Psychology Bulletin, 31,* 111-120.

Staud, R., Price, D. D., Robinson, M. E., Mauderli, A. P., & Vierck, C. J. (2004). Maintenance of windup of second pain requires less frequent stimulation in fibromyalgia patients compared to normal controls. *Pain, 110,* 689-696.

Staud, R., Robinson, M. E., & Price, D. D. (2005). Isometric exercise has opposite effects on central pain mechanisms in fibromyalgia patients compared to normal controls. *Pain, 118,* 176-184.

Tangney, J., Baumeister, R. F., & Boone, A. L. (2004). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *Journal of Personality, 72,* 271-324.

Taylor, J. J., Borckardt, J. J., & George, M. S. (2012). Endogenous opioids mediate left dorsolateral prefrontal cortex rTMS-induced analgesia. *Pain, 153,* 1219-1225.

Towse, J. N., & Neil, D. (1998). Analyzing human random generation behavior: A review of methods used and a computer program for describing performance. *Behavior Research Methods, Instruments, & Computers, 30*, 583-591.

Van Wijk, G., & Veldhuijzen, D. S. (2010). Perspective on diffuse noxious inhibitory controls as a model of endogenous pain modulation in clinical pain syndromes. *The Journal of Pain, 11,* 408-419.

Vohs, K. D., Baumeister, R. F., Mead, N. L., Ramanathan, S., & Schmeichel, B. J. (2012). Engaging in self-control heightens urges and feelings. *Unpublished raw data.*

Vohs, K. D., Baumeister, R. F., Schmeichel, B. J., Twenge, J. M., Nelson, N. M., & Tice, D. M. (2008). Making choices impairs subsequent self-control: A limited-resource account of decision making, self-regulation, and active initiative. *Journal of Personality and Social Psychology, 94,* 883-898.

Watson, D., & Clark, L. A. (1999). The PANAS-X: Manual for the positive and negative affect schedule – expanded form. *Iowa Research Online.* Retrieved May 21, 2012 from http://ir.uiowa.edu/psychology_pubs/11.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief

measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54,* 1063-1070.

Weissman-Fogel, I., Sprecher, E., & Pud, D. (2008). Effects of catastrophizing on pain perception and pain modulation. *Experimental Brain Research, 186,* 79-85.

Wiseman, R. W., Beck, T. W., & Chase, P. B. (1996). Effect of intracellular pH on force development depends on temperature in intact skeletal muscle from mouse. *American Journal of Physiology, 271,* 878-886.

Wong, S.W., Masse, N., Kimmerly, D.S., Menon, R.S., & Shoemaker, J.K. (2007). Ventral medial prefrontal cortex and cardiovagal control in conscious humans. *Neuroimage, 35*, 698-70.

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20848-20852.

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