

Running Head: CHRONIC PAIN, EXECUTIVE FUNCTIONING, PAIN PERCEPTION

Chronic Pain History and its Relationship to Executive Function and Pain Perception

Dillon Taylor

UNC-Chapel Hill

taylords@email.unc.edu

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Advisor_____

Dr. Mark Hollins

Reader_____

Dr. Beth Kurtz-Costes

Reader_____

Dr. Kristen Lindquist

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Abstract

Chronic pain is a burdensome and potentially debilitating condition that affects approximately one-third of the United States population. A large body of research has indicated that individuals with chronic pain typically exhibit a number of deficits. Executive functioning levels are diminished, touch perception is amplified, and pain is perceived as more intense and unpleasant as compared to matched controls. While this literature is invaluable in characterizing the profile of chronic pain, little research has examined individuals with a *history* of chronic pain. The current study aims to fill this gap in the literature by examining executive functioning, touch perception, and conditioned pain modulation in individuals with a history of chronic pain. It was found that individuals with a history of chronic pain had better performance on an attentional control task (Stroop test) than control participants but no difference in a working memory task (Ospan). Those with a history of chronic pain exhibited a lower threshold for tactile (pressure) unpleasantness than control subjects, under baseline conditions, but not while simultaneously experiencing a painful thermal stimulus. These individuals also exhibited higher ratings of pressure sensation unpleasantness and intensity while simultaneously experiencing a painful thermal stimulus, but not during the neutral thermal stimulus. These results indicate that individuals with a history of chronic pain not only differ from individuals without a history of chronic pain but also from individuals (described in the literature) with current chronic pain. Future studies should aim to better understand the causal relationships among these variables and how they transform over an individual's life course.

Cognitive aspects of pain perception

Pain perception has long been understood as a complicated and subjective experience with differences between individuals being substantial. While this has been observed and understood for a good deal of time, the exact extent to which cognitive factors can play into this has been largely unexplored until fairly recently. Therefore, it remains a subject worthy of further exploration.

Prior to understanding the relationship between cognition and pain, researchers discovered a broader relationship between that of cognitions and perceptions of one's body (Chapman, 1978). How we perceive ourselves can act as a level of feedback which can in turn alter our bodily states and cognitions. While people often feel as if they just simply "know" how they feel, whether that be tired, joyful, or in pain, this understanding actually arises from a number of independent factors of which we may not be explicitly aware. For instance, someone who hears themself breathe heavily while exercising can make them feel more fatigued they would otherwise. This is due to the fact that attention, whether implicit or explicit, to such physiological feedback can alter bodily states. Conversely, if attention is drawn away from such feedback, individuals find themselves less fatigued. However, the feedback that one receives does not even have to be genuine for this effect to hold true. Continuing with the exercise example, listening to someone else's heavy breathing can produce a similar effect of increased fatigue (Chapman, 1978). Again, it is the attentional factor that drives the difference.

The same effect holds true for pain, which has likely been experienced first-hand by almost all individuals. One useful way to make pain less severe or intense is to distract oneself from it. Correspondingly, increased attention to pain will cause it to be perceived as worse

(Arntz, Dreessen, & Merckelback, 1991). Those who are more introspective to their bodily states generally have lower pain threshold and tolerances (Pollatos, Füstös, & Critchley, 2012). The “rubber hand illusion” is a classic example that depicts how intensely attention can alter pain (Botvinick & Cohen, 1998). In this illusion, individuals look at a rubber arm that is made to appear as if it is potentially attached to their body. While looking at this rubber arm, their real arm and their “new” arm are touched simultaneously in the same places to create the illusion that sensations are being experienced through this rubber arm. At this point, if the rubber arm is harmed, say hit by a hammer, the person will often rapidly pull back their real hand and possibly even let out a brief shout; people report experiencing a painful sensation when this happens. As this illustrates, pain can be produced in lieu of any direct physical stimulation when attention and the expectation of sensation have been properly created.

Conditioned Pain Modulation

Conditioned pain modulation (CPM) is a research paradigm that is used in order to study and better understand diffuse noxious inhibitory control (DNIC) which is the tendency for pain to inhibit pain (Moont, 2010). Better understanding DNIC is of high interest as it is an endogenous form of pain inhibition. By determining the processes by which this occurs, novel methods of pain inhibition could be developed. It has been previously hypothesized that DNIC is a predominantly attentional process. One potential explanation posited that with an additional painful stimulus, less attentional resources would be allotted to the initial painful stimulus which would in turn cause that stimulus to be experienced as less painful. There is evidence that this is at least partially true as discrimination among painful stimuli is worsened when attention is drawn to another painful stimulus (Miron, 1989). Further studies however have demonstrated

that pain is not the only factor in the phenomenon as additional innocuous distractors can increase DNIC beyond that of just noxious distractors (Moont, Pud, Sprecher, Sharvit, & Yarnitsky, 2010).

While DNIC is observed in the general population, variation in levels of DNIC is associated with various conditions. Fibromyalgia and temporomandibular disorder are both chronic pain disorders that are associated with lower levels of DNIC as compared to age matched controls (Edwards et al., 2003; Kosek and Hansson, 1997). DNIC also decreases with age and can ultimately result in negative DNIC, an occurrence in which an additional noxious stimulus will increase the pain of a test stimulus. Furthermore, it has been shown that levels of DNIC are not associated with individuals' pain thresholds or tolerances or psychological factors such as stress, self-efficacy, or knowledge of DNIC (Edwards et al., 2003). Pre-surgery levels of DNIC have been found to be associated with one's likelihood to develop chronic neuropathic pain after the surgery (Granovsky, 2013). While the factors that drive DNIC remain partially unknown, it is clear that it has a strong negative relationship with chronic pain.

Chronic pain and Hypervigilance

Chronic pain and chronic pain disorders are becoming more prevalent as our global population's average lifespan continues to increase. Approximately one third of the United States population has chronic pain (Global Industry Analysts, Inc., 2011). As a result of medication and therapy advancement, there has been an increase in the quality of life for these individuals. Nonetheless, there is still more to be learned about how chronic pain is developed and maintained. While the symptoms can be treated, these conditions must be understood at their core if a cure is ever to be found.

Hypervigilance is an intensified perceptual style that is present in a number of different diseases/disorders and is one of the leading characteristics of fibromyalgia, a chronic pain disorder (McDermid, Rollman, & McCain, 1996). Hypervigilance has also been observed in people who otherwise have normal health as it is not a disorder in and of itself. Over the past few decades, much research has been done to better understand the extent of this hypervigilance. At first, it was believed that those who are hypervigilant show an intensified perception of only noxious somatosensory stimulation (Rollman & Lautenbacher, 1993). Subsequent studies have shown that this perceptual amplification is present for innocuous stimulation as well. For example, it has been demonstrated that this perceptual amplification is present not only for somatosensory stimulation, but for auditory stimulation as well (Hollins et al., 2009). In summation, it seems that those who show a hypervigilant style are more sensitive to both painful and non-painful stimuli of multiple modalities. While many researchers have speculated on the etiology of this perceptual style, little is actually known. As related to what was previously mentioned, it seems attention and bodily awareness plays a huge factor in the presentation of these symptoms.

Pain's effects on cognitive functioning

While pain may reasonably be thought of as the main symptom of a chronic pain condition, there are in fact many additional detrimental symptoms that are commonly experienced alongside physical pain, such as emotional and mental disturbances. Pain is inconvenient, unpleasant, and restricting, often demanding stressful and emotionally draining accommodations that influences how one lives. Individuals with chronic pain are more likely to suffer from depression or anxiety than those who do not. While the potential causal direction is unclear, the conditions provide positive feedback to each other only worsening symptom

severity. Another potentially less noticeable symptom is change in cognitive functioning. Those with current chronic pain often show lowered performance on tasks that measure attentional control, working memory, and general executive functioning as a whole (Abeare et al., 2010). Lastly, it is common for those with chronic pain to sleep on average a few hours less than what is recommended. It is known that failing to get enough sleep is either associated with or can potentially cause most of the aforementioned other symptoms (Kahn-Greene, D. Killgore, Kamimori, Balkin, & W. Killgore, 2007).

In addition to the differences that are seen among chronic pain populations, there have also been some similar changes found in individuals who have experienced acute pain early in life. Acute pain during early stages of development has been shown to be associated with cognitive and motor deficits later in life (Grunau et al., 2009; Wollgarten et al., 2009, 2011). This similarity between acute and chronic pain is important to note as it shows that such associations are not specific only to chronic pain.

Measures and implications of executive functioning

There are many tests of executive functioning that are commonly used in the literature. However, the Stroop interference test and the operation span task are not only widely used but assess overarching functioning, rather than focusing on a specific aspect of cognition (Stroop, 1935; Turner, 1989). The Stroop test measures one's ability to ignore irrelevant information while attending to a specific set of information. In particular, the task requires participants to identify the color of a text that spells out a different color. The two sets of information conflict, as it is often people's first impulse to read out a word rather than identify its color. This returns back to how attention and the ability to attend to specific information is important, both directly in the context of pain and in this broader context as well (Unsworth, Heitz, Schrock, & Engle,

2005). The operation span task similarly requires attentional control in addition to an intensive amount of working memory. It requires the answering of math problems while memorizing a sequence of letters that must be sequentially recalled (Le Bars, Dickenson, & Besson, 1979).

Current Study

While there is a vast amount of research regarding chronic pain, executive functioning, and pain perception, studies largely focus on populations who are currently experiencing chronic pain. This is invaluable for better understanding clinical populations but restricts what can be learned about these variables on a generalizable basis. The current study aims to fill this gap in the literature by exploring the relationships between these variables in individuals who specifically have a history of chronic pain. Doing so may reveal which symptoms are specific to current chronic pain and which can result from periods of chronic pain earlier in life.

We hypothesize that 1) increased levels of hypervigilance are specific to individuals experiencing current chronic pain, and that therefore, individuals with a history of chronic pain (CPH) will not have significantly different scores from those in the no history of chronic pain (NCPH) control group. 2) The CPH and NCPH groups will not perform significantly differently on the operation span task as we believe previously found performance deficits in current chronic pain sufferers are caused by their current chronic pain. 3) The CPH group will have less Stroop interference as compared to the NCPH group potentially caused by higher attentional facilities as provided by their chronic pain history. 4) The CPH group will demonstrate lower levels of CPM as compared to the NCPH group. 5) Lastly, we hypothesize that the CPH group will have a lower unpleasantness threshold and will rate the pressure stimuli as more unpleasant and intense.

Method

Participants

Twenty six individuals, eleven with a history of chronic pain and fifteen without, participated in the study. Chronic pain history was self-reported in the pain history questionnaire. All recruiting was done through UNC's SONA system, a recruiting website that consists of psychology 101 students who participate in studies as a component of their class. Potential participants were excluded from the study if they did not meet the age requirement (18-25), were in a class taught by Dr. Hollins, had been diagnosed with diabetes, urticaria, Raynaud's disease, or a peripheral vascular disease, had neurological impairment, had surgery or nerve damage to either hand or forearm, had a current injury to either hand or forearm, or were colorblind or had abnormal color vision. While it is possible some potential participants did not sign up for the study due to these exclusion criteria, no participants who signed up for the experiment were excluded by these criteria.

Apparatuses

The pressure stimulator apparatus used was previously described in Hollins et. al, (2009) with a few minor changes. The apparatus consisted of a rectangular platform with an upright divider in the center. This divider had a hole cut out of it at the base through which participants extended their right hand and forearm, allowing the weighted rod to be lowered onto their right forearm. There was a mounted frame that allowed the weighted rod to be manually lowered at the discretion of the experimenter. The rod itself had a 5mm Delrin tip which came into contact with participants' forearms. Circle weights were loaded onto two vertical upward facing rods in

order to alter the pressure delivered by the device. The center divider in addition to two lateral dividers hid the frame and the weights from the participants' view.

The apparatus for the conditioned pain modulation portion of the task consisted of a small ten liter cooler, a plastic divider with holes to ensure that ice did not come into direct contact with the participants' hands, and a small electronic bubbler (Tetra) that pumped air through a plastic tubing with rested in the cooler to help the water circulate. For the cold condition, a combination of refrigerated water, room temperature water, and ice was used in order to achieve and maintain a target water temperature of 6° centigrade as measure by a K/J thermometer (421502; Extech Instruments Corp., Nashua, NH, USA) with a K bead thermocouple (TP870; Extech Instruments Corp.). Temperatures within the range of 5.5° – 6.5° centigrade were deemed acceptable. Room-temperature tap water was used for the control condition which had a target temperature of 32° centigrade. Temperatures within the range of 31° – 33° centigrade were deemed acceptable.

Measures

The Pain History Questionnaire (PHQ) was used to determine if participants had previously experienced any chronic pain, and was used to determine if participants were in the history of chronic pain group or no history of chronic pain group. The questionnaire also asked for age(s) of onset of chronic pain, doctor diagnosis (if applicable), age and description of their earliest pain memory, typical locations of pain by body region, if pain had significantly interfered with daily activities, and type of pain past medication use if any. This questionnaire was modified from a previous version designed by Mullis (2011).

The Current Pain Questionnaire (CPQ) is a set of questions regarding the location and intensity of any current pain that participants may be having. It distinguishes between acute and chronic pain and also asks if the participant is taking any medication for pain. This was used also used to determine if participants had any current pain that warranted their exclusion from the study. The CPQ was produced by our lab.

The Pennebaker Inventory of Limbic Languidness (PILL) (Pennebaker, 1982) was used to determine if participants were hypervigilant. It lists a number of commonly experienced symptoms (runny nose, cough, headaches...) and asks participants to report how often they experience each symptom. It was developed to test for cognitively driven perceptions of symptoms. Here, it is used as a measurement of hypervigilance, an intensified perceptual style in which individuals have greater frequencies of recalled symptoms as shown by the PILL, and have lowered pain and unpleasantness thresholds and tolerances (Hollins, 2009).

The first cognitive task used was the operation span (ospan) task and was completed on a computer. This computer automated version of the ospan was developed by Unsworth et al. (2005) and runs on Inquisit, an application which is used to develop and run stimuli for research. The program itself is available for free download on Millisecond's website (<http://www.millisecond.com/download/library/OSPAN/>), the company that sells Inquisit. In this task, participants were asked to solve simple math problems while remembering a series of letters. First, math problems were presented; on the following screen, a solution to the math problem was shown and the participant was instructed to either agree or disagree with that answer; next, a letter for the subject to remember was presented. These steps were repeated 3-7 times per trial with different combinations of math problems and letters. At the end of each trial, participants were presented with a screen which had twelve letters on each. Participants then

recalled the letters that they were presented with in order by clicking each letter. Corrections could be made by erasing an entry and making a new one. If participants could not recall a letter they had the option of entering a “blank” at that position. Each participant completed 30 trials.

The second cognitive task, the Stroop task, was also computerized. This task required participants to state aloud the color of given text. There were two different blocks to this task, a control block and a test block. In the control block, participants stated aloud the color of a series of the capitalized letter “X”. In the test block, participants stated aloud the color of text that spelled out various colors. For example, if the word “red” appeared printed in green, the participant should respond by saying “green”. Similarly, if “XXXXXX” appeared printed in yellow, the participant should respond by saying “yellow”. There were 45 trials per block for a total of 90 trials. Times were recorded for each block, and the net difference between the two blocks was their Stroop interference level. These stimuli and methods were the same as used by Harper and Hollins (2012).

The pain perception task used the two apparatuses described above. Participants submerged their left hand in the water while pressures were applied to their right forearm. Participants rated the intensity of sensation and unpleasantness of sensation of each weight. They also categorized each weight as painful, unpleasant but not painful, or neutral.

Procedure

Upon arriving in the lab, each participant was informed of the layout of the study and the tasks that they would complete. Upon giving informed consent, participants first completed the PHQ, the CPQ, the PILL, and a brief demographics form in this order. After completing these, participants began the operation span task. They were seated at a computer and told to follow the

instructions on screen and to ask if anything was unclear. The instructions walked the participants through how the task would work and provided practice questions to acclimate them to the task. Once the participants completed the practice questions and fully understood how to complete the task, they continued to the test phase of the task. Each step had a time limit which was based on the average time it took each individual participant to complete the practice questions with the exception of the letter recall step, which was untimed. Additionally, participants had to maintain a minimum of 85% accuracy on the math portion of the task. Participants were explicitly told of both of these conditions.

The Stroop task was administered next at the same computer. Participants first received instruction on how to complete the task and were given a few practice trials. After they completed the practice trials they moved onto the test trials. All participants completed the control condition first (only “XXXXXX”s) and the Stroop condition (color words) second. If participants incorrectly identified a color, they could correct themselves and continue. Total incorrect color identifications, uncorrected incorrect color identifications, and total time were recorded.

The final task, the pressure and thermal stimulation task, was then completed. The participant rested his/her right forearm, volar side down, on a small pillow through the apparatus. Immediately before any pressures were applied to the right forearm, the participant placed his/her left hand into the cooler of water up to their wrist. Participants were instructed to remove all jewelry from their hands and arms. This arrangement allowed the experimenter to apply various levels of pressure to the participant’s right forearm using a weighted rod for fifteen seconds at a time while the participant’s left hand was in the water. During these fifteen seconds, the rod was gradually lowered onto the forearm for approximately one second and gradually

raised off the forearm for approximately one second, resulting in approximately thirteen seconds of uninterrupted rod to forearm contact. After the weighted rod was raised off of the forearm, the participant rated the intensity of the sensation it produced on a scale from 0-100, where 0 meant “no sensation” and 100 meant “the most intense sensation imaginable.” Next, the participant classified the sensation as neutral, unpleasant but not painful, or painful. Finally, the participant rated the unpleasantness of the sensation on a 0-100 scale, where 0 meant “not at all unpleasant” and 100 meant “the most unpleasant sensation imaginable.” This was repeated for a total of six trials per participant with weights ranging from 77 grams to 1077 grams in steps of 200 grams. The orders of the weights were randomized for each participant. For the first six trials, the participant’s left hand was in neutral warm water, and for the second six trials, their hand was in the painfully cold water. Water temperature was measured and recorded both before and after each set of six trials to ensure that it consistently stayed in the acceptable temperature range. If at any point in time, the pain on either arm became intolerable, participants had the option to remove their arm(s) or end participation in the study entirely. If the participant’s hand was still in the water after five minutes, they were asked to remove it as this was the maximum amount of time a participant was allowed to have their hand in the water. Each set of six weighted rod trials took typically around four minutes for each participant, after which they would remove both their hands from the apparatuses and dry off their left hand with provided paper towels. Once they had removed their hand, they rated the intensity of thermal pain using a 0-100 scale on which 0 meant no pain and 100 meant the most intense pain imaginable. They also rated the unpleasantness of thermal pain using a 0-100 scale on which 0 meant not at all unpleasant and 100 meant the most unpleasant pain imaginable. After the completion of this, participants were debriefed about the study and given research credit on the UNC SONA system.

Results

The study was completed by twenty-eight participants. The first two participants in the study were pilot participants and their data were not used in the analyses. The remaining twenty-six individual's data were used for the analyses. Three of these twenty-six had their participation in the study ended early; two chose to end their participation in response to the painfully cold thermal stimulus, and one participant was unable to complete the study due to lack of enough cold water for the cold thermal stimulus. Partial data from these three participants is used where applicable. Eleven participants reported a history of chronic pain and fifteen reported no history of chronic pain. The chronic pain history group had a mean age of 19.00 (SD = 1.18) and the no chronic pain history group had a mean age of 18.93 (SD = .96); this difference was not significant. In all statistical tests, a significance criterion of $p = .05$ is used.

Questionnaires

Of the eleven participants with a history of chronic pain, three had received a doctor's diagnosis of a chronic pain condition. Besides the questions pertaining to history of chronic pain the PHQ revealed no differences between groups. Participants' mean age of their earliest pain memory was 7.4 (SD = 4.4) and they had an average of 2.1 (SD = 1.3) typical pain locations. Eight participants reported that pain had significantly interfered with their daily life at some point in time and eight reported having regularly taken some sort of pain medication at some point in their lives.

Similarly, there were no group differences in responses for the CPQ. On a zero to one hundred scale, average recent (i.e. during the last two weeks) pain intensity ratings were 19.55

(SD = 16.65) for the CPH group and 11.73 (SD = 17.43) for the NCPH group. Mean recent pain unpleasantness was 20.73 (SD = 18.13) for the CPH group and 12.67 (SD = 21.23) for the NCPH group. Mean recent time in pain by percent of waking hours was 11.18 (SD = 10.15) for the CPH group and 10.07 (SD = 17.37) for the NCPH group. On a zero to one hundred scale mean current pain intensity was 2.91 (SD = 4.68) for the CPH group and 4.67 (SD = 9.89) for the NCPH group. Mean current pain unpleasantness was 2.64 (SD = 3.89) for the CPH group and 5.87 (SD = 11.01) for the NCPH group. Four participants reported current chronic pain and two reported that they were currently taking medication for their current pain.

The mean score for the PILL was 19.15 (SD = 8.98). The mean score was 20.55 (SD = 9.62) for the chronic pain history group and 18.13 (SD = 8.68) for the no chronic pain history group. An independent samples t-test between groups showed no significant difference in their scores (figure 1).

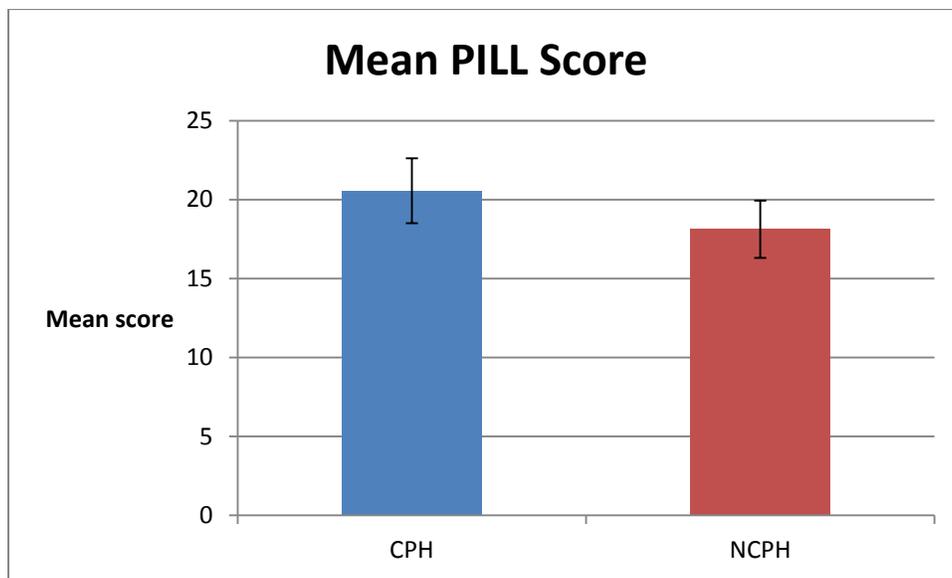


Figure 1. Bar chart showing the mean PILL scores by group. Error bars give \pm SEM.

Cognitive tasks

All participants were able to maintain a score of 85% on the math portion of the ospan task, so no data were excluded. Two different scoring methods were used in this test. In the original method, a participant's score is the sum of all letters in recalled sequences that were entirely correct. For example, if five out of five letters were recalled correctly, five points were added to the participants score. However, if six out of seven letters were correctly recalled for one set, zero points were added. Through this method of scoring, the mean scores were 44.91 (SEM = 4.30) for the chronic pain history group and 42.53 (SEM = 3.61) for the no chronic pain history group. A t-test revealed that there was no significant difference between these values. As this method of scoring results in some lost information, we also scored the test an alternative way in which each correct letter response simply corresponds to one point towards a participant's score (Unsworth et al., 2005). By this method, the mean scores were 60.45 (SEM = 2.42) for the chronic pain history group and 60.33 (SEM = 1.73) for the no chronic pain history group. There was still, however, no significant difference between means.

Stroop interference scores were calculated by subtracting participants' control times from their experimental times. The chronic pain history groups mean interference time was 12.81 seconds (SEM = 1.16) and the no chronic pain history group had a mean interference time of 18.31 seconds (SEM = 1.83). An independent samples t-test showed that this difference was significant, $t(26) = -2.34$, $p < .05$ (figure 2). To see if this difference was caused by a difference in control scores, another t-test was performed on control time; no significant difference between groups was found. Next, t-tests between chronic pain history and no chronic pain history groups were performed for the number of total mistakes and the number of uncorrected mistakes for both the control condition and the Stroop condition of the Stroop test. There were no significant group differences for any of these four tests.

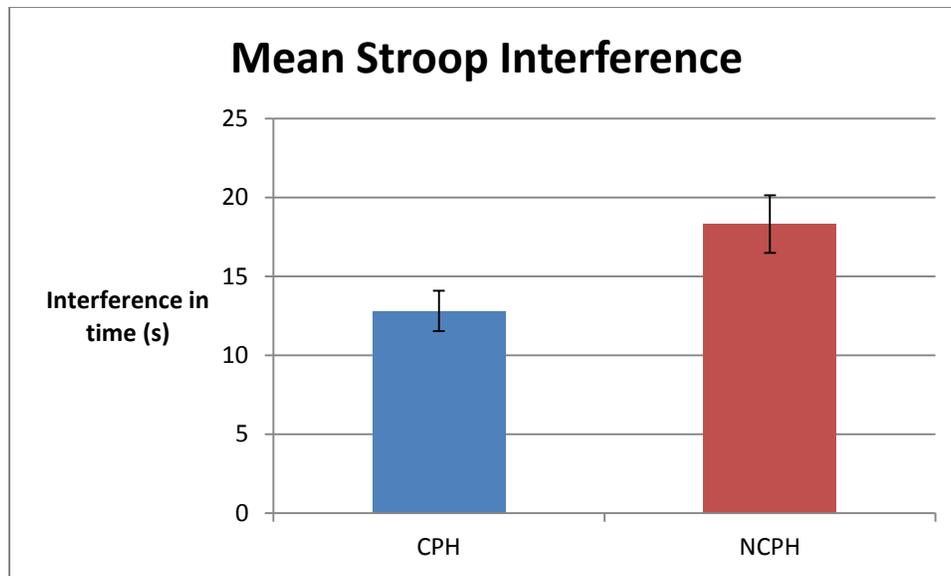


Figure 2. Bar chart showing mean Stroop interference scores by group. Error bars give \pm SEM.

Touch and Pain Perception Task

Unpleasantness thresholds for both thermal conditions were calculated. Pain thresholds could not be calculated for either thermal condition as there was not a sufficient number of participants who reported any pressures as painful. Only nine participants reported any weight as painful in the control thermal condition, and only two reported any pressure as painful in the painful thermal condition. A participant's unpleasantness threshold was considered to be the least amount of pressure that they reported as unpleasant but not painful. In the neutral thermal stimulus condition, the CPH group had a mean unpleasantness threshold of 422g (SEM = 39g) and the NCPH group had a mean unpleasantness threshold of 597g (SEM = 73g). A t-test showed that this difference was significant, $t(20.83) = -2.12$, $p < .05$ (figure 3). In the painfully cold thermal stimulus condition, the CPH group had a mean unpleasantness threshold of 452g (SEM = 77g) and the NCPH group had a mean unpleasantness threshold of 465g (SEM = 110g). A t-test showed that these differences were not significant (figure 4).

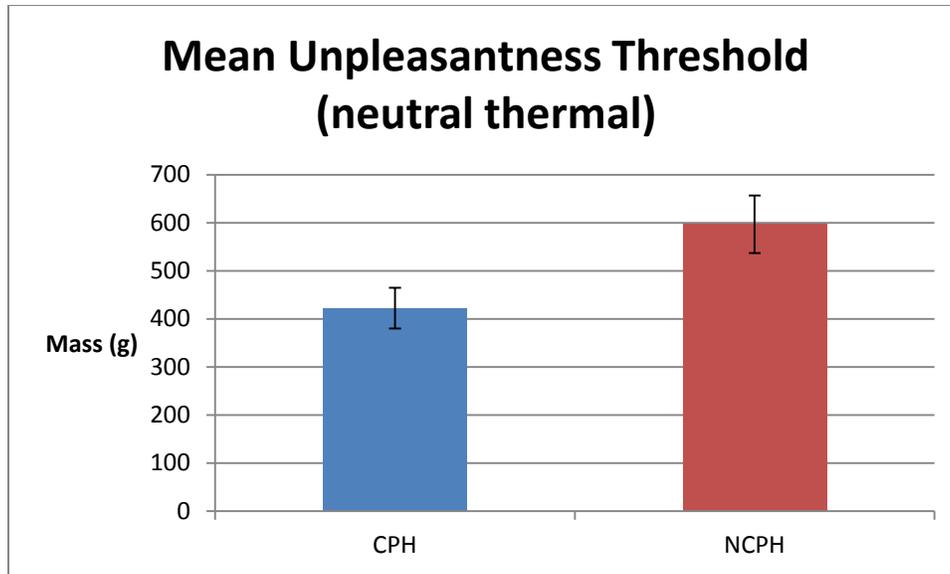


Figure 3. Bar chart showing mean unpleasantness threshold by group for the neutral thermal condition. Error bars give \pm SEM.

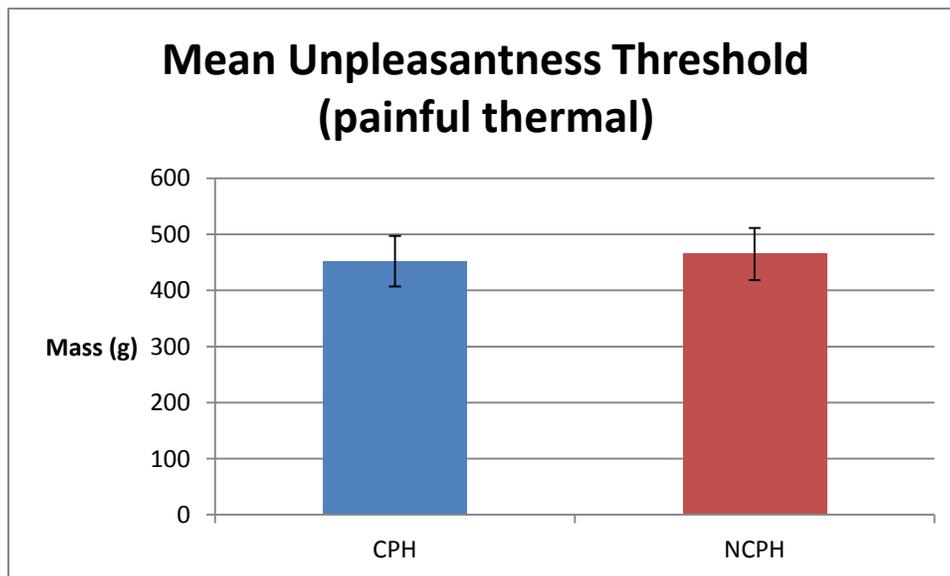


Figure 4. Bar chart showing mean unpleasantness threshold by group for the painful thermal condition. Error bars give \pm SEM.

For analyses using ratings on 0-100 scales, data were transformed into logarithmic form as is standard for ratio scaling experiments (Gescheider, 1997). Ratings of zero were replaced with a small nonzero number in order to allow the logarithmic transformation to successfully occur for all values. Zeros were replaced with .5, half of the smallest nonzero value (one) reported by any participant (Hollins, 2009). Four 2(chronic pain history) by 6(force) mixed model ANOVAs were performed for unpleasantness and intensity ratings for both the neutral and painfully cold thermal conditions. There was no main effect of group for either unpleasantness or intensity ratings in the neutral thermal condition. A main effect of group was found for both unpleasantness, $F(1, 21) = 14.85, p < .01$, and intensity, $F(1, 21) = 15.28, p < .01$, for the painfully cold thermal condition. A main effect of pressure was found for all four ANOVAs. There were no significant group interactions found in any of the four ANOVAs. Figures 5-8 below plot these four analyses.

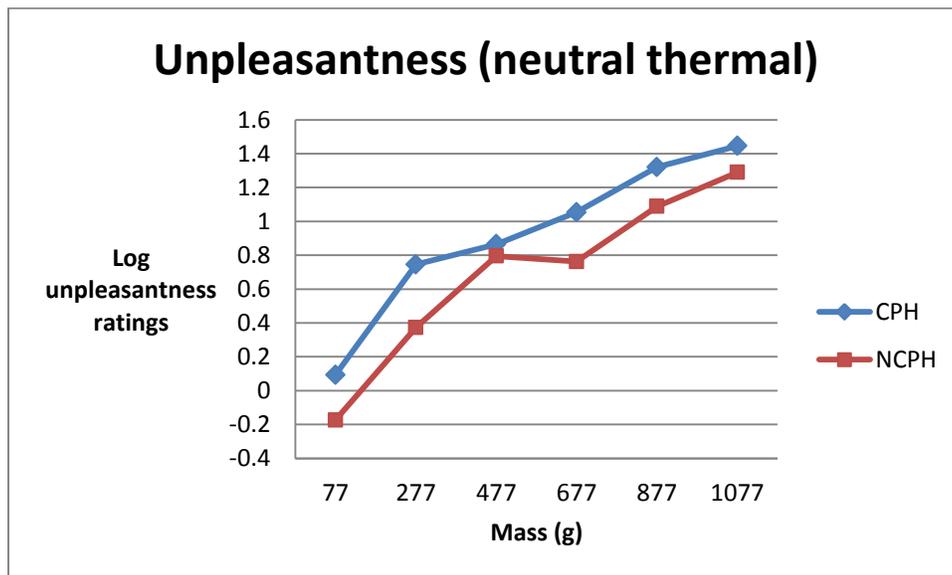


Figure 5. Line graph showing data from 2(group) by 6(mass) mixed ANOVA for unpleasantness ratings during the neutral thermal stimulus.

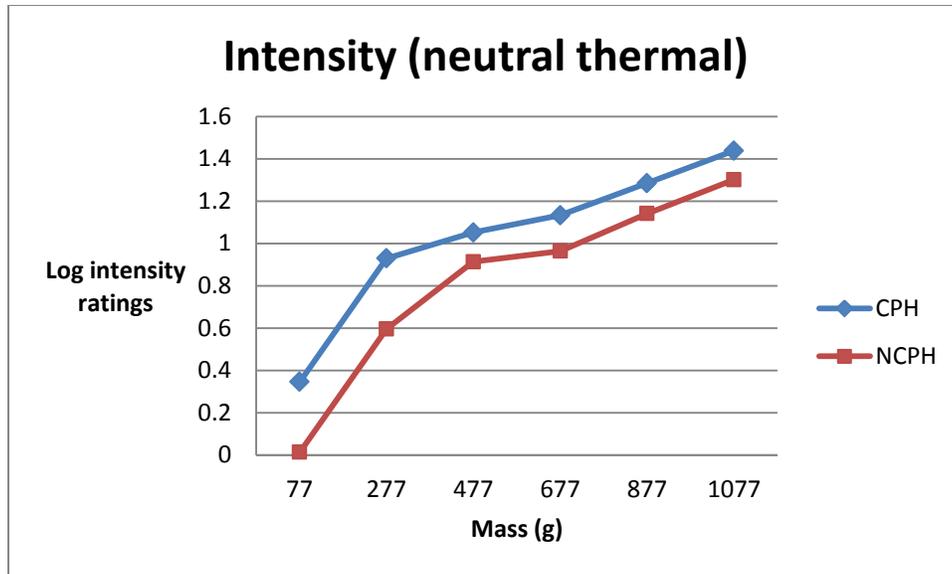


Figure 6. Line graph showing data from 2(group) by 6(mass) mixed ANOVA for intensity ratings during the neutral thermal stimulus.

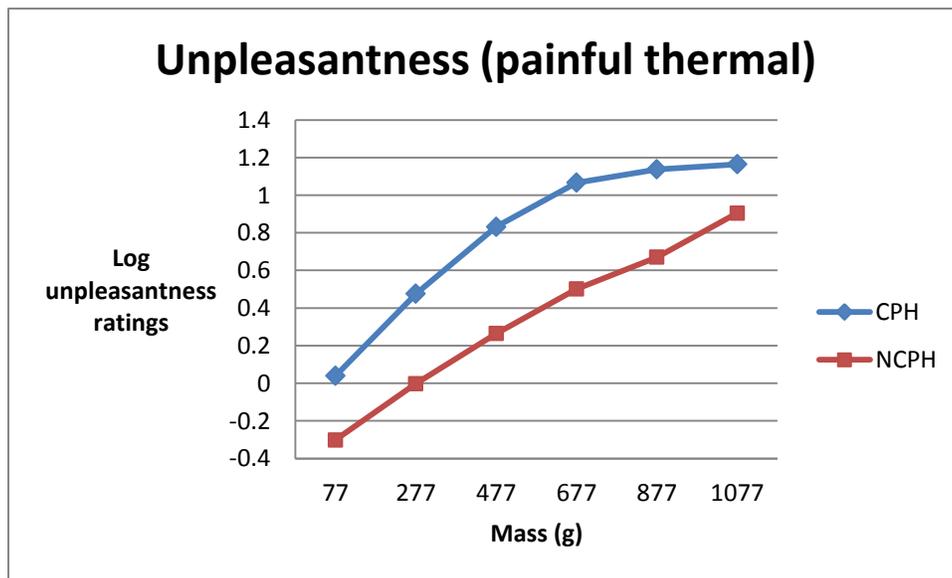


Figure 7. Line graph showing data from 2(group) by 6(mass) mixed ANOVA for unpleasantness ratings during the painful thermal stimulus.

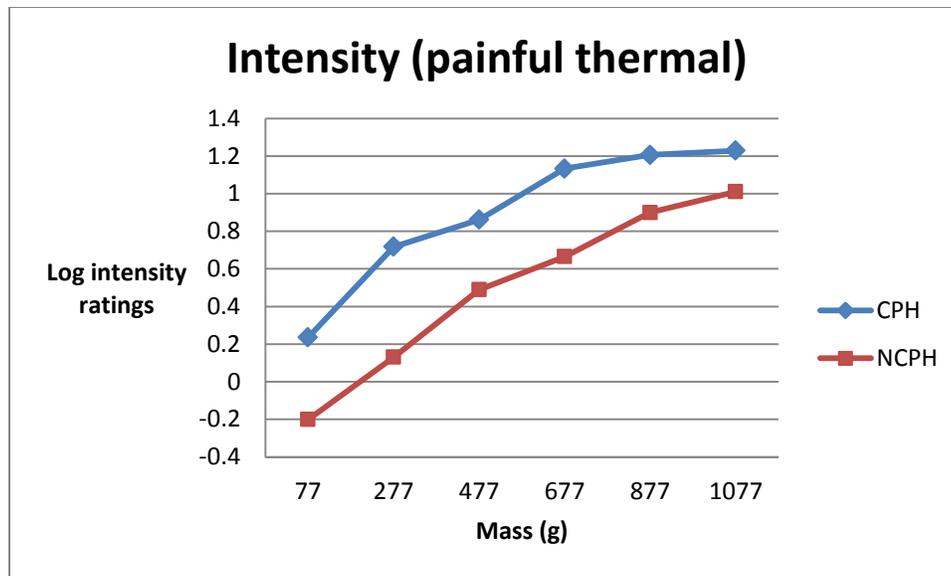


Figure 8. Line graph showing data from 2(group) by 6(mass) mixed ANOVA for intensity ratings during the painful thermal stimulus.

Conditioned sensation intensity modulation (CSIM) and conditioned sensation unpleasantness modulation (CSUM) scores for each pressure were calculated for each participant by subtracting painfully cold thermal stimuli scores from neutral thermal stimuli scores. These two scores are used as a substitute for CPM as not enough pressures were found painful to calculate CPM. Two 2(chronic pain history) by 6(force) mixed model ANOVAs were performed, one for CSIM and one for CSUM. For the CSIM ratings, there was a significant main effect for force, $F(1, 24) = 5.62, p < .05$, but not a main effect of group, $F(1, 24) = 3.03, p = .09$. The interaction between the two was not significant, $F(1, 24) = 1.59, p = .167$. For CSUM there was also a main effect for force, $F(1, 24) = 7.57, p > .05$, but not for group, $F(1, 24) = 2.81, p = .11$. Again, the interaction between the two was not significant, $F(1, 24) = 2.04, p = .077$. These data are shown below in figures 9 and 10 respectively.

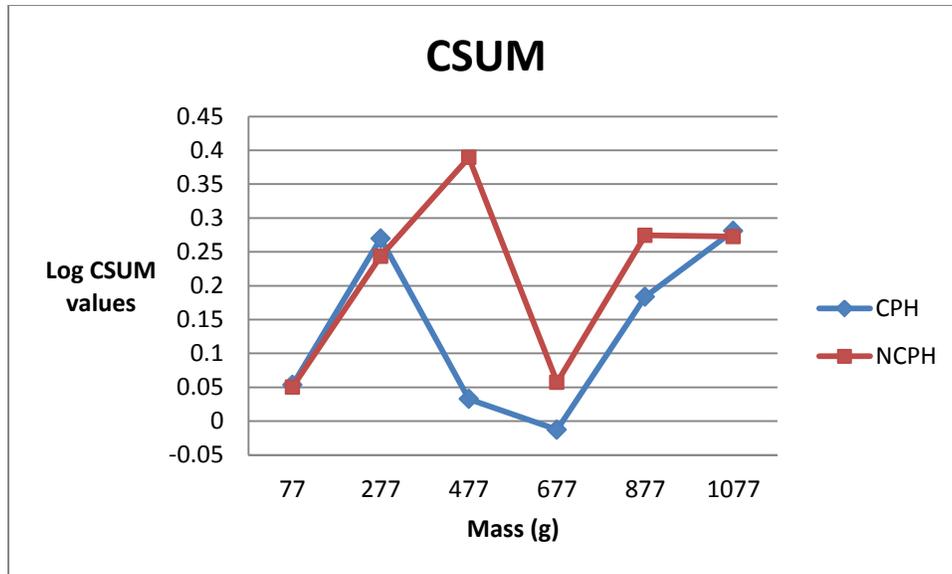


Figure 9. Line graph showing data from 2(group) by 6(mass) mixed ANOVA for CSUM scores.

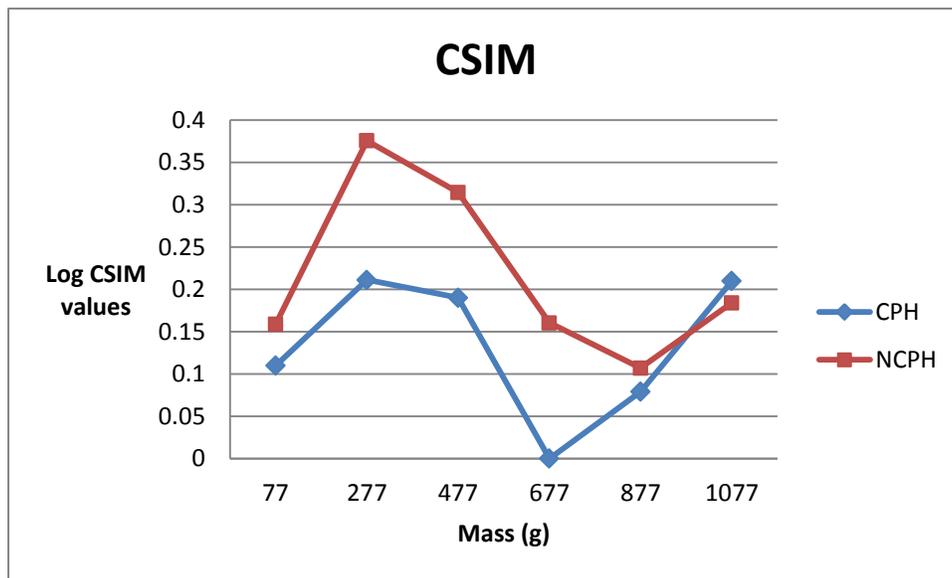


Figure 10. Line graph showing data from 2(group) by 6(mass) mixed ANOVA for CSIM scores

Discussion

Questionnaires

The main finding from the questionnaire data was that individuals with a history of chronic pain and individuals without a history of chronic pain have comparable levels of hypervigilance, as determined by the PILL. This lack of difference is interesting since higher levels of hypervigilance are commonly associated with individuals who currently have chronic pain. Of the four participants that exhibited current chronic pain, they did not have significantly different levels of hypervigilance as compared to those without current chronic pain. This result is not unexpected however given a group size of only four. While we were unable to collect data on hypervigilance at the time of chronic pain for the rest of the participants, past research suggest that they likely were hypervigilant during this time. If this were the case, then these results support the potential for levels of hypervigilance to decrease to normal once chronic pain is absent. Alternatively, since levels of hypervigilance in adolescent chronic pain patients have not been specifically measured, it is possible that they were not hypervigilant at the time of chronic pain. If so, this would suggest that hypervigilance does not have to precede or co-occur with chronic pain. For this matter, longitudinal studies provide the best possibility of further understanding the direction of this relationship.

No measures regarding pain history or current pain were significantly associated with any other variables of interest. As it was found that those with a history of chronic pain had a lower unpleasantness threshold in the neutral thermal stimulus condition it may have been expected that they would report higher levels of current pain on the CPQ, but this was not the case. It seems that in spite of having this lower threshold, it is not severe enough to cause increased levels of current pain; this may be due to a number of factors. The calculated threshold was of

unpleasantness of sensation in response to a stimulus, whereas the questionnaire asked for ratings of spontaneous pain, not sensation ratings. While it is known that these two are closely related they are not synonyms with each other. Therefore, a lower unpleasantness threshold may not actually translate to increased current pain on average. Another potential explanation is that the level of attention required in the pressure experiment is different from the level of attention given to current levels of pain. It is possible that levels in current pain between these groups may vary given an attentional manipulation.

Cognitive Tasks

Both groups performed comparably on the automated operation span task. While executive functioning is generally impaired in individuals who have chronic pain (Abeare et al., 2010), here it was found that a history of chronic pain was not associated with the difference. Similar to levels of hypervigilance, this may indicate that executive functioning impairments that exist during chronic pain can be reversed once the chronic pain has ended. Alternatively, it is possible that adolescents who develop chronic pain do not experience the same deficits that adults do. This may be because chronic pain alone is not adequate to produce such deficits in a young population.

Individuals with a history of chronic pain had significantly less Stroop interference than the no chronic pain history group. This effect was not caused by difference in control time and there were no significant differences of number of mistakes between groups. This finding most strongly differs from previous literature regarding individuals who are suffering from current chronic pain in that usually there is no difference between groups or the direction of this effect is the opposite; individuals experiencing chronic pain typically perform worse on such attentionally

based inhibitory control task (Abeare et al., 2010; Grisart & Plaghki, 1999). One main difference observed between these two findings is current vs past chronic pain, a discrepancy that may be responsible for the variation in results. Experiencing current chronic pain may worsen an individual's performance on this task as the pain itself may be distracting. This alone however does not explain why the chronic pain history group outperformed the control group. We believe that this finding may be caused by better attentional control as learned through coping with past chronic pain. The ability to distract oneself from pain can be immensely helpful in reducing pain and increasing quality of life. If individuals learned such attentional strategies explicitly or implicitly during their chronic pain, it is possible that this skill could transfer over to other attentional tasks, such as the Stroop test. This could also help explain why current chronic pain sufferers perform worse at such tasks. If they have to allot cognitive attentional resources for pain inhibition, they will have fewer resources to complete such a task.

Touch and Pain Perception Tasks

Conditioned Pain Modulation

Average levels of CPM were not significantly different but were approaching significance. The chronic pain history group had lower levels of CPM on average as compared to the control group (figures 8 & 9). When individual forces were analyzed it was found that the chronic pain history group had significantly less CPM at the force of 6.8N. This was the case for both measures of intensity and unpleasantness. For this force, the chronic pain history group actually displayed negative CPM. This is consistent with the lower levels of CPM observed in individuals with current chronic pain. These measures of CPM also suggest that these individuals may be at risk of developing another chronic pain disorder (Granovsky, 2013). While average

CPM was not significant across groups, it seems that this may be due to insufficient power. Given the relatively small sample size and trend towards significance, it seems likely that a larger sample size would have yielded significant results. Regardless, the significant result at the force of 6.8N still provides valuable information. At least for this pressure, the two groups have a fundamentally different system of pain perception. Whether attentional or physiological, combined noxious stimuli intensify rather than diminish pain. This difference may be vital in understanding how and why individuals develop chronic pain conditions.

Unpleasantness Threshold

The chronic pain history group showed a lower unpleasantness threshold for the neutral thermal condition but no difference in unpleasantness threshold was found for the painfully cold thermal condition. This suggests that CPM neutralized the difference in threshold between groups. Based off of the mean thresholds for both conditions between groups, it appears that the no chronic pain group experienced a decrease in threshold as caused by the CPM while the chronic pain history group's threshold remained essentially the same. The other possible driving force would have been an increase in threshold for the chronic pain history group, but this is not the case. Rather, the baseline unpleasantness scores for the chronic pain history group look the same as the no chronic pain history group's DNIC ratings. It essentially appears like the chronic pain history group is always under the effect of an additional noxious stimulus.

Sensation Intensity and Unpleasantness ratings

Differences in sensation intensity and unpleasantness ratings between groups in the neutral thermal stimulus condition were largely insignificant, with the exception of intensity ratings for two of six forces. In the cold thermal stimulus condition however, all but one of twelve ratings were significantly different between groups, with the chronic pain history group

giving higher ratings in all cases. These findings are highly important as they show for the first time a significant difference in touch perception in a group of individuals that has a history of chronic pain as opposed to only current chronic pain.

Limitations and Future Directions

While the current study found multiple significant and thought provoking outcomes, as with any study, there are ways in which it could have been improved upon to provide more useful data. Given the young and generally healthy sample used, application of the findings may be in clinical populations dealing with chronic pain. However, this is still advantageous as most studies that examine chronic pain do so either with current chronic pain sufferers or older populations. Thus, the sample used here has yielded results that have not yet been displayed in those populations, providing a new invaluable perspective on chronic pain history, executive functioning, and pain perception.

One other limiting factor of this research was sample size. A larger sample would have been preferable as there was likely not sufficient power here to show some potentially significant effects, such as total CPM levels between groups. In spite of this, however, we still managed to identify many statistically significant differences which speak to the intensity of effect size for these variables.

Looking forward, future studies should aim to discern causal directions among the variables explored here. Large scale longitudinal studies appear most promising for accomplishing this goal. Taking the same measurements that were taken here over a course of years would allow researchers to see the order in which phenomena (CPM, threshold changes, and executive functioning changes) come into existence and evolve in response to one another.

This information would in turn allow for better chronic pain prevention and treatment in addition to more broad knowledge regarding pain and executive functioning as a whole. With such advancements, we can hope to see decreased rates of chronic pain and increased quality of life in those who have chronic pain, ameliorating a social, economic, and personal burden that currently negatively affects the global population as a whole.

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