INVESTIGATION OF THE RELATIONSHIP BETWEEN MENTAL WORKLOAD AND CHRONIC PAIN

A Thesis

by

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ABSTRACT

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Chronic pain is experienced by one in five adults in the U.S. and significantly impacts the individuals' day to day life. Chronic pain is often accompanied by fatigue, poor sleep quality, and psychological symptoms. These negative factors related to chronic pain are also associated with increased mental workload levels, particularly in the workplace. Mental workload refers to the amount of cognitive effort used by an individual to complete a task(s). The present study assesses the relationship between chronic pain and mental workload. Participants with and without chronic pain completed four variations of N-back tasks (used to induce mental workload at increasing levels). After completing each variation of the N-back task, participants completed the NASA-Task Load Index (TLX). The NASA - TLX is a validated subjective measure of workload. A mixed repeated measures ANOVA and Bayesian mixed repeated measure ANOVA were computed to assess the relationship between chronic pain and mental workload (as evaluated by NASA - TLX), The results suggest an interaction of chronic pain and mental workload, in which individuals who experience chronic pain had increased workload levels on three of the four variations of the N-back task. An interaction between chronic pain and mental workload was suggested by the results, F

(3,135) = 4.720, $p = .004$, $\eta^2 = 0.84$. A Bayesian ANOVA revealed that the data were approximately 8 times more likely to occur under an interaction model of chronic pain and mental workload ($BF_{inclusion} = 8.348$). Future studies should be completed to investigate further the relationship between chronic pain and mental workload, including electrophysiological measures (to assess workload better) and measures of fatigue (to assess fatigue's role in the relationship). The results suggest that workload and chronic pain have a relationship in which individuals with chronic pain report higher workload than individuals without chronic pain. This relationship is important to understanding and mitigating the negative symptoms of chronic pain.

Keywords: Chronic Pain, Mental Workload, Cognitive Workload, NASA - Task Load Index, N-Back

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CHAPTER I

INTRODUCTION

Chronic pain, defined as ongoing pain lasting 12 weeks or longer, affects 1 in 5 U.S. adults (Treede et al., 2015; Dahlhamer et al., 2018). However, the presence of chronic pain does not exempt these adults from activities required for daily living. Only about 18% of people with chronic pain are employed but may continue to experience strain to meet their expectations at work, leaving about 72% of chronic pain sufferers being unemployed (Dahlhamer et al., 2018).

Cognitive workload is a measure often used in workplace settings to assess whether individuals are working at a level that is efficient and maximizes productivity (Blanco et al., 2018; Castro et al., 2019). A higher level of workload indicates that individuals may be overloaded and thus performing tasks in a less than optimal state which may produce errors (Castro et al., 2019). Workload can be affected by several factors including, sleep, stress, and fatigue (Gao et al., 2013; Torres et al., 2016; de la Vega et al., 2018; Bonvanie, 2016; Finan et al., 2013; Aaron & Buchwald, 2003; Naughton et al., 2007; Ericsson et al., 2002). Poor sleep quality and the presence of fatigue results in many errors and low productivity, indicating less than optimal workload levels (Lerman et al., 2012).

Chronic Pain

Approximately 20% of U.S. adults are estimated to experience chronic pain based on data from 2016 (Dahlhamer et al., 2018). Chronic pain brings forth a variety of additional challenges that an individual must face. Fatigue, stress, and poor sleep quality have all been found in individuals experiencing chronic pain (Finan et al., 2013). These negative consequences can impact the day to day life of the individual causing them to miss work, time with family, spend additional money on treatments and medications and experience an overall decrease in quality of life (Dahlhamer et al., 2018; de la Vega et al., 2018).

Sleep quality is highly related to chronic pain (de la Vega et al., 2018; Bonvanie, 2016; Finan et al., 2013). Sleep significantly predicts chronic pain as well as produces a long-term increase in pain severity (Bonvanie, 2016). Sleep issues significantly predicted chronic pain onset as well as the persistence of chronic pain. Bonvanie (2016) observed the relationship between chronic pain and sleep issues to be mediated by fatigue as well as psychological symptoms such as depression and anxiety.

The relationship between fatigue and pain is also strong and heavily researched (de la Vega et al., 2018; Aaron & Buchwald, 2003). Fatigue refers to the mental and physical tiredness that is often experienced by individuals, sometimes as a result of a particularly extenuating activity and sometimes with no specific identifiable cause (Aaron & Buchwald, 2003). The effects of mental and physical fatigue, although different in origin, often produce similar results, such as slow reaction times and increased errors (Torres et al., 2016). Fatigue is also associated with sleep issues, physical disability, and depressive symptoms, all symptoms of chronic pain (de la Vega et al., 2018).

In addition to the physical issues that are accompanied by chronic pain, psychological symptoms are also common (Naughton et al., 2007; Ericsson et al., 2002; Keogh et al., 2006). Depression is significantly correlated with and even predicts, pain related disability (Naughton et al., 2007; Ericsson et al., 2002). Furthermore, pain rating is correlated with Beck Depression Inventory scores as well as Pain Anxiety Symptom Scale scores (Keogh et al., 2006).

Workload

Cognitive workload refers to the amount of mental effort used by an individual to complete a task(s) (Gao, et al., 2013; Xie & Salvendy, 2000). The understanding of workload is crucial in many areas of life, such as driving (Castro et al., 2019) and piloting (Blanco et al., 2018). Workload is affected by a variety of factors, including the task at hand and its complexity, the emotional status of the individual, level of motivation, and fatigue (Gao et al., 2013).

Mental workload is mediated by sleep quality in individuals with musculoskeletal disorders (Heidarimoghadam et al., in press). Occupational fatigue is found to have a positive correlation with mental workload within an administrative work setting (Sartang et al., 2018). Furthermore, workload is one of the most crucial factors resulting in fatigue (Lerman et al., 2012). It is suggested that fatigue may be responsible for workers losing concentration, making mistakes, falling asleep, and having a decreased reaction time (Transport Canada as cited in Torres et al., 2016).

Workload is typically measured using four techniques; physiological measures, subjective measures, secondary task measures, and primary task measures (Meshkati et al., 1995). Primary tasks are simply the task completed by the individual. For instance, when assessing the workload of an individual completing a written test, the score of the written test should be utilized (Hicks & Wierwille as cited in Meshkati et al., 1995). Secondary tasks are tasks that an individual is asked to complete while still maintaining success in a primary task (Meshkati et al., 1995). If the primary task is maintained while the secondary task is also maintained, the primary task is then assumed to require a lower workload. If the primary task becomes too difficult to maintain due to the presence of the secondary task, the primary task is then assumed to require a higher workload (Knowles as cited in Meshkati et al., 1995). Subjective measures of the task refer to the individual completing the task's subjective review about the difficulty of the task. Physiological (or psychophysiological) measures can be very broad, as this refers to the many physiological changes that may occur as a result of workload, including EEG activity and skin conductance response (Meshkati et al., 1995; Charles & Nixon, 2019).

Purpose of the Study

As described above, there is minimal research investigating the relationship between chronic pain and workload. Further understanding the relationship between the two variables may lead to better mitigation of issues faced by individuals with chronic pain. The study aimed to investigate whether individuals with chronic pain maintain an equivalent workload level as those without chronic pain when completing cognitive tasks. It was hypothesized that the chronic pain group will demonstrate increased levels of workload in comparison to the no chronic pain control group, specifically when completing cognitive tasks. This is based on previous research that suggests a relationship between factors that accompany chronic pain (i.e. fatigue, sleep issues, and psychological symptoms) and workload,

CHAPTER II

METHODS

Participants

A total of 47 participants completed this study (*M* age = 24.45; *SD* = 4.24); 21 individuals comprised the chronic pain group, and 26 individuals included in the no chronic pain (control) group. Participants were recruited using the SONA enrollment management system, email, flyers, and word of mouth. To determine the eligibility of enrollment in the chronic pain group of the study, individuals self-reported the presence of ongoing pain lasting 12 weeks or more (Treede et al., 2015). This was validated with a t-test to compare Short-Form - McGill Pain Questionnaire scores between chronic pain and no chronic pain groups. Participants were between the ages of 18 - 35 years of age to allow the study results to be used as the foundation for a future study including electroencephalography (Hultsch et al., 2000). No identifiable information about participants was collected.

Measures

Participants completed the short-form McGill Pain Questionnaire (SF-MPQ) to ensure that the chronic pain group has significantly different scores than the control group (Melzack, 1987). The SF-MPQ has been previously validated (Melzack, 1975). Participants were asked to rate 11 sensory words (throbbing, shooting, stabbing, sharp, cramping, gnawing, hot-burning, aching, heavy, tender, and splitting) and four affective words (tiring-exhausting, sickening, fearful, and punishing-cruel) on a 4 point scale labeled none, mild, moderate, and severe (Melzack, 1987). Lastly, the SF-MPQ has a question focused on the present pain intensity (PPI) index; participants rate their current pain on a 6 point scale labeled no pain, mild, discomforting, distressing, horrible, and excruciating. The ratings on the entire SF-MPQ were summed to score the participant in which a higher score indicates more severe pain (Melzack, 1987).

The N-Back task, introduced by Kirchner (1958), can be administered in several formats; however, the concept of the task itself remained the same. A stream of informationwas presented to the participant (e.g., positions of a marker in a grid, shapes, numbers, letters, etc.), and the participantwas then asked to report when the target piece of information matches the target presented *n* trials ago (Kirchner, 1958). In the current study, individuals were asked to identify if the position of a marker in the grid they were viewing matches the one presented *n* (1 or 2) trials ago.

The dual N-Back task, a modified version of the N-back proposed by Jaeggi et al. (2003), is another form of the induction of workload. This task follows the same structure as the N-back task, except participants were presented with a stream of two types of information (e.g. positions of a marker in a grid and shape; Jaeggi et al., 2003). Participants identified if the marker was in the same position on the grid as it was *n* (1 or 2) trials ago, and if the shape of the marker matches the shape presented *n* (1 or 2) trials ago.

The NASA - Task Load Index (TLX), proposed by Hart and Staveland(year)(as cited in Sartang et al., 2018), is a common and validated subjective measure for workload (Sartang et al., 2018; Torres et al., 2016; Gao et al., 2013). The instrument asks participants to respond to 15 pairwise comparisons of the six different subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration. The pairwise comparison simply asks which factor was more important to their experience (Sartang et al., 2018). The pairwise comparisons were collected only on the initial administration of the NASA-TLX. Next, participants respond via Likert scale labeled either ‘low’ to ‘high’ or ‘poor’ to ‘good’ what level of each subscale best represents their experience completing each level of the tasks (Sartang et al., 2018).

Procedure

The study was administered via Google Forms. After providing informed consent, participants completed the demographic questions, the pain self-report question, and the Short-Form - McGill Pain Questionnaire (Melzack, 1987). All N-back trials were completed on BrainScale.net; trials were preceded with specific instructions as to how to set settings and complete the task (Dual N-Back Training). The initial N-back block consists of 21 practice trials with N-back set at one, 24 practice trials with N-back set at two, 21 practice trials for the dual N-back set at one, and finally, 24 practice trials for the dual N-back set at two. The purpose of the practice trials was to ensure participants can understand the expectations of the task before beginning the task. After the practice block of the N-back tasks was completed participants began the final N-back block.

After the first 21 trials with N-back set at one, the participants completed the initial NASA - TLX, including the pairwise comparisons. The next N-back trial consisted of 24 trials, however, N-back will be set at two. Once again, the participants completed the NASA - TLX, but without pairwise comparisons. Following the completion of the different levels of the N-back and associated NASA - TLX administrations, the participants completed 21 trials of the dual N-back task with N-back set at one, followed by the NASA - TLX. The participants completed 24 trials of the last dual N-back task with N-back set at two, followed by a final NASA - TLX administration.

Data Analyses

Data are reported as mean ± SD. All responses were collected in a Google Form document and exported into a corresponding Google Sheet document. Responses were scored in the Google Sheet. All data analyses were completed with JASP software (JASP Team, 2020) and SPSS software (IBM Corp., 2017). Chi square tests were computed to examine relationships between pain and no pain groups with demographics (age, gender, and race). An independent samples t-test assessed the difference in SF-MPQ scores between the chronic pain and no chronic pain groups. A mixed repeated measures ANOVA was computed to examine the relationship between workload levels as computed by the NASA - TLX and chronic pain. Bonferroni post hoc tests further examined the interaction between group (chronic pain and no chronic pain) and N-back level. An independent samples t-test assessed the impact of chronic pain on workload levels, provided by the NASA - TLX. The alpha criterion was $p = .05$, and multiple comparisons were not conducted.

A Bayesian mixed repeated measures ANOVA was computed to assess the relationship between mental workload as measured by the NASA - TLX. The use of the Bayesian mixed repeated measures ANOVA allowed the comparison of separate models accounting for each main effect and interaction effect separately (Faulkenberry et al., in press; Hinne et al., in press). Additionally, the Bayesian mixed repeated measures ANOVA was utilized to observe data over time for optional stopping (Rouder, 2014).

CHAPTER III

RESULTS

The purpose of the study was to assess the relationship, if any, between chronic pain and mental workload. The hypothesis was that individuals with chronic pain would present higher NASA - TLX scores on the different variations of the N-back task in comparison to individuals without workload.

Chi Square tests examined relationships between pain and no pain groups with all demographics (age, gender, and race). There was no difference between groups on age, X^2 (15, N = 47) = 14.67, p = 0.475. There was no difference between the gender of the groups, X^2 (1, N = 47) = 0.685, p = 0.408. There was no significant difference between groups on race, X^2 (5, N = 47) = 3.201, p = 0.669. Demographics of participants split by group (chronic pain or no chronic pain) are in Table 1.

Table 1. Participant Demographics by Group

	Total (n =47)		Chronic Pain (n = 21, 44.68%)			No Chronic Pain (n =26, 55.32%)				
Variable	n	%	n	% Group	% Total	n	% Group	% Total	X^2	p
Age (years)									14.7	.475
<21	8	17.02%	2	9.52%	4.26%	6	23%	12.77%		
21-25	23	48.94%	9	42.86%	19.15%	14	54%	29.79%		
26-30	11	23.40%	5	23.81%	10.64%	6	23%	12.77%		
31- 35	5	10.64%	5	23.81%	10.64%	0	0%	0.00%		
Gender									0.69	.408
Male	4	8.51%	1	4.76%	2.13%	3	12%	6.38%		
Female	43	91.49%	20	95.24%	42.55%	23	88%	48.94%		
Race									4.31	.635
American Indian/ Alaskan Native	2	4.26%	1	4.76%	2.13%	1	4%	2.13%		
Asian American	1	2.13%	1	4.76%	2.13%	0	0%	0.00%		
African American	6	12.77%	2	9.52%	4.26%	4	15%	8.51%		
Caucasian	33	70.21%	16	76.19%	34.04%	17	65%	36.17%		
Hispanic/Latino	4	8.51%	1	4.76%	2.13%	3	12%	6.38%		
Other	1	2.13%	0	0.00%	0.00%	1	4%	2.13%		

The independent samples t-test to compare SF-MPQ scores by group revealed that individuals with chronic pain (13.52 ± 7.21) scored significantly higher than the no chronic pain group (5.04 ± 7.71), $t(45) = -3.860$, $p < .001$. Descriptives of the NASA-TLX scores as well as SF-MPQ scores are in Table 2.

Table 2. SF-MPQ Data by Group

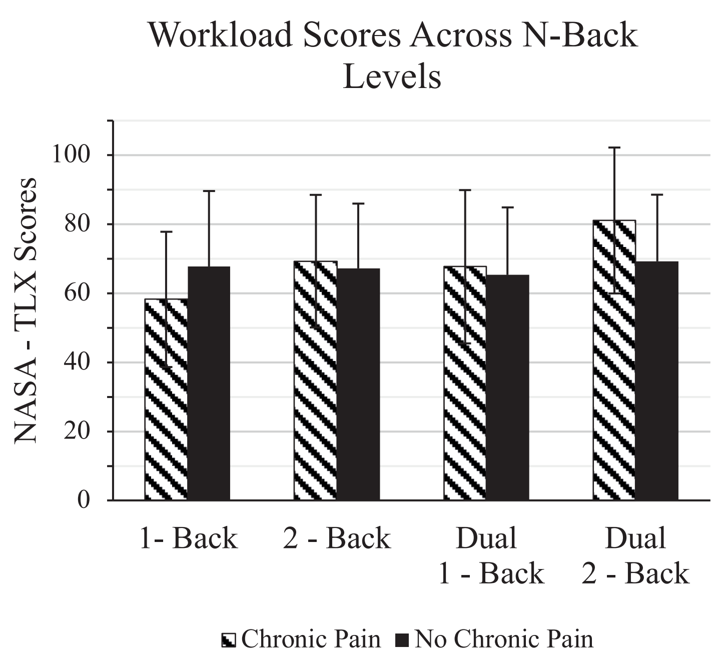
	Total (n=47)		Chronic Pain (n= 21, 44.68%)			No Chronic Pain (n=26, 55.32%)				
Variable	n	%	n	% Group	% Total	n	% Group	% Total	t	p
SF-MPQ Score									-3.86	< .001
< 10	28	59.57%	7	33.33%	14.89%	21	81%	44.68%		
10 - 20	14	29.79%	11	52.38%	23.40%	3	12%	6.38%		
21 - 30	4	8.51%	2	9.52%	4.26%	2	8%	4.26%		
> or = 31	1	2.13%	1	4.76%	2.13%	0	0%	0.00%		

The mixed repeated measures ANOVA computed to compare the four levels of N-back workload ratings (within subjects) across the two groups (between subjects) revealed a main effect of N-back level, $F(3,135) = 6.469$, $p<.001$, $\eta^2 = 0.115$ and no main effect of group, $F(1,45) = 0.117$, $p=.734$, $\eta^2 =.003$. There was a significant interaction effect between chronic pain and workload scores, $F(3,135) = 4.720$, $p = .004$, $\eta^2 = 0.84$ (Table 3 and Fig. 1).

Table 3. NASA-TLX Ratings Data by Group

N-Back Level	**Total (n=47)**	**Chronic Pain (n= 21, 44.68%)**	**No Chronic Pain (n=26, 55.32%)**
1- Back	63.55 ± 21.16	58.22 ± 19.59	67.85 ± 21.76
2 - Back	68.18 ± 18.74	69.30 ± 19.20	67.28 ± 18.69
Dual 1 - Back	66.35 ± 20.60	67.68 ± 22.20	65.28 ± 19.59
Dual 2 - Back	74.58 ± 20.73	81.08 ± 21.13	69.33 ± 19.22

Figure 1.



The Bayesian mixed repeated measures ANOVA was conducted to examine further the relationship between the null and alternative hypotheses, H_0 and $H_{1,}$ respectively. The data are approximately 25 times more likely under the model accounting for the effect of N-Back than under any model that does not account for N-back ($BF_{inclusion}$ = 25.301). The data are approximately 2 times more likely under the model representing an effect of chronic pain only than under any model that does not account for chronic pain ($BF_{inclusion}$ = 2.072). Lastly, the data are approximately 8 times more likely under the model accounting for an interaction between N-back and chronic pain than under a model that does not account for this interaction ($BF_{inclusion}$ = 8.348).

CHAPTER IV

DISCUSSION

The purpose of this study was to investigate any relationship that may exist between mental workload and chronic pain. Understanding this relationship may lead to better mitigation of the effects of chronic pain experienced by individuals in the workplace. It was hypothesized that individuals within the chronic pain group would display increased mental workload as opposed to the group that did not have chronic pain.

Three Chi Square tests assessing if there was any difference between groups (chronic pain and no pain) on each of the demographics (age, gender, and race) were not significant. This demonstrated that there was no cause for concern that the chronic pain and no pain groups were significantly different. The significance of the t-test comparing SF-MPQ scores across groups demonstrates that the chronic pain group did experience higher levels of pain than the no chronic pain group. This is vital to the study because if there is not a true chronic pain group, the relationship between chronic pain and workload cannot be truly assessed.

The variations of the N-back were utilized in the study to provide an induction of workload at four, increasingly levels of difficulty, and the main effect of N-back level within the mixed ANOVA confirmed that the levels were different. The mixed ANOVA also demonstrated an interaction effect of chronic pain and workload during the four N-back levels. This demonstrates that there is a relationship between the two variables. However, post hoc tests are needed to understand the specifics of the relationship. The Bonferroni post hoc analysis revealed that the no chronic pain group had no significant differences in workload ratings between the different N-back levels.

In contrast, the analysis revealed significant differences in workload ratings between N-back levels within the chronic pain group. Specifically, the chronic pain group reported lower levels of workload (as scored by the NASA - TLX) on the 1-back level than on the 2-back, dual 1-back, or dual 2-back. Individuals with chronic pain demonstrated a significantly higher workload on the 2-back than 1-back, but considerably lower levels on the dual 1-back. Lastly, individuals with chronic pain reported the highest workload levels on the dual 2-back than any level of the N-back task. These results demonstrate that individuals with chronic pain found the levels of N-back to require more mental workload providing support for the hypothesis. No chronic pain individuals did not display significantly higher workload levels on any N-Back level over another.

A Bayesian ANOVA compares several models and compares each model to the best model. The N-back only model provides insight to how likely the data are under a model that only accounts N-back level. The chronic pain only model displays how likely the data are under a model that only accounts for the presence, or lack thereof, of chronic pain. The interaction model displays how likely the data are under a model that accounts for chronic pain as well as N-back level. The Bayesian mixed ANOVA suggests the data are most likely under the N-back only model compared to all other models, which provides internal validity that the N-back levels were progressively more difficult as each participant proceeded in the study. The data were also more likely under the interaction model than the null, which supports the mixed ANOVA presentation of an interaction effect. Finally, the Bayesian mixed ANOVA demonstrated that the data were also more likely under the chronic pain only model than under the null. The Bayesian mixed ANOVA aligns well with the reports of mixed ANOVA and provides evidence to support the hypothesis that individuals with chronic pain would present an increased workload.

Previous literature shows a gap in research regarding the relationship between chronic pain and mental workload. Chronic pain symptoms commonly include poor sleep quality, stress, as well as fatigue (Finan et al., 2013). Fatigue is also common when individuals are mentally overloaded (Gao et al., 2013). Results generally show support for the hypothesis because the chronic pain group reported higher levels of workload than the no chronic pain group. Additionally, the task was subjectively rated by the chronic pain group to require significantly more workload as the N-back level increased. This suggests that there is indeed a relationship between chronic pain and mental workload. Furthermore, it is important to the study of chronic pain as without understanding the full scope of effects of chronic pain, it cannot be properly mitigated.

Limitations in this current study included the demographic data was extremely skewed towards females. This may be because psychology students are predominantly female at Tarleton State University. Additionally, participants could have understood the cognitive tasks as well as the NASA-TLX better with an in-person explanation, allowing them to ask questions to settle any confusion. However, participants may be more honest in an anonymous survey setting.

Futures studies should be completed with the inclusion of electrophysiological measures, including electroencephalogram (EEG) and galvanic skin response. EEG literature of mental workload provides a formula for calculating workload from raw EEG signals. Wang et al. (2019) provided a calculation of workload based on the Holm et al. (2009) study. Averages from all frontal theta power divided by averages from all parietal alpha power equate to a workload score (Wang et al., 2019; Holm et al., 2009). When repeating the study utilizing the listed electrophysiological measures it is hypothesized that, results will be replicated. Additionally, the inclusion of a measure of fatigue may be useful to examine whether fatigue moderates the relationship between chronic pain and mental workload.

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