THE EFFECTS OF INDUCED PAIN ON MEASURES OF EXECUTIVE FUCTIONING

by

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A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Arts
with a Major in Psychological Research
August 2017

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ACKNOWLEDGEMENTS

I would like to thank Dr. Etherton for seeing my potential and working closely with me in producing this thesis.

I would also like to take this opportunity to thank my committee members, Dr. Oberle, and Dr. Tooley for their insightful contributions to forming this thesis.

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LIST OF ABBREVIATIONS

Abbreviation	Description
D-KEFS	Delis-Kaplan Executive Function System
PCS	Pain Catastrophizing Scale
CWIT	Color Word Interference Test
TM	Trail Making Test
VF	Verbal Fluency Test
FMP	Fibromyalgia Patients
PVAQ	Pain Vigilance and Awareness Questionnaire
fMRI	Functional Magnetic Resonance Imaging
NCSE	.Neurobehavioral Cognitive Status Examination
DN4	Douleur Neuropathique 4
BPI	Brief Pain Inventory
PSI	Processing Speed Index
WMI	Working Memory Index
WAIS-IV	Wechsler Adult Intelligence Scale
VCI	Verbal Comprehension Index
PRI	Perceptual Reasoning Index
TBI	Traumatic Brain Injury

ABSTRACT

Cognitive complaints are frequently reported by patients with chronic pain, but studies of the effects of pain on different forms of cognition have reported inconsistent findings. In two studies, cold-pressor pain was induced in nonclinical undergraduate volunteers who, under normal conditions, completed the color word interference subtest (CWIT), trail making subtest (TM) and verbal fluency subtests (VF) of the Delis Kaplan Executive Functions System battery (D-KEFS), followed by same or alternate D-KEFS subtests taken during either cold-pressor pain induction or a non-painful control condition. Included in this two part study was the presence of a simulator group which was instructed to convincingly simulate cognitive impairment. Only those participants who attempted to appear impaired demonstrated significantly poorer performances. These results indicate that induced pain is not associated with poor performance on tasks associated with these D-KEFS subtests, but may be associated with deficit exaggeration or other factors. Generalizability of these findings may be limited by the fact that patients with chronic pain may differ in their pain experience from nonclinical volunteers with induced pain.

I. INTRODUCTION

The potential effects of pain on cognition has been a topic of interest for many years. The existing literature is inconsistent regarding whether pain interferes with various cognitive functions. For example, patients with chronic pain report cognitive complaints including forgetfulness, poor concentration, and memory retrieval problems (Iverson & McCraken, 1997). Alternatively, cold pressor induced pain on healthy volunteers does not impair processing speed or working memory index performance as measured by the WAIS-IV (Etherton, 2013). According to one influential model, cognitive complaints by chronic pain patients (mentioned above) are assumed to be the result of pain; pain distracts, interrupts attention, and is difficult to disengage from. Since attentional processing is interrupted by pain, pain can cause a decline in performance for some cognitive tasks (Eccleston & Crombez, 1999). This view would suggest that chronic pain could cause impaired performance on neuropsychological measures as a result of its disruptive nature on a variety of cognitive functions.

II. LITERATURE REVIEW

Psychosocial Factors of Chronic Pain

Chronic pain is defined as long-term pain in the head, face, limbs, chest, abdomen, or low back; long term is any pain lasting more than 12 weeks (3 months) and generally persists even longer (Blyth et al., 2001: Merskey, 1986). Studies and review articles have established that chronic pain is frequently accompanied by emotional distress. Specific symptoms, like sleep disturbance (Hart, Wade, & Martelli, 2003), poorer health and greater perceived stress (Rintala, Loubser, Castro, Hart, & Fuhrer, 1998), and such negative emotions as fear, anger, anxiety, and depression (Gatchel, Peng, Peters, Fuchs, & Turk, 2007), are commonly found in chronic pain patients. Overall, chronic pain findings and the symptoms associated with it, suggest that pain-related stress and negative emotions influence cognitive functioning independently from the effects of pain intensity (Hart, Wade, & Martelli, 2003). Chronic pain contains many psychological problems which are associated with its diagnosis.

Gatchel (2004) describes the toll that chronic pain takes on emotions and psychological systems. Gatchel states that suffering and dysfunction are perpetuated through chronic pain because the pain produces stress. This stress weighs on the immune system, creating an increased likelihood for illness and compounding the problem of pain. Also, the two major neurotransmitters in mood disorders, norepinephrine and serotonin, are involved while experiencing pain (Gatchel, 2004). Because pain affects these neurotransmitters it allows for pain to influence mood. Chronic pain is commonly co-diagnosed with affective disorders, anxiety disorders, and substance abuse disorders (Dersh, Polatin, & Gatchel, 2002). This further supports the idea that psychological and

emotional factors may play a prominent role in chronic pain patients, beyond the direct effects of pain itself.

Further muddying the effects of chronic pain, a study investigating fear and attention levels during pain of chronic pain patients found that increased fear towards pain correlated with more intense feelings of pain (Crombez, Viane, Eccleston, Devulder, & Goubert, 2013). The majority of participants reported that their pain started gradually. Nearly half of the participants reported using pain medication three or more times a day. These participants were instructed to carry around an electronic palmtop computer for two weeks. Eight participants randomly selected times each day the computer would beep and the participant would complete a diary entry. The diary entry used the Pain Vigilance and Awareness Questionnaire (PVAQ; McCracken, 1997), using a 7 point Likert scale. The PVAQ measures pain intensity, attention to pain measures, fearful thinking about pain, and positive and negative affect. Fear can cause a stronger than normal intensity rating of pain. A positive finding of the study was that when a participant was feeling good, they attended less to pain. Attention to pain should be considered dynamic because pain is a relatively stable state while the attention to pain by the patient is constantly shifting. The more attention given to pain, the stronger the intensity. This supports the idea that emotional states may influence pain through attention regulation (Crombez et al., 2013).

Furthermore, chronic pain research has shown that risky and emotional decisions are interpreted as more difficult by the pain patient (Apkarian, Sosa, Krauss, Thomas, Fredrickson, Levy, & Chialvo, 2004). With this conclusion they used the Iowa Gambling Task (Bechara, Damasio, Damasio, & Anderson, 1994) to test emotional decision-making

ability between chronic pain patients and healthy volunteer controls. They found that chronic pain is associated with cognitive decline especially during risk taking situations (Apkarian et al., 2004). While emotional decision making is associated with chronic pain, there are also many other psychosocial factors influencing the performance of chronic pain patients.

Along with psychological and emotional problems, chronic pain is a major drain on societal resources and productivity; pain costs 70 billion dollars and affects over 50 million Americans annually (Gatchel, 2004). This is a major use of medical resources devoted just towards chronic pain patients. Chronic pain also elicits a fear and harm avoidance response from the individual experiencing the pain, which may cause them to try to escape and avoid risk and risky situations. This will typically follow with protective and passive behaviors induced by fear, which can affect work and productivity (Turk & Okifuji, 2002). Chronic pain is a major concern because not only does it use a large amount of medical resources but it also causes the inability of chronic pain patients to work. Besides concerns of loss of productivity, chronic pain has been associated with impairment on several different cognitive tasks.

Cognitive Impairment with Chronic Pain

Pain has been associated with impairment on several different cognitive tasks. One study found that chronic non-malignant pain patients showed slower reaction times in oddball detection than those who have taken opioids alleviating them from their pain and stress (Lorenz, Beck, & Bromm, 1997). The Auditory Oddball Task is an auditory repeated sequence of tones that uses baseline tones of 500 Hertz (Hz) and oddball tones of 1000 Hz. The participant listens for the 1000 Hz and responds by pressing a button

whenever they hear the “oddball” 1000 Hz tone. This method investigates dysfunctions in sensory and cognitive processing (Williams, Simms, Clark, & Paul, 2005). When considering morphine-induced sedation it was expected that cognitive performance would decline; however, cognitive performance improved. This suggests chronic pain acts as a distractor, and has a negative effect on cognitive processing (Lorenz, Beck, & Bromm, 1997).

Chronic pain can also affect verbal reaction time, verbal working memory, and spatial working memory; patients with chronic whiplash- associated disorder were compared to matched healthy controls on a cognitive test battery (Antepohl, Kiviloog, Andersson, & Gerdle, 2003). This battery included the testing of verbal and spatial, reaction time and working memory to make 4 testing categories (verbal reaction time, spatial reaction time, verbal working memory, & spatial working memory). For the verbal reaction time task, those taking the test would respond to a three-letter stimulus as either being a word or not (Ronnberg, Arlinger, Lyxell, & Kinnefors, 1989). In the spatial reaction time task, participants judged if a non-meaningful figure was mirror rotated or not (Shepard & Metzler, 1992). For the verbal working memory task, there were two sentences comprised of three words increasing to eight words presented, and the participant had to remember either the first or last word of each sentence (Baddeley, Logie, Nimmo-Smith, & Brereton, 1985). The spatial working memory task tested the participant’s ability to recall the order of symbol movements of 10 white or black common geometrical shapes, which individually moved every one second, on either a horizontal or vertical axis. Participants would verify the move by pressing the corresponding directional key on their keyboard. After the movements were made,

participants were given a start sheet and had to recall all the individual movements made from each shape (Engle, 2002). Pain levels were reported before testing and in between each subtest on a visual analogue scale. Chronic pain patients performed poorly compared to healthy controls, especially on working memory tasks. Verbal reaction times were significantly worse for chronic pain patients. The more pain the participant reported, the worse the performance was during the verbal reaction task. The findings support the hypothesis that pain might be an important factor leading to cognitive impairment, specifically with verbal reaction time, verbal working memory, and spatial working memory (Antepohl et al., 2003).

The potential effect of fibromyalgia-related chronic pain on response inhibition, a cognitive function typically measured via a go/no go task, was evaluated by comparing a sample of fibromyalgia patients (FMP) with a healthy control group, with both groups undergoing functional magnetic resonance imaging (fMRI) (Glass, Williams, Fernandez-Sanchez, Kairys, Barjola, Heitzeg, & Schmidt-Wilcke, 2011). The go/ no go task is a test of response inhibition which involves speeded reactions, which are usually key presses as response stimuli. During the Go trials, participants are required to respond as quickly as possible to a "Go" stimulus. They are also required to refrain from responding during a "No Go" stimulus. Since the Go trials are more numerous than the No Go trials, there is a prepotency built up to respond which the participant has to randomly inhibit (Heitzeg, Nigg, Yau, Zucker, & Zubieta, 2010). No significant performance difference was observed in either reaction time or accuracy between FMP and healthy controls. The fMRI's of the FMP revealed lower activation in the midcingulate cortex, supplementary motor area, putamen, and right premotor cortex. Therefore, FMP showed less brain

activation of areas involved with inhibition and attention while simultaneously showing increased activation of brain areas not normally part of the inhibition network (Glass et al., 2011) Glass and other researchers suggest that inhibition and pain processing may use overlapping networks; so if the pain process is taking up resources then there may be less resources available for other processes.

A systematic review conducted by Berryman, Staton, Tabor, Mcfarlane, and Moseley (2013) of 24 separate published studies of working memory performance in chronic pain included nine different chronic pain populations. In 23 of the 24 studies examined, they found that people who endure chronic pain perform more poorly on measures of working memory than healthy control patients. A consistent significant moderate effect was found of worse working memory performance by those experiencing chronic pain (Berryman et al., 2013). Despite research suggesting pain as impairs cognitive function in chronic pain patients, there are still reasons to question whether the impairment is due specifically to the experience of pain.

Chronic Pain and Covariates

Older research has shown that patients experiencing chronic pain perform significantly lower on cognitive measures than age-matched controls (Kewman, Vaishampayan, Zald, & Han, 1991). However, this result is perhaps due to covariates such as distress. A study that controlled for distress found no observed impairment (Kewman et al., 1991). In this study, the Neurobehavioral Cognitive Status Examination (NCSE) was used to measure orientation, language functioning, attention, visual constructional ability, reasoning, memory, and arithmetic calculation for cognitive dysfunction. The participant's objective pain complaints were gathered using parts of the

McGill Pain Questionnaire (Melzack, 1975). From this sample of 73 outpatients with acute or chronic musculoskeletal pain complaints, 32% (24) of participants showed significant cognitive deficits by scoring below their age-corrected cutoff on one or more cognitive domains. Thirteen subjects had impairment of one domain, seven were impaired in two domains, two had deficits in three domains, and one had deficits in four cognitive domains. Those with lower scores on the NCSE also reported higher levels of pain. However, after controlling for psychological distress, there was no longer a significant correlation between pain and scores on the NCSE (Kewman et al., 1991).

Continuing with the idea that pain is a more complicated construct than originally thought, another study found that pain has a negative impact on cognitive function, but only when not controlling for depression (Brown, Glass, & Park, 2002). Patients with rheumatoid arthritis were used to measure the effect of pain, depression, and age on cognitive function. The participants that performed poorly on the cognitive task were typically older and reported higher levels of pain and depression. When the analyses controlled for depression and age, pain was no longer a significant predictor of cognitive function (Brown et al., 2002). This suggests that the construct of pain, specifically chronic pain, can be associated with related variables, such as depression.

A three-stage model has been developed that helps illustrate why there would be differences between chronic pain and induced pain (Jacobs, 2013). Patients who are experiencing pain inevitably experience a variety of complex psychological responses. During stage 1, the transition from acute pain to chronic pain, the individual may feel initial psychological distress, specifically fear. Stage 2 involves development of psychological problems (symptoms and impairments) varying per individual, largely

influenced by character structure and social factors. Finally, a chronic pain patient may regress to an identity involving abnormal illness behavior due to the acceptance that they are sick (Jacobs, 2013). Chronic pain is highly correlated with a history of stressful life events such as childhood abuse. A life containing abuse either in development or later typically precedes a chronic pain patient (Lampe et al., 2003). Pain puts stress on certain psychosocial characteristics, which enable and reinforce the chronic experience of pain.

As discussed earlier, people have different socioeconomic and psychological factors which influence the experience of chronic pain which moderates the patient's cognitive performance, along with their reported symptoms (Gatchel et al., 2007). Prior to chronic pain, chronic pain patients have preexisting and inactive characteristics that then become active and compounded from stress. These activated characteristics allow for the diagnosis of chronic pain (Dersh et al., 2002). One reason that pain patients end up being and remaining chronic pain patients is due to the psychosocial differences common to chronic pain patients. Chronic pain patients are less likely to adhere to their treatment due in part to the negative affect associated with chronic pain (Gatchel et al., 2007). With the patient not adhering to the treatment regime, they rarely get better. Each patient with chronic pain would not be attended to effectively without attending to a patient's emotional state as well (Gatchel et al., 2007). Chronic pain also acts as a significant stressor which can take a toll on the stress system. This can cause physical decline which produces a vicious cycle of pain-stress-reactivity (Gatchel, 2004). To summarize, chronic pain is typically preceded by a combination of psychosocial factors and is activated by the stress brought by pain. Therefore, if we test chronic pain patients,

we have a variety of confounds influencing the cognitive ability of a patient. This makes it difficult to attribute cognitive impairment to pain specifically.

To further support the model that pain is preceded by psychosocial factors, Attal and colleagues (2014) reported that premorbid limited memory capacity and cognitive flexibility may cause pain chronicity. The researchers examined 189 patients that were scheduled to undergo total knee arthroplasty or breast cancer surgery. Baseline measures were taken before the survey and post-test measures taken afterward. Both times, the patients underwent alternate forms of the Trail-Making Test (Reitan, 1992) and the Rey-Osterrieth Complex Figure (Stern, Singer, Duke, Singer, Morey, Daughtrey, & Kaplan, 1994), which assess cognitive flexibility, visuospatial processing, and visual memory. The patient's development of chronic pain and neuropathic symptoms were measured through the Douleur Neuropathique 4, Brief Pain Inventory, and pain rating scales (0: no pain to 10: the worst pain you can imagine). The researchers also used a 7-item DN4 which is a present/not present inquiry of different types of pain (burning, electric shocks, needles, tingling, numbness, inching, and painful cold; Bouhassira, 2005). The Brief Pain Inventory (BPI) rapidly assesses the severity and impact of pain in patients (Cleeland & Ryan, 1994). Participants were reassessed after 6 months (96% retention) and again after 12 months (88% retention). Results showed that those with limited cognitive flexibility and memory capacities before their surgery were significantly more likely to develop chronic pain symptoms and have a greater risk of pain chronicity after painful events (Attal, Masselin-Dubois, Martinez, Jayr, Albi, Fermanian, & Baudic, 2014). The studies mentioned earlier focus on chronic pain, which may be predisposed through personality

and cognitive ability. Using a pain-induction method directly investigates the impact pain has on cognitive functioning.

Other studies have induced temporary pain in healthy participants. The temporary or acute pain is typically induced by cold pressor or transcutaneous electrical nerve stimulation, so as to prevent tissue damage. Acute pain is momentary pain, which in the lab setting would be induced. The distinction between chronic and acute pain is important because when a patient experiences chronic pain there are typically many comorbidities that are present (Brown et al., 2002; Hart, Wade, Martelli, 2003; Kewman, Vaishampayan, Zald, & Han, 1991). However, induced pain in healthy volunteers allows us to control for or eliminate such confounds.

Influence of Induced Pain on Cognition

A literature review of chronic pain and neuropsychological functioning highlights inconsistent evidence showing whether induced pain in healthy volunteers (nonclinical pain populations) has a negative influence on cognitive functioning (Hart, Martelli, & Zasler, 2000). For example, some studies indicate impairment but do not report attempts to control for confounds such as depression. Induced pain can cause significant cognitive impairment. Another study involved inducing pain using an ischemic upper-arm tourniquet while participants performed an auditory oddball task and a memory search task. The memory task presented either 2 (low memory load) or 6 (high memory load) consonants from the alphabet. The participant would have to say whether the following presented letter was one of the 6 presented or not, over an average of 30 trials. Accuracy, response time, and event related potentials were evaluated. It was found that those in the

induced pain group performed more slowly and less accurately in the memory search task when compared with a no-pain control group (Lorenz & Bromm, 1997).

Methods of Pain Induction

There are three main pain fibers in the body that send signals associated with different types of pain sensations; Aβ, Aδ, & C-fibers. Aβ and Aδ fibers have been commonly referred to as a shallower, instant, and relying on a reactive pain signal pathway. C-fibers are commonly described as the pain pathway for chronic pain due to their longer-lasting and deeper sensation. Although the study above used a tourniquet method, there are many different methods of pain induction that can be used. Typical pain induction methods used on human experiments are chemical (capsaicin and mustard oil), mechanical (pinprick and pressure), electrical, and thermal (contact heat and cold pressor) stimulation (Staahl & Drewes, 2004).

A common method for chemical stimulation of induced pain is capsaicin. Capsaicin is a chemical which when applied as a topical application or intradermal injection evokes pain sensations at the applied location (Staahl & Drewes, 2004). The chemical pain is primarily experienced by C-fibers, which represents the sensations felt during chronic pain due to similar pathways by pain signals (Wallace, Barger, & Schulteis, 2002). The other method of chemical stimulation is mustard oil, which is a topical application. This creates a burning pain followed by an inflammatory reaction at the applied location, along with a heightened sensitivity to pain. This utilizes both Aβ for a topical instant pain and C fibers for a deeper and long-term sensation of pain (Curatolo, Petersen-Felix, & Arendt-Nielsen, 2000).

Common methods for mechanical stimulation are pinpricking and creating pressure pain such as a tourniquet. Pinpricks are believed to activate Aδ-fibers creating a very short acute pain sensation, which is reported as a front-end pain that quite quickly dissipates. This method is too brief for conventional measures to be used during testing of pain (Le Bars, Gozario, & Cadden, 2001). Tourniquets can be used in order to create a pressure pain sensation which activates both Aδ and C-fibers. Pressure as well as pinprick create a pain sensation that is too short lasting to test with conventional measures (Handwerker & Kobal, 1993).

There are several different devices which can evoke an electrical pain stimulation. Each electrical pain stimulation methods have various effects such as varying waveforms, durations, and frequencies that will evoke varying pain sensations (Handwerker & Kobal, 1993; Le Bars et.al., 2001). The importance of electrical stimulation is that it circumnavigates the pain receptors and activates nerve fibers directly which does not allow for specific activation of the nociceptors (Handwerker & Kobal, 1993).

There are two methods of thermal stimulation of pain: heat and cold. Initially rapid skin heating causes the signal to travel across the Aδ-fiber which is described as the first pain. Following the first pain will be a burning and swelling sensation utilizing the C-fiber, which is longer in duration and less localized (Hughes, Rhodes, Fisher, Sellers, & Growcott, 2002). Using cold thermal stimulation involves the application of a sub 40 degree Fahrenheit stimulus directly to skin. The most commonly used method is cold pressor which is performed with the immersion of an extremity into an ice-water bucket. This is thought to have a simultaneous activation of both Aδ-fibers and C-fibers, which is most similar to chronic pain (Curatolo et al., 2000).

Influence of Cold Pressor Pain on Cognition

In order to isolate and control pain while representing similar pain sensations as chronic pain, the use of a cold pressor has been used in many experiments as the pain induction method Curatolo and colleagues (2000) had nonclinical volunteers undergo cold pressor-induced pain. When controlling for pain, it has been found that pain does not significantly impair performance on processing speed index (PSI) or working memory index (WMI) as tested by the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008). PSI measures the ability to rapidly process information and respond while the WMI measures ability to hold and manipulate information to produce a result (Wechsler, 2008). No significant effect of pain (on any measure) was observed. Induced pain in nonclinical volunteers did not cause impairment on the performance of the WMI or PSI of the WAIS-IV, which suggests that, in chronic pain patients, pain *per se* should not be expected to affect these specific cognitive functions (Etherton, 2013).

This methodology was applied to the examination of the effects of induced pain on WAIS-IV Verbal Comprehension Index (VCI) and Perceptual Reasoning Index (PRI) tasks (Etherton, 2015a; 2015b). The VCI constructs were measured with the WAIS-IV, which utilized the subtests Information (questions that address a broad range of general knowledge topics; Wechsler, 2008), Similarities (participant is presented with 2 stimuli and have to assess how they are similar; Wechsler, 2008), and Vocabulary (participant names or defines a stimulus presented either visually or orally; Wechsler, 2008). The PRI utilized the subtests Block Design (a time constrained task which uses red and white blocks to recreate a visual pattern; Wechsler, 2008), Matrix Reasoning (involves selecting from a list of options that would complete an incomplete matrix visually

presented; Wechsler, 2008), Visual Puzzles (a time constrained task which uses a combination of three shapes from six, that when organized together make the picture presented; Wechsler, 2008). The results of this experiment showed that neither of these tasks are impaired by induced pain alone. Findings from both of these studies suggest that induced pain is not associated with impairment on any of the four WAIS-IV index scores (Etherton, 2015a; 2015b).

In another study, pain was associated with a significant decline in performance on both O-Span and Digit Span backwards tasks (Schoofs, Wolf, & Smeets, 2009). The O-Span Task is a math problem (e.g., "Does (6/2)-2=1?") and then a word is presented after the operation (e.g., FALL). After a series of problems and words have been presented, the participants recall the words that followed each operation. The number of operation-word strings in a sequence is increased and decreased to measure the participant's operation span (Turner & Engle, 1989). Digit Span of the WAIS-IV presents 3-9 numbers, which the participant has to either read back verbatim, read reversely, or organize in sequential order (Wechsler, 2008). Schoofs et al. (2009) observed that both Digit Span backwards and O-Span Tasks performance worsened, which led to the conclusion that pain induced by cold pressor caused a significant decline in working memory performance. The declines were most observed in tasks which specifically involved executive functioning (Schoofs et al., 2009).

Executive Functions

Executive function is the overarching term for the cognitive system including functions such as the following: inhibition, mental flexibility, initiation of action, monitoring of action, and planning. Inhibition is the ability to control one's own behavior,

which includes stopping behavior at the appropriate time, including actions and thoughts. Mental flexibility is the ability to adjust behavior freely from one situation to another in order to respond appropriately to the situation. Monitoring action is the ability to gauge individual performance against some standard of what is needed or expected. Lastly, planning is the ability to manage current and future behavior in accordance with the actions necessary to achieve goals (Chan, Shum, Toulopoulou, & Chen, 2007).

To examine whether pain causes distraction and thus impairment in measures of executive functioning, Keogh, Moore, Duggan, Payne, and Eccleston (2013) investigated thermal heat pain and executive functioning. Two tasks were used. The Breakfast Task is a computerized task of executive functioning assessing working memory, processing speed, inhibition, reasoning and prospective memory. The task requires participants to concurrently set places at a simulated table while at the same time preparing a simulated breakfast (Rose, Luo, Bialystok, Hering, Lau, & Craik, 2015). The second task is the Word Generation Task, which assesses ability to task set switch (in reaction to task performance) and allocate time across multiple tasks. The Word Generation Task requires participants to use two separate sets of letters in order to generate words (Payne, Duggan, & Neth, 2007). Induced pain was associated with a decline in performance towards secondary responsibilities of the tasks but increased performance for the central responsibilities. Specifically, in the Breakfast Task, the main responsibility of preparing breakfast showed an improved performance. However, there was a decline in the ability to prepare the table simultaneously. With the Word Generation Task, there were no performance differences on the main task of generating words. However, the group that experienced hot thermal pain had more difficulty with processing strategies (i.e., poorer

time allocation on tasks, and switching between tasks many more times; Keogh, Moore, Duggan, Payne, & Eccleston, 2013). However, with these specific lab made tests, it is difficult to relate them back to the clinical concern, from which the problem of pain originates, simply due to the lack of normed data which causes more room for error in generalizability.

Importance of Clinically Relevant Measures

Many previously mentioned studies use lab specific tasks, (e.g., Brown et al., 2002; Crombez et. al., 2013; Glass, et. at., 2011; Keogh, et. al., 2013; Lorenz and Bromm, 1997) while other studies use clinically relevant measures (Etherton, 2013; 2014; 2015; Schoofs, et. at., 2009). It is important to use clinical measures in order to enhance external validity by allowing comparable measures with the clinical population. One of the standard clinical measures of executive function is the Delis Kaplan Executive Function System (D-KEFS). The D-KEFS is a collection of nine standalone lab-specific tests, which were collected together to measure verbal and non-verbal executive functions as a standalone battery for children and adults (ages 8-89). The D-KEFS is a valuable test for the clinical population because it has been normed which allows for individual scores to be interpreted as impaired. Since the D-KEFS is comprised of nine tests which were designed to be standalone, it is the best battery to administer with pain induction since each individual test does not go over 10 minutes and can conveniently accommodate breaks for relief from pain without spoiling the test. Also, it provides strong measures of executive functioning without delivering a full testing battery (Delis, Kaplan, & Kramer, 2001).

Current Study

As previously mentioned, inconsistent findings with chronic pain have left gaps in the literature as to whether cognitive deficits are caused specifically by the experience of pain during chronic pain. The purpose of the current study is to investigate the interaction between pain and cognitive ability using cold pressor pain induction method to most closely resemble chronic pain in healthy volunteers; in doing this methodology we can circumnavigate the potential comorbidities associated with chronic pain and investigate solely the sensation of pain. It is my hypothesis that cognitive ability will not be influenced by cold pressor induced pain. The reason for this hypothesis is in part due to the most recent wave of pain literature with various cognitive functions showing that induced pain in healthy volunteers does not cause cognitive defects. Also, previous research has controlled for depression and other various comorbidities associated with chronic pain which we know would cause deficits in cognitive functioning, however when controlled for there is no significant cognitive deficits. This current research is important because with this information the clinical treatment of chronic pain can adjust towards a more thorough treatment of a patient's psychology as suggested by, Gatchel, et. al., (2007) rather than the experience of pain, since the problem lies within developing pathology of chronic pain victims.

III. METHODS

Participants

The study was conducted at a large state university in the Southwestern United States. University institutional review board approval was obtained for the study. One hundred and twenty nonclinical volunteer participants (94.2% right handed) were recruited from undergraduate psychology courses and offered extra credit by their instructors as incentive. Half of the participants completed Color Word Interference Test and Trail Making B of the D-KEFS and the other half completed the Verbal Fluency of the D-KEFS. Per IRB requirements participants were not allowed to be induced with pain for more than 10 minutes total which is why half participants completed two subtests and the other half completed Verbal Fluency as to not exceed the 10 minute requirement. Exclusion criteria for participation included a history of traumatic brain injury (TBI), stroke, or other neurological condition. In addition, to avoid excessive cold-related pain, volunteers were asked to decline participation if they have peripheral neuropathy, vascular disease, or Raynaud disease. The participants were randomized into one of three groups, Control (warm water immersion), Pain Induction (cold-pressor), and Roleplaying disability group (simulator).

Instruments

D-KEFS. The D-KEFS (Delis, Kaplan, & Kramer, 2001) includes the following tests: Trail Making Task (TM), Verbal Fluency (VF), and Color Word Interference (CWIT). Testing involved normal administration of these 3 subtests of D-KEFS. Since Executive Functioning is such a broad grouping of different higher thought functions, the

three subtests were chosen to concentrate on inhibition, category switching, and flexibility of thinking. All three test examine the participant's ability in these three functions. The TM test requires the participant to connect labeled points in a sequential order; this test engages visual scanning and sequencing. Trail making part B requires sequential pairing shifting from numerical and alphabetical order; this requires visual scanning, set shifting, sequencing, and inhibition. The VF test allows the participant 60 seconds after being assigned a letter cue to tell as many words as they can that start with that letter; they cannot say proper nouns (e.g., Benjamin or Detroit) or a different form of the same word (e.g., peaches and peach). This test engages their ability to recall certain words and inhibit proper nouns and same words. There are 3 different sections of the VF test. The first section is to recall as many words as you can remember that start with a certain letter. The second would ask the participant to name as many things of a certain category that they could (e.g. Animals or Boy's Names) and they had no restriction of what letters the words started with, this was category fluency. The last section required the participant to alternate between two categories (e.g. fruits and musical instruments). The participant would say an entry from one category, then something from the other, this added a task set switching executive function. The CWIT has certain colors written in an alternate ink (the word purple is written in an ink color that is not purple). The participant is told to repress the natural urge to read the word and instead say the color of ink they are looking at, unless they see the ink color red which they will read the word written (which could be any word but red). This tests the participant's ability to inhibit automatic responses and set shift according to the rules set. There was also a subtest of the CWIT which asked the participant to read the word printed if the word was

surrounded by a black box, this cause the participant to go back and forth mentally to adhere to the rules of the test which added a task set switching executive function aspect. Both the CWIT and TM are measured in seconds required to complete the task, therefore a higher score is a poorer performance. In contrast, the VF requires words to be named with more correct hits in an allotted time; therefore, a lower score shows poorer performance. All three subtest scores were analyzed in raw scores to compare participants in a university setting. This battery was selected as it assesses a wide range of executive functions using tasks that have been shown to be valid and reliable, even though, the reliability coefficients for the DKEFS tests were generally less than .80, this test is comparable with other neuropsychological tests, and it is expected that with each assessment, test complexity is central to performance variability.

Pain Catastrophizing Scale. Participants also completed the Pain Catastrophizing Scale (PCS; Sullivan, Bishop, & Pirik, 1995). The PCS can be completed and scored in less than 5 minutes, which makes it easily amenable to inclusion within standard clinical practice. Prior knowledge of a patient's level of catastrophic thinking, in addition to other pain-related variables, enables treatment plans to be more individually tailored. The PCS is a 13-item instrument which requires a reading level of approximately Grade 6. The PCS instructions ask participants to reflect on past painful experiences, and to indicate the degree to which they experienced each of 13 thoughts or feelings when experiencing pain, on 5-point scales with the end points (0) not at all and (4) all the time. The PCS yields a total score and three subscale scores assessing rumination, magnification and helplessness. The Cronbach Alpha index for the total PCS is .93, which show that the total PCS has a moderately acceptable reliability (Osman et al, 1997).

Pain Rating Scale. Participants are oriented to a Pain Rating Scale which is an 11-point pain-rating scale placed within their view. The numbers 0 to 10 were written from left to right, with verbal descriptors below: 0=no pain, 2=mild pain, 5=moderate pain, 8=severe pain, and 10=very severe pain. Participants are then instructed to provide pain ratings during water immersion using this scale. The Cronbach Alpha index for the total PCS is .93, which show that the total PCS has a moderately acceptable reliability.

Effort Rating Scale. Lastly introduced an Effort Rating Scale was given which is a rating scale for the degree of effort during testing, and their estimate of their current level of performance as a percentage of best possible performance was utilized.

Procedure

Testing was conducted in the laboratory space of the second author, in closed rooms relatively free from visual or auditory distraction. Volunteer participants were evaluated individually according to the standardized administration procedures for each task. Tests were administered by undergraduate and graduate research assistants, who have received training and practice in research protocol and test administration. On arrival, participants were provided with an overview of the study, after which written informed consent was obtained. Participants were then randomly assigned to one of the three possible groups by rolling a dice: pain (n=40), control (n=40), and simulator (n=40). Once enough participants were obtained for each group based on preliminary power analysis then the group would be omitted in the random assignment procedure.

Participants in the pain group placed their hand in a bucket of ice water, whereas participants in the control group placed their hand in a bucket of lukewarm water.

Participants in the pain group were told that they could remove their hand from the cold water at any time, either for a temporary break or to terminate their participation. To avoid prolonged discomfort, all participants are prompted to remove their hand briefly at 2-min intervals even if they had already chosen to take a break themselves. To ensure uniformity across conditions, control participants were also prompted to remove their hand briefly at 2-min intervals, despite the absence of pain. Pain ratings were requested during water immersion, for both pain and control groups, at approximately 2-min intervals. Pain ratings and assigned breaks were established between items to avoid interrupting task performance.

The simulator group was added to investigate the natural response from participants in how they would attempt to successfully malinger to the performance of these specific subtests. Participants were asked to roleplay as though their cognition was being assessed for a disability claim, and that they needed to appear disabled. However, if the participant appeared too disabled then their roleplaying would be found and their disability case would be thrown out. The warm water immersion condition served as a control for potentially distracting extraneous variables other than acute pain associated with the cold-pressor procedure, such as holding one's limb in water or being asked to provide pain ratings.

Because the three D-KEFS subtests could possibly require more than 10 minutes at a time under a cold pressor (violates IRB requirement), half of the participants completed the TM and CWIT paired (control, n=20; pain, n=20; and simulator, n=20) and VF administered for the other half of participants (control, n=20; pain, n=20; and

simulator, n=20). Due to the split requirement there was a total of 120 volunteer participants, none of which repeated participation.

For the pain, control, and simulator groups, subtest order was partially counterbalanced. For both sets of participants, counterbalancing was used when determining the order of which the tests were given to the participant. For the baseline tests in the first half, some participants had the TM presented before the CWIT, whereas other participants had the CWIT presented before the TM. Due to the lack of availability of D-KEFS alternate form of CWIT and TM, the current study used a repeated measure mixed design to determine if our specific executive functions of concentration (inhibition, category switching, and flexibility of thinking) scored poorer with thermal pain induction than warm water immersion. The first half used the exact same TM task set shifting test and CWIT for both the baseline and test measures for all three groups (control, pain, and simulator). This method includes practice effects; however, since all three groups include the practice effects the analysis still investigates whether the pain induction causes more of a decrease in executive functioning performance than those who dipped their hand in warm water (control). The second half used the VF subtest of D-KEFS which used either the standard or alternate form for the baseline, then the other form for the test measure for all three groups (control, pain, and simulator).

Each participant completed a baseline measure of the Pain Catastrophizing Scale and assigned subsections of D-KEFS. After the baseline measurements, a rating scale for the degree of effort during testing, and a percentage of best possible performance were completed; then the participant's non-dominant hand was placed in either a bucket with ice water (mean starting temperature 43.90f; pain condition) or a bucket of lukewarm

water (mean starting temperature 88.30f; control condition). While the non-dominant hand was submerged, the D-KEFS subtests were administered allowing for intermediate breaks. Every 2 minutes a mandated break was taken and a pain score was collected. During the breaks on the cold pressor pain condition and the warm water control condition, participants were asked to give their pain rating on an 11-point pain scale (0-10). After all subtests were performed, water temperature was recorded (mean pain final temperature 43.30f; mean control final temperature 88.13f) and another Pain Catastrophizing Scale, a rating scale for the degree of effort during testing, and a percentage of best possible performance were conducted. The participant was then debriefed and thanked for their participation.

Analyses

In order to test the hypothesis that pain does not influence cognitive ability, six 3 x 2 mixed-design ANOVAs were conducted, with Pain Group (Pain—hand immersed in ice water; Control—hand immersed in warm water; Simulator—perform as if in pain and believing that pain would negatively impact performance) as the between-subjects independent variable, Time (Time 1—before immersion; Time 2—during immersion) as the within-subjects independent variable, and the scores of the subtests (CWIT Inhibition score; CWIT Task Set Switching score; TM score; VF Verbal Fluency score; VF Category Fluency score; VF Category Switching score) as the dependent variables for the six different ANOVAs. Bonferroni post hoc tests were conducted to explore group differences at baseline and any significant Experimental Group X Time interactions. An alpha level of .05 was used to determine significance for the ANOVA tests. Lastly, simple correlations were run to investigate the effect of pain catastrophizing on D-KEFS

scores. Also a simple correlation was run to see if effort scales influenced the outcome on D-KEFS scores.

IV. RESULTS

CWIT and TM

At Time 1 (baseline), there were no significant differences between the groups on the CWIT Inhibition score, $F(2, 57) = .053$, $p = .819$; on the CWIT Task Set Switching score, $F(2, 57) = 5.06$, $p = 0.01$; or on the TM score, $F(2, 57) = .006$, $p = .936$ (see Table 1 for M and SD values). The Experimental Group X Time interactions were significant for the CWIT Inhibition score, $F(2, 57) = 15.268$, $p < .001$; for the CWIT Task Set Switching score, $F(2, 57) = 12.726$, $p < .001$; and for the TM score, $F(2, 57) = 20.380$, $p < .001$. From Time 1 to Time 2, the simulator group significantly declined in performance on the CWIT Inhibition test $F(2, 57) = 20.380$, $p < .001$; on the CWIT Task Set Switching test, $F(2, 57) = 12.726$, $p < .001$; and on the TM test, $F(2, 57) = 20.380$, $p < .001$. With the first half of participants the average pain rating for those in the Pain condition was 5.3/10, which reflects a moderate pain severity.

Table 1

Means (Standard Deviation) – First Half

	Time 1			Time 2		
	CWIT: Inhibition	CWIT: Task Set Switching	TM	CWIT: Inhibition	CWIT: Task Set Switching	TM
Control Group	47.85 (12.52)	54.40 (12.77)	71.35 (16.21)	42.80 (10.21)	46.10 (11.55)	54.30 (15.69)
Pain Group	46.75 (8.45)	53.35 (8.11)	64.25 (23.07)	42.20 (5.99)	44.15 (8.82)	50.95 (16.62)

Simulator Group	44.40 (8.79)	56.30 (11.44)	73.35 (19.78)	54.90 (17.24)	62.40 (19.59)	102.90 (36.52)

With regards to the PCS, Table 2 shows the Pearson correlation coefficients of the total PCS scores and the D-KEFS scores in the first half of participants. Table 3 depicts correlations between effort scales (the first being Effort Rating and the second being Percent of Best Effort) and D-KEFS scores for time 1. Following is Table 4 which depicts correlations between effort scales (the first being Effort Rating and the second being Percent of Best Effort) and D-KEFS scores for time 2.

Table 2

PCS vs Condition – First Half

	CWIT Inhibition	CWIT Task Set	TM
PCS-Control group	*r*=.286, *p*=.222	*r*=.251, *p*=.287	*r*=.600, *p*=.005
PCS-Pain Group	*r*=-.284, *p*=.225	*r*=-.067, *p*=.777	*r*=-.122, *p*=.608
PCS-Simulator Group	*r*=.185, *p*=.435	*r*=.245, *p*=.297	*r*=-.366, *p*=.113

Table 3

Effort Rating and Percent of Best Effort (PBE) for Time 1 – First Half*

	CWIT Inhibition	CWIT Task Set	TM

Effort-Control Group	*r*=-.022, *p*=.927	*r*=.077, *p*=.746	*r*=.262, *p*=.264
PBE- Control Group	*r*=-.381, *p*=.098	*r*=-.043, *p*=.857	*r*=-.198, *p*=.402
Effort-Pain Group	*r*=-.048, *p*=.842	*r*=-.068, *p*=.776	*r*=-.269, *p*=.252
PBE- Pain Group	*r*=.018, *p*=.939	*r*=-.124, *p*=.604	*r*=-.302, *p*=.196
Effort-Simulator Group	*r*=.191, *p*=.419	*r*=.133, *p*=.576	*r*=.289, *p*=.217
PBE- Simulator Group	*r*=-.088, *p*=.712	*r*=-.063, *p*=.791*	*r*=-.244, *p*=.300

Table 4

Effort Rating and Percent of Best Effort (PBE) for Time 2 – First Half

	CWIT Inhibition	CWIT Task Set	TM
Effort-Control Group	*r*=-.167, *p*=.482	*r*=-.173, *p*=.465	*r*=-.042, *p*=.861
PBE- Control Group	*r*=.071, *p*=.767	*r*=.191, *p*=.420	*r*=-.210, *p*=.375
Effort-Pain Group	*r*=.021, *p*=.929	*r*=-.173, *p*=.465	*r*=-.042, *p*=.861
PBE- Pain Group	*r*=.118, *p*=.621	*r*=.191, *p*=.420	*r*=-.210, *p*=.375
Effort-Simulator Group	*r*=.326, *p*=.160	*r*=-.046, *p*=.846	*r*=-.463, *p*=.040

PBE- Simulator Group	*r*=.240, *p*=.308	*r*=.004, *p*=.987	*r*=-.145, *p*=.543

The simulator group showed significantly poorer performance compared with both the control and pain groups for CWIT Inhibition factor (Simulator; time 1: 44.40, time 2: 54.90), CWIT Task Set Switching factor (Simulator; time 1: 56.30, time 2: 62.40). However, with the TM Task Set Switching factor the simulator group only significantly differed from the control group $F(2, 57)= 20.380$, $p< .001$ (Simulator; time 1: 73.35, time 2: 102.90). Even though the simulator and pain group were statistically similar the pain and control group also performed statistically similar. With regards to the simulator group, CWIT Inhibition factor interaction was statistically significant, $F(2, 57)= 15.268$, $p< .001$. Also, with the simulator group, CWIT Task Set Switching factor interaction showed to be statistically significant, $F(2, 57)= 12.726$, $p< .001$. Lastly, with regards to the simulator group, TM Task Set Switching factor interaction was significant, $F(2, 57)= 20.380$, $p< .001$. When comparing time 1 to time 2 the simulator group significantly declined in performance, whereas neither the Pain, nor the Control group demonstrated such a reduction in performance from time 1 to time 2. The simulator group also showed a deliberate increase in errors (incorrect items) compared to the control and pain groups from time one to time two for both CWIT Inhibition factor and CWIT task set switching factor. With the errors of the simulators CWIT Inhibition condition by time interaction was statistically significant, $F(2, 57)= 14.238$, $p<.001$. Lastly, on CWIT Task Set Switching condition interaction showed to be statistically significant, $F(2, 57)= 12.515$, $p<.001$.

Table 5

Means (Standard Deviation) – Color Word Interference Errors (Number of Incorrect Items)

	Time 1		Time 2	
	CWIT: Inhibition	CWIT: Task Set Switching	CWIT: Inhibition	CWIT: Task Set Switching
Control Group	1.2 (1.152)	1.9 (1.553)	1.0 (1.076)	1.8 (1.542)
Pain Group	1.9 (1.651)	2.3 (1.625)	1.4 (1.142)	1.55 (1.191)
Simulator Group	1.4 (1.040)	3.3 (3.596)	10.1 (10.285)	10.75 (12.413)

Verbal Fluency

At Time 1 (baseline), there were no significant differences between the groups on the Verbal Fluency score, $F(2, 57) = 14.795$, $p = .764$; on the Category Fluency score, $F(2, 57) = 16.233$, $p = .854$; or on the Category Switching score, $F(2, 57) = 7.933$, $p = .247$ (see Table 5 for *M* and *SD* values). The Experimental Group X Time interactions were significant for the Verbal Fluency score, $F(2, 57) = 20.483$, $p < .001$; and for the Category Fluency score, $F(2, 57) = 12.437$, $p < .001$. From Time 1 to Time 2, the simulator group significantly declined in performance on the Verbal Fluency test, F(2, 57)= 20.483, p< .001; and on the Category Fluency test, F(2, 57)= 12.437, p< .001; The Category Switching score also significantly differed between Time 1 and Time 2 for the Simulator Group F(2, 57)= 1.85, p= .041. Finally, the Experimental Group X Time

interaction was not significant for the Category Switching score, $F(2, 57) = 1.431$, $p < .257$. The Category Switching score did not differ between Time 1 and Time 2 for the Simulator Group F(2, 57)= 1.85, p= .041. The average pain rating from the second half of participation for those in the Pain condition was 6.6/10, which reflects a moderate pain severity.

Table 6

Means (Standard Deviation)-Second Half

	Time 1			Time 2		
	VF: Verbal Fluency factor	VF: Category Fluency	VF: Category Switching	VF: Verbal Fluency factor	VF: Category Fluency	VF: Category Switching
Control Group	35.30 (11.69)	41.10 (9.26)	13.40 (2.87)	35.70 (11.93)	39.20 (8.59)	13.40 (3.33)
Pain Group	33.30 (6.37)	38.65 (5.12)	13.40 (1.96)	34.15 (6.60)	39.30 (6.11)	12.30 (3.44)
Simulator Group	32.00 (7.15)	36.25 (7.9)	12.45 (2.74)	20.10 (6.83)	24.15 (10.66)	10.25 (2.83)

Simulator group performance was significantly poorer than both the control and pain groups for Verbal Fluency factors (Simulator; time 1: 32.00, water immersion: 20.10), Category Fluency factor (Simulator; time 1: 36.35, water immersion: 24.15). However, with the VF Task Set Switching factor the simulator group only significantly

differed from the control group F(2, 57)= 1.431, p= .257 (Simulator; time 1: 12.45, water immersion: 10.25). While the simulator group performed significantly worse than the control group on the VF Task Set Switching task, performance for the simulator and pain groups was not significantly different from each other on this measure. In addition, there was no significant difference in performance between the pain and control groups. With regards to the simulator group, Verbal Fluency factor interaction was statistically significant, F(2, 57)= 20.483, p< .001. Also, with the simulator group, Category Fluency factor interaction was statistically significant, F(2, 57)= 12.437, p< .001. Lastly, with regards to the simulator group, VF Test Task Set Switching factor interaction was not statistically significant, F(2, 57)= 1.431, p= .257.

With regards to the PCS, Table 6 shows the correlations of PCS scores with D-KEFS water immersion trials with regards to the second half of participants. Table 7 depicts correlations between effort scales and D-KEFS baseline trials. Table 8 depicts correlations between effort scales and D-KEFS water immersion trials. Finally Table 9 shows the ANOVA results investigating the main effect for both pain vs control and for simulator vs pain and control.

Table 7

PCS vs Condition – Second Half

	VF: VF combined	Category Fluency	Category Switching
PCS-- Control Group	*r*=-.297, *p*=.203	*r*=-.038, *p*=.287	*r*=-.486, *p*=.030
PCS-- Pain Group	*r*=-.409, *p*=.074	*r*=-.560, *p*=.010	*r*=-.167, *p*=.482

PCS-- Simulator Group	*r*=.323, *p*=.165	*r*=.262, *p*=.265	*r*=.247, *p*=.293

Table 8

Effort Rating and Percent of Best Effort (PBE) for Time 1 – Second Half

	CWIT Inhibition	CWIT Task Set	TM
Effort-Control Group	*r*=.045, *p*=.846	*r*=-.542, *p*=.011	*r*=.451, *p*=.040
PBE- Control Group	*r*=-.120, *p*=.604	*r*=-.381, *p*=.088	*r*=.281, *p*=.218
Effort-Pain Group	*r*=.180, *p*=.435	*r*=-.091, *p*=.694	*r*=.005, *p*=.982
PBE- Pain Group	*r*=.276, *p*=.226	*r*=.008, *p*=.972	*r*=.278, *p*=.222
Effort-Simulator Group	*r*=.508, *p*=.022	*r*=.502, *p*=.024	*r*=.548, *p*=.012
PBE- Simulator Group	*r*=.116, *p*=.625	*r*=-.098, *p*=.681	*r*=-.162, *p*=.494

Table 9

Effort Rating and Percent of Best Effort (PBE) for Time 2 –Second Half

	CWIT Inhibition	CWIT Task Set	TM
Effort-Control Group	*r*=-.228, *p*=.334	*r*=-.116, *p*=.627	*r*=.147, *p*=.537

PBE- Control Group	*r*=-.023, *p*=.924	*r*=.039, *p*=.872	*r*=.437, *p*=.054
Effort-Pain Group	*r*=.173, *p*=.465	*r*=-.101, *p*=.670	*r*=-.282, *p*=.228
PBE- Pain Group	*r*=.506, *p*=.023	*r*=.166, *p*=.483	*r*=-.276, *p*=.239
Effort-Simulator Group	*r*=.223, *p*=.344	*r*=-.180, *p*=.447	*r*=.234, *p*=.321
PBE- Simulator Group	*r*=-.069, *p*=.771	*r*=-.210, *p*=.375	*r*=-.198, *p*=.404

Table 10

F values for Condition interactions

	CWIT: Inhibition	CWIT: Task Switching	TM	VF: Verbal fluency factor	VF: Category Fluency	VF: Category Switching
Control vs Pain Group	F(1, 38)= .054 *p*= .818	F(1, 38)= .223 *p*= .639	F(1, 38)= .693 *p*= .410	F(1, 38)= .050 *p*= .825	F(1, 38)= 1.306 *p*= .260	F(1, 38)= .472 *p*= .496
Simulator vs Control and Pain Group	F(2, 57)= 15.268 *p*< .001	F(2, 57)= 12.726 *p*< .001	F(2, 57)= 20.380 *p*< .001	F(2, 57)= 20.483 *p*< .001	F(2, 57)= 12.437 *p*< .001	F(2, 57)= 1.431 *p*= .257

V. DISCUSSION

The current project investigated the potential effects of cold-pressor pain induction on D-KEFS' TM, CWIT, and VF tests performances in nonclinical volunteers. Induced pain was not associated with significant decrement in performance for any of these measures. These D-KEFS subtests primarily involve executive functions, including inhibition and task set shifting. The results from the current study indicate that both inhibition and task set shifting, along with other executive functions, are not influenced by the induction of a moderate level of pain on a nonclinical volunteer (mean pain ratings: 5.3/10 for Study 1, and 6.6/10 for Study 2).

The results of the PCS had very few statistically significant correlations associated with the outcomes of D-KEFS testing. However, both of the task set switching tasks (TM and VF Category Switching) outcomes from the control group were significantly correlated with the PCS scores. With the TM test those in the control group that scored higher in pain catastrophizing also were likely to take longer to complete the TM task. With the VF category switching test those in the control group that scored higher in pain catastrophizing also were likely to not be able to switch back and forth between their categories as efficiently. As well, the Pain group had a strong significant negative correlation between their PCS and VF category fluency scores. That is when someone from the pain group catastrophized pain they would tend to be able to say less items per category.

Chronic pain patients often report a variety of cognitive problems which are frequently attributed to the experience of pain. Chronic pain has been associated with complaints and cognitive decline during executive functioning tasks (Apkarian et al.,

2004). The current study indicates that pain itself does not specifically cause significant decrement in D-KEFS' TM, CWIT, and VF tests performances, and should not likely cause impairment in similar tasks involving these executive functions.

Previous research indicates that induced pain does not cause a detectable decrement in aspects of cognition measured by the WAIS-IV (Etherton 2014; 2015), or the visual working memory and auditory memory indexes from the Wechsler Memory Scale - Fourth Edition (Etherton & Tapscott, 2015). The results of the current study are consistent with these prior results in finding that the executive functions of flexibility of thinking on a visual-motor sequencing task, letter fluency, category fluency, category switching, and inhibition, as measured by the CWIT, TM, and VF subtests of the D-KEFS, are not affected by the experience of pain.

Contrary to the traditional belief that pain causes impairment, this study shows that pain does not have a statistically significant effect on executive function performance. Instead chronic pain patients may perceive themselves as impaired when they are not, which may cause them to potentially perform worse, but more importantly causes them to complain that they are performing more poorly on daily tasks at home or work. Due to the disruptive nature and longevity of the pain, chronic pain patients are motivated to avoid and escape from situations that may cause or trigger their pain. The persisting avoidance is typically maladaptive by leading to increased fear and limited activity which allow for the persistence of pain and increase disability (Gatchel et al., 2007).

Another potential explanation for why chronic pain patients may have cognitive complaints (and believe that they may be performing more poorly than they actually are),

is explained in a theory which involves incorrect self-estimations of pre-injury functions by chronic pain patients. Whenever a victim suffers from a mild traumatic brain injury, they often underestimate the frequency of cognitive complaints, such as forgetfulness, prior to the injury. This can influence their perception of their current level of cognitive and physical difficulty, and may lead them to inaccurately attribute ordinary forgetfulness to the effects of the injury (Iverson, Lange, Brooks, & Rennison, 2010).

Self- reported complaints of cognitive problems may not be matched by true poorer cognitive performance, per se. Regarding the alternative theory of pain, if a clinical patient with chronic pain does perform significantly below the expected outcome then the results of the current study should encourage consideration of other factors that may be influencing cognitive performance and contribute to the impairment (e.g. depression, poor effort, or medications; Kewman et. al., 1991; Etherton, Bianchini, Heinly, & Greve, 2006; Dersh et al., 2002).

Chronic pain patients have socioeconomic and psychological factors that may influence their cognitive ability (Gatchel et al., 2007). Dersh et al. (2002) suggested that chronic pain acts as a stressor which influences preexisting and inactive characteristics, within the patient, that then become active, and compound problems from the stress of the long term experience of pain, which leads to the diagnosis of chronic pain. These compounded problems could possibly manifest as comorbidities such as depression or anxiety disorders which are known for having cognitive deficits (Gatchel et al., 2007). However, there are inconsistencies in the literature regarding the presence and nature of cognitive deficits in depression and anxiety disorders. One reason that pain patients are initially diagnosed and remain chronic pain patients is due to the psychosocial and

behavioral factors such as poorer treatment adherence. Reduced adherence has been associated with increased negative affect, which often accompanies chronic pain (Gatchel et al., 2007).

A distinct feature of the current study included the presence of a simulator group. The simulator group was comprised of nonclinical volunteers who were instructed to perform as if they were impaired (based on their understanding of how to appear impaired) while completing the D-KEFS subtests. They were also warned to be cautious about overplaying their impairment to avoid having their exaggeration detected. Malingering of pain-related disability is typically expressed through test performance by exaggeration of deficits; the exaggeration is significant enough that cutoffs can be set to detect probable malingering on clinical measures (Greve, & Bianchini, 2004).

The effort scales compared with the outcomes on D-KEFS scores showed that both operated relatively independent from each other. However, there was a significant correlation of interest between effort scales and D-KEFS scores. During the TM test the simulator group had a moderate correlation which shows that those who thought they did well on their performance generally took longer to complete the TM task. The other simulation effort scales did not significantly associate with D-KEFS testing performance

The current study found that on all three subtests simulator's performances were consistent with data from current malingering research. When attempting to appear impaired, participants exaggerated their symptoms in order to appear impaired. The participants in the simulator group performed significantly worse than either of the pain or control groups. With regards to errors in CWIT inhibition and task set switching measures, none of the three groups showed substantial errors in baseline and only the

simulator groups differed from the pain and control groups during water immersion; displaying significantly more errors. Only those participants who attempted to appear impaired demonstrated significantly poorer performances on CWIT, TM, and VF of the D-KEFS. This shows that poor performance is associated with intentional deficit exaggeration and not the experience of pain.

The current study uses a mixed design repeated measure ANOVA which allows for both a within-subjects and a between-subjects examination of the potential effects of pain on cognitive performance. The within-subject factor allows each participant to serve as their own comparison on the D-KEFS subtests, which allows for greater sensitivity in detecting and investigating potential decrements within a cognitive domain (Charness, Gneezy, & Kuhn, 2012). The condition by time interaction indicates whether those in the Pain condition demonstrated a significant reduction in performance from their standard administration condition (Time 1) to the cold-pressor administration (Time 2), relative to Time 1 to Time 2 performance changes for the Control group. The absence of such an interaction indicates that those in the Pain condition did not perform more poorly during pain induction compared to their initial performance on the same task.

Another strength of the current study is that it was conducted in a similar testing environment as clinical assessments. In the clinical practice the D-KEFS is one of the most frequently used measures of, executive function. A trained testing technician administered each subtest in a one on one setting in a relatively secure room free from distractions. As such, the results of the current study generalize to clinical settings through using exact measures and clinical practices that would have been used to gauge the cognitive performances of chronic pain patients. However, instead of patients we used

healthy volunteers to control for extraneous variables associated with chronic pain, in order to examine more precisely the influence of pain. Along with that, we utilized the cold pressor to resemble the closest experience of chronic pain to date. As mentioned above, this is thought to have a simultaneous activation of both Aδ-fibers and C-fibers, which is most similar to chronic pain (Curatolo et al., 2000).

One potential weakness in this study was the inclusion of practice effects due to the lack of alternative tests for the CWIT and TM subtests. Since there were not alternative tests available, the exact same tests were used at baseline and the experimental measure in Part 1 of the study. However due to the mixed measure design of the study, practice effects were essentially equivalent for the control, pain, and simulator groups, thus controlling practice effects across conditions. Those in the pain condition had just as much chance at benefitting from practice as those in the control group did. As such, practice effects should not be considered a confound.

The generalizability of the current study to chronic pain settings may be limited. The current students experienced induced pain, which may be different from the experience of chronic pain. Although the cold pressor is regarded as the method most consistent with the experience of chronic pain, there may be substantial differences between chronic pain patients and healthy volunteers. One example may be the motivational factors of healthy volunteers during laboratory testing as compared to clinical patients who are undergoing extensive formal psychological testing. Chronic pain patients also frequently report comorbidities such as depression, pharmaceuticals, or sleep deprivation, all of which may affect cognition and all of which would likely be less prevalent in a sample of nonclinical volunteers. None of these factors were examined in

the current study. The results of the current study show that the experience of pain itself should not contribute to a significant reduction in performance on the D-KEFS' TM, VF, and CWIT subtests, and so would not be expected to affect performance on other tasks which require these same cognitive abilities.

From here the investigation of the other subtests of D-KEFS should be conducted to find whether induced pain effects the other cognitive abilities not represented by these three subtests. With these 3 tests and the assumptions (which have been very clearly defined from previous studies) that the test has high validity and specificity; we can conclude that pain itself does not influence executive function task performance involving flexibility of thinking on a visual-motor sequencing task, letter fluency, category fluency, category switching, and inhibition. The remaining executive functions, including Task Initiation, Problem Solving, Visual Fluency, Organization, and Self-Monitoring, should be investigated in order to examine whether induced pain influences any aspect of executive functioning.

Another place for further research to be conducted is investigating the sensitivity of D-KEFS to socioeconomic, psychological, and behavioral factors which may influence test performance. The D-KEFS is a battery designed to investigate executive functioning ability, it would be interesting if we understood how depressive, sleep deprived, or medicated profiles performed on the D-KEFS' subtest. This would be used to help explain unexpected poor performances on the D-KEFS in patients with chronic pain.

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