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Effect of Chronic Pain on Prospective Memory Performance

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EFFECT OF CHRONIC PAIN ON PROSPECTIVE MEMORY PERFORMANCE

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ABSTRACT

Chronic pain is among the most widespread and disabling conditions worldwide. In the United States, approximately 50 million people suffer from chronic pain. Prospective memory, the process by which people remember to perform an action in the future after a delay, appears to be affected by the experience of pain, especially when a prospective memory task is more cognitively demanding. While self-report studies of individuals with chronic pain suggest that pain adversely affects both their retrospective and prospective memory, there is scant literature investigating this relationship with more objective methods. Similarly, few studies have been conducted that examine the role of subjective ratings of sleep on prospective memory performance. The current study administered an online prospective memory task paradigm to participants with and without chronic pain to address whether prospective memory performance differs by pain status. The sample consisted of 188 adults residing in the United States with a mean age of 31.16 years (*SE* = .65). Of these, 95 participants were coded as being in the pain group, and 93 were coded as being in the no-pain group. The pain group performed significantly more poorly on the prospective memory task and exhibited significantly worse sleep functioning than the no-pain group. However, no evidence was found that sleep functioning mediated or moderated the relationship between pain status and prospective memory performance. These findings suggest that chronic pain is associated with impairments in prospective memory and poorer sleep functioning, although further experimental research is necessary to establish causal relationships between pain and prospective memory.

LIST OF ABBREVIATIONS AND SYMBOLS

PM	Prospective Memory
PAM	Preparatory Attentional and Memory processes theory
MPV	Multiprocess view of prospective memory
PMQ	Prospective Memory Questionnaire
PSQI	Pittsburgh Sleep Quality Index
HDQ	Health and Demographics Questionnaire
CPAQ	Chronic Pain Assessment Questionnaire
HAM-A	Hamilton Anxiety Rating Scales
PHQ-9	Patient Health Questionnaire (Depression), 9 Items
FARs	False alarm responses
RTs	Response times
M	Mean value
SD	Standard deviation
SE	Standard error of the mean
η^2	Eta squared effect size

LIST OF TABLES

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TABLE OF CONTENTS

I. INTRODUCTION

Physical pain is a nearly ubiquitous human experience. It is so common, in fact, that it has been proposed as the "fifth vital sign" to be assessed and charted for all medical patients (Baker, 2017), alongside heart rate, blood pressure, respiratory rate, and body temperature. Worldwide, an estimated 1.9 billion people suffer from tension-type headaches and one billion people suffer from migraines (Vos et al., 2017). Low back and neck pain are also widespread with some 750 million people affected by these conditions. Together, low back pain and migraine represent the two most disabling medical conditions globally by years lived with disability, demonstrating that functional impairment is prominently associated with pain conditions (Vos et al.). Pain is also financially burdensome, especially when considering chronic pain conditions. In the United States alone, some 50 million people experience chronic pain (CDC, 2016), and daily chronic pain is reported by approximately 25 million Americans (Nahin, 2015). The economic burden of pain management—pain patients seeking diagnosis, treatment, and cures—exceeds $600 billion in the United States annually (Mills, Torrance, & Smith, 2016).

Pain's comorbidity with other disabling medical and psychiatric concerns such as depression, anxiety, sleep disturbance, and opioid misuse complicates research into its management and its etiology (Lerman, Rudich, Brill, Shalev, & Shahar, 2015; McCracken & Iverson, 2002; Weiss et al., 2014). Despite substantial literature about pain's relationships with such problems, chronic pain's association with several aspects of cognitive functioning is not well understood. One such process is prospective memory (PM), which is the process by which one remembers to complete an action in the future (Harris, 1984).

The present study investigated whether the experience of chronic pain impairs PM performance in a computerized PM paradigm as well as how sleep functioning might be associated with pain, PM performance, or both. This paper defines PM and discusses established paradigms designed to investigate it, and then it explores research about chronic pain, sleep functioning, and their relationship to PM performance.

Prospective Memory

The process of remembering to perform an action in the future, PM (Harris, 1984), requires that some amount of time passes between when the intention for action is formed and when the action can be performed. Two common types of PM tasks are *time-based* and *event-based* tasks. Time-based PM involves creating an intention for an action contingent on elapsed time or a target time (Huang, Loft, & Humphreys, 2014). A practical example of time-based PM relevant to an individual experiencing pain would be medication adherence: She might need to remember to take her medication after four hours have passed, or to take her medication at a given time (e.g., 5 p.m.). In event-based PM, environmental events signal that an individual is able to perform some intended action. For instance, one might need to remember to stop at the pharmacy to pick up medications, and the environmental cue would occur when one sees the pharmacy on the drive home. This paper will focus on event-based PM research, as the proposed study will rely upon an event-based PM paradigm.

Often, PM is described as including both a prospective and retrospective component. The prospective component involves remembering *that* an action needs to be performed; the retrospective component involves remembering *what* needs to be done and *when* it should occur. An event-based example of these components might be a pain patient remembering to stop at the pharmacy to pick up her medication; in this case, the prospective component would be

remembering that she must perform some action, while the retrospective component would be remembering that the action is to buy her pain medication and that this action should be done when she stops at the pharmacy instead of the hardware store.

Experimental paradigms of PM typically include both an ongoing task and a PM task that are administered concurrently (e.g., Einstein & McDaniel, 1990; Einstein, Smith, McDaniel, & Shaw, 1997). PM tasks are sometimes described as being "embedded" within the ongoing task in these paradigms, as the ongoing task is an activity that participants engage in that must be interrupted to perform the PM task. In this way, ongoing tasks mirror common daily activities that individuals perform that are punctuated by PM intentions. For example, Einstein and McDaniel (1990) administered an ongoing task to participants in the form of a working memory task which required participants to view series of words on a computer screen and then orally recall the words in order of appearance. Embedded within this working memory task was the PM task, in which participants were asked to press a key when the word *rake* appeared.

Event-based Theories of PM

Several extant theories attempt to describe how PM tasks are performed. In the case of event-based PM, there is debate about whether PM tasks necessarily require a cost to available cognitive resources. The preparatory attentional and memory processes theory (PAM; Smith, 2003) proposes that in order to successfully complete PM tasks, individuals must allocate some cognitive capacity toward preparing to identify environmental events that signal that a task can be completed. Because preparatory attention is not required to be constantly engaged but must operate only in an appropriate context, PAM proposes that we make decisions about prospective activities during transitions between tasks or locations (Smith, 2008). While this preparatory process might be explicit and at the center of attention, more often it occurs peripherally to some

other task. However, PAM offers that even if the process is peripheral, it is still within conscious control (Smith, 2016).

The multiprocess view of PM (MPV; McDaniel & Einstein, 2000) synthesizes several previous models of PM, including the simple activation model, notice-plus-search model (Einstein & McDaniel, 1996), and strategic monitoring. The MPV proposes that a PM intention can be retrieved either through strategically monitoring for an opportunity to perform a PM task or through spontaneous retrieval when encountering a PM target event (McDaniel & Einstein, 2007). Spontaneous retrieval thus describes situations in which the PM intention subjectively seems to "pop to mind" without conscious monitoring. The MPV would predict that a PM intention is automatically retrieved when the PM target is simple, salient, and the ongoing task focuses on stimulus features relevant to the PM target. In other words, spontaneous retrieval is most likely when the PM intention is low in cognitive demand. If these criteria are not met, the MPV would predict that individuals are more likely to strategically monitor for the PM target to maximize their chance of successful PM actions.

Theories of event-based PM might predict that when pain is experienced during a PM task, performance will be impaired when an individual is in pain because experiencing pain is reliably associated with decrements in working memory and attention (Eccleston & Crombez, 1999; Dick, Eccleston, & Crombez, 2002; Berryman et al., 2013). As the PAM and MPV describe, cognitive resources are required (in many circumstances) to monitor for environmental events that signal that an individual can perform the delayed behavior. According to the MPV, if the PM task relies on strategic monitoring, then an effect of pain on PM performance is predicted because pain would interrupt this monitoring and thereby decrease performance. If the task relies on automatic processing instead of strategic monitoring, no effect of pain on PM performance is

expected because the experience of pain would not interrupt any monitoring processes. However, the MPV offers that an effect of pain is possible in cases of automatic retrieval if the experience of pain interferes with carrying out the PM intention in some way after retrieval.

One aspect of the PM target that can inform whether automatic retrieval or strategic monitoring would be relied upon is the level of focal processing (Einstein & McDaniel, 2005). A *focal task* encourages processing of stimulus features that overlap with, or are similar to, features that define some event as a PM target event. An example of this might be asking participants to complete a lexical decision task, in which they are to determine if a presented string of letters create a word (e.g., "tortoise"). If participants are to press a response key when the letters form a specific word, this would be a focal task, because the ongoing task is promoting the processing of information at the level of words. Because of this overlap in features, focal tasks are described as low in resource demand; according to the MPV, retrieval with focal tasks is likely to be automatic. Conversely, if a task is *non-focal*, processing of similarities between features of the ongoing task stimulus and the PM target event is not encouraged (or there is little-to-no overlap between such features). Because of this, resources must be expended to process both the ongoing task stimulus features and PM target features. For example, if participants are completing a lexical decision task but are asked to press a response key when a particular syllabic string appears (e.g., "tor") instead of an entire word, this would be considered a non-focal task because the ongoing task directs attention to information at the word level but not the syllable level. Because more resources would be allocated to monitoring for PM targets, non-focal tasks are described as highly resource-demanding and are more likely to rely on strategic monitoring (Einstein et al., 2005).

Prospective Memory and Working Memory

Although the experience of pain is reliably associated with impaired working memory (Berryman et al., 2013), the degree to which working memory and PM are related is a distinct question. In fact, an association has been observed between aspects of working memory and PM performance (e.g., Kliegel, Kliegel, & McDaniel, 2003; Mioni & Stablum, 2014; Ball, Vogel, & Brewer, 2019). For example, greater working memory span appears to be associated with better event-based PM performance when executive control is required to detect PM targets (Smith & Bayen, 2005). Ball, Vogel, and Brewer (2019) argued that the relationship between working memory and PM is due to an individual's strategic control of both their attention and their memory abilities, as both of these functions meaningfully contribute to PM performance. This might indicate that in addition to relevant memory tasks, factors related to attention should be measured in PM experiments.

The Experience of Pain

Though physical pain is a nearly universal experience, it can be highly variable in its quality and presentation. A number of organizations have classified pain based on its overall duration, but there is no standard for what these durations should be. Pain is typically diagnosed as *acute* if its duration is less than one month, and it is diagnosed as *chronic* if the pain has lasted longer than either three or six months (Thienhaus & Cole, 2002). As an example, the eleventh revision of the International Classification of Diseases (World Health Organization, 2018) defines the criterion for primary chronic pain duration to be three months or longer (Nicholas et al., 2019). However, the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (American Psychiatric Association, 2013) defines a minimum pain duration of six months as the criterion for somatic symptom disorders. While both are intended as diagnostic taxonomies, their

difference in chronic pain duration highlights a significant difficulty in defining its boundaries. Pain has been associated with short-term autonomic responses such as minor increases in blood pressure, increased heart rate, and skin conductance (Cowen, Stasiowska, Laycock, & Bantel, 2015), though these indicators might not be robust across all contexts or durations. As such, the assessment of pain remains a predominantly subjective endeavor.

Despite this difficulty in defining acute and chronic pain, another common and important designation of pain is used: An *intermittent* course, sometimes known as *episodic* pain, describes non-persistent conditions (Mercadante et al., 2001). Intermittent pain conditions are defined by their paroxysmal nature, typically in the form of longer, less debilitated periods punctuated by shorter "flare-ups" or severe recurrence of pain (Lasheen, Walsh, Sarhill, & Davis, 2010). A wide range of conditions might produce an intermittent course of pain, including neurological, musculoskeletal, and autoimmune disorders (Neogi, 2013). For example, most common headache disorders, such as migraine or tension-type headache, involve intermittent pain experiences that, once treated or resolved, give way to typical functioning without pain-related disability or sequelae. As stated above, migraine and tension-type headache are some of the most common conditions worldwide with billions of reported cases, and migraines tend to be particularly disabling. Other conditions that often present with an intermittent pain presentation include arthritic conditions such as osteoarthritis, relapsing-remitting forms of multiple sclerosis, back pain, and systemic lupus erythematosus (Hawker et al., 2008; McIntosh, Carter, & Hall, 2016).

Chronic Pain and Executive Function

A relationship between the experience of pain and cognitive dysfunction has long been assumed (Eccleston & Crombez, 1999; Hart, Martelli, & Zasler, 2000; Iezzi, Duckworth, Vuong,

Archibald, & Klinck, 2004), and several theoretical models of how pain affects cognition have been suggested. For example, individuals with chronic pain might become hypervigilant toward bodily sensations which in turn diverts their attention away from important tasks (Legrain, Iannetti, Plaghki, & Mouraux, 2011). Individuals with chronic pain also frequently self-report cognitive deficits secondary to their pain condition. Patients seeking chronic pain treatment report more cognitive dysfunction than patients seeking general medical care, dental care, or psychotherapy (Schnurr & MacDonald, 1995). This might suggest that the experience of pain adversely affects cognition, or it might suggest that treatment-seeking individuals with chronic pain represent a particularly disabled subpopulation. McCracken and Iverson (2001) found that more than one in five chronic pain patients in a university pain management center reported "forgetting a lot, recent things, appointments," and 18.7% reported difficulty maintaining attention. Self-report might reflect a genuine relationship between chronic pain and cognitive functioning, though other factors secondary to chronic pain (e.g., use of narcotic analgesics, fatigue and sleep disruption) might contribute to patients' perceptions about their cognitive function. For instance, an individual with chronic low back pain might experience difficulty with concentration because of the pain itself; he might be getting less restful sleep because of the pain, and thus have trouble concentrating due to fatigue; or he might be prescribed medications that impact his cognitive functioning. Regardless, the preponderance of self-report findings seems to suggest that those with chronic pain experience, or perceive that they experience, broad yet relatively minor cognitive dysfunction.

Objective measures of neuropsychological functioning point to similar conclusions. Hart, Martelli, and Zasler (2000) reviewed studies that examined neuropsychological functioning in individuals with chronic pain and found that clinical pain patients tend to experience deficits in

attentional capacity and processing speed. Ziegler and Paolo (1995) had previously compared pain patients who sought treatment for headache to nonpatient volunteers with similar frequency and average pain and found group-level differences on MMPI-2 subscales; this suggests that a sample seeking medical care for less-than-severe pain conditions might have differences in their attitude, tolerance, and perception of pain that contributes to their treatment-seeking behavior. The selection factors highlighted by Ziegler and Paolo might account for the differential findings in the review by Hart et al.: The effects of pain on neuropsychological functioning were weaker in studies with nonclinical samples, suggesting that selection effects led to an overestimation of pain's effect on cognitive functioning.

In the case of working memory, there has long been an established view that those with chronic pain experience deficits in working memory functioning (Dick, Eccleston, & Crombez, 2002; Moriarty, McGuire, & Finn, 2011). However, quantitative analysis of this specific relationship has been meager. In a meta-analysis of 23 studies, Berryman et al. (2013) found a consistent, moderate effect of chronic pain on working memory functioning, although heterogeneity in methodology and lack of clarity in sample selection were evaluated as potential risks to validity. One particular concern raised by Berryman et al. was that ten studies included in their meta-analysis did not disclose criteria for chronic pain, and most did not screen for medication use and sleep. The effect found by Berryman et al. might thus reflect iatrogenic effects of narcotics or fatigue rather than a genuine working memory deficit.

Induced Pain and Working Memory

While an association between chronic pain and working memory has been observed, the relationship between experimentally induced pain and working memory function is less clear. Schoofs, Wolf, and Smeets (2009) applied a cold pressor, a device that briefly exposes

participants to cold water, to the arm of otherwise healthy young men and assessed their working memory performance with digit span and operation-span tasks. Schoofs et al. found that digit span backward task performance was impaired among those who underwent the cold pressor manipulation, but digit span forward performance was not impaired by induced pain. These tasks are believed to assess related but distinct cognitive processes: The backward task is considered a measure of temporarily storing information in working memory and simultaneously manipulating that information (Lezak, Howleson, & Loring, 2004), while the forward task is considered a more passive storage process (Richardson, 2007). Thus, Schoofs et al. propose that induced pain affects more complex, controlled cognitive functions, but it does not affect more passive storage functions of working memory.

In a similarly designed experiment, Hood, Pulvers, and Spady (2013) applied a forehead cold pressor to otherwise healthy men and women and administered a letter-number sequence task to assess verbal working memory, mental sequencing, and attention span. Participants in the cold pressor condition were compared to a control condition in which participants wore the cold pressor pad but no water was circulated. One working memory trial was completed while pain was induced and then another trial was completed 20 minutes after the pain condition ended. However, Hood et al. were also interested in the timing of the cold pressor and between-gender differences in working memory performance. In this case, an interaction of timing and gender was found: During the working memory trial with concurrent cold pressor exposure, women in the cold pressor condition had significantly poorer working memory performance than men exposed to the cold pressor and men and women in the control condition, while men in the cold pressor condition demonstrated working memory performance equal to the control conditions. However, 20 minutes after the cold pressor exposure, there were no significant differences

between any of the experimental or control groups. Hood et al.'s findings provide additional context for studies involving experimentally manipulated pain, suggesting that participant gender as well as the timing of assessment might be important factors in understanding how induced pain affects working memory. Taken together, the conclusions of Schoofs et al. and Hood et al. suggest that induced pain adversely affects more complex tasks (i.e., higher in resource demand) rather than simple ones, and female participants might experience greater decrements in their working memory when exposed to experimentally induced pain.

Experience of Pain and PM

The literature described thus far suggests that pain impairs executive functions such as working memory and attention, and these factors are associated with PM performance. However, pain's effect appears only, or most prominently, when tasks are particularly challenging or complex. These findings suggest that pain might have an effect on PM performance through shared relationships with executive functions.

Self-report Measures of PM among Chronic Pain Patients

Ling, Campbell, Heffernan, and Greenough (2007) recruited a sample of 50 treatment-seeking participants with chronic low back pain alongside a control sample of 50 pain-free participants and administered the Prospective Memory Questionnaire (PMQ; Hannon et al., 1995). The PMQ is a 52-item self-report measure that asks respondents to estimate how often they experience failures of PM and use strategies to help their memory, with items divided into three content subscales: *long-term episodic, short-term habitual,* and *internally cued*. In addition to the PMQ, the Zung Depression Scale was administered in order to control for a reported relationship between depression and cognitive dysfunction. Patients' pain duration and current pain level were also assessed to ensure that patients were experiencing pain and that it had

persisted long enough to be considered chronic pain. Ling et al. found that short-term PM was the only subscale from the PMQ demonstrating a group difference, and that those with chronic pain reported significantly more errors of short-term PM. The authors proposed that individuals with chronic pain might experience higher levels of stress, and that this could lead to memory dysfunction. Another explanation for this difference could be analgesic use, especially in higher doses. If individuals were using narcotic analgesics, adverse effects of these medications such as drowsiness might better account for impairment in PM performance than the experience of pain itself.

Limitations of self-report. Although PM questionnaires are efficient, they are unable to objectively measure participants' memory abilities. It is possible that self-reported memory failures reflect cognitive dysfunction secondary to extraneous variables rather than the experience of pain, such as stress (as suggested by Ling et al.). Additionally, studies using self-report of PM rely upon participants' previous diagnoses, but with such heterogeneity in the intensity, frequency, presentation, and course of pain, this methodology can limit inferences about PM and the experience of pain.

Uttl and Kibreab (2011) raised another important concern with common PM self-report measures: They tend to be reliable, but they often fail to demonstrate convergent and divergent validity. Uttl and Kibreab assessed psychometrics for several PM self-report measures, including the PMQ; the Prospective-Retrospective Memory Questionnaire (Smith, Della Sala, Logie, & Maylor, 2000); and the Comprehensive Assessment of Prospective Memory. The authors found promising validity for the PMQ but limited validity for the PM subscale of the Prospective-Retrospective Memory Questionnaire. This evidence suggests that self-report PM measures should not be used as proxies for PM performance, but they might be effective and reliable as

estimates for *self-perceptions* of respondents' PM failures. To address this concern, objective measures of PM can be administered in order to quantify PM performance, which can largely eliminate memory distortions and cognitive biases frequently seen in PM self-report.

Objective Measures of PM Performance

Miller, Basso, Candilis, Combs, and Woods (2014) administered the Memory for Intentions Screening Test (MIST), an objective measure of PM, to 96 multiple sclerosis patients with chronic pain and 29 healthy participants. The MIST involves eight PM intentions during a 30-minute test period, during which participants complete a word-search puzzle as an ongoing task. Miller et al. also assessed patients' pain severity and multiple sclerosis-related quality of life. Similar to the study of Ling et al., Miller et al. administered a scale for depression to control for psychiatric symptoms and comorbidities. Multiple sclerosis patients were found to have significantly lower MIST total scores, lower time-based memory scores at 15 minutes, and lower scores for memories requiring a verbal response. These differences suggest that multiple sclerosis pain negatively affects prospective memory performance. One notable omission from Miller et al.'s variables of study was fatigue, a common and pronounced symptom of multiple sclerosis, which the authors suggested might be an important contributor to declines in cognitive performance compared to healthy controls. Notably, the limited research in this area provides an opportunity for the proposed study to clarify, through a computerized PM task design, whether chronic pain reliably impairs PM performance.

Sleep

The neurobiological role of sleep in cognitive and physical functioning has been extensively investigated, including research about memory consolidation during REM sleep (Siegel, 2001) and slow-wave sleep (Diekelmann & Born, 2010). Such research typically makes

use of electrophysiological monitoring like electroencephalography, which might be used alone or as one of many measurements in a multiparametric battery such as polysomnography. Objective measures of the physical substrates of sleep such as eye movement, brain and muscle activity, pulse, and breathing rate can be monitored to provide information about a person's biological functions and sleep architecture. While research in this vein has discovered much about sleep as a physical phenomenon, sleep's psychological role is also highly pertinent to daily functioning. Thus, a distinction must be made between objective and subjective measures of sleep and how these measures are applied to cognitive research.

Though sleep patients with abnormal polysomnographic results tend to report disturbed sleep, it is possible to have abnormal findings and to report satisfactory sleep. Conversely, it is possible to have normal polysomnographic results yet experience disrupted sleep. Much like the experience of pain, satisfaction and perceived quality of sleep are subjective, so measuring these subjective ratings is integral to both empirical research and clinical assessments of sleep.

Sleep quality is one prominent form of sleep measurement. It is typically described as a constellation of interrelated sleep variables such as duration, time to onset, subjective sleep quality ratings, and number of interruptions. However, because sleep quality is also frequently used to describe a singular, subjective rating of "how well" one sleeps as with a Likert-type scale (Krystal & Edinger, 2008), we will herein use *sleep functioning* to refer to the overall construct and *sleep quality* to refer to subjective ratings of "how well one sleeps." Perhaps the most widely used sleep functioning questionnaire is the Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989), which instructs respondents to answer based on the "majority of days and nights in the past month" and includes items about hours in bed per night, hours of sleep per night, ease of falling asleep, bad dreams, and subjective ratings of one's sleep

quality. The PSQI generates seven component scores as well as a global score (the sum of the component scores), which is compared to a normed cutoff score for "poor sleep."

Although a majority of American adults report that they sleep at least seven hours per night, approximately one-third do not (CDC, 2014). Data from the CDC Behavioral Risk Factor Surveillance System (2014) suggest that undersleeping is a major concern because it is linked extensively to negative health comorbidities such as obesity and cardiopulmonary disease. This is borne out in more granular visualizations of reported sleep duration by geographic region as well: In areas of the United States with higher rates of obesity, including the South and Appalachia, a greater proportion of Americans report undersleeping (CDC).

Sleep research about adults in other nations tends to dovetail with the results of the CDC (2014). In a large community sample (N = 9284) of German adults who completed the PSQI, Hinz et al. (2017) found that approximately 36% of respondents would exceed the accepted cutoff score for poor sleep. This comports with results of previous studies, with 32% of the general population of Austria (Zeitlhofer et al., 2000) and 39% of the general population of Hong Kong (Wong & Fielding, 2011) exceeding the poor sleep PSQI cutoff score. Hinz et al. also found that several demographic factors were associated with PSQI global scores. In particular, women reported more sleep problems than men; those of higher socioeconomic status reported fewer sleep problems than lower SES respondents; and obese respondents reported more sleep problems than those of normal body mass index.

Sleep and Pain

The multidimensional relationship between sleep and pain has been well-established (Finan, Goodin, & Smith, 2013; Smith & Haythornthwaite, 2004). Sleep and pain appear to share a bidirectional relationship: Pain tends to disturb sleep, while disturbed sleep often intensifies

pre-existing pain (Doufas, Panagiotou, & Ioannidis, 2012). More than half of chronic pain patients report sleep dysfunction, with some estimates suggesting that nearly 90% of pain patients have significant sleep disturbance (Atkinson, Ancoli-Israel, Slater, Garfin, & Gillin, 1988; Smith, Perlis, Smith, Giles, & Carmody, 2000). Similarly, more than half of individuals with insomnia as a primary diagnosis also experience some form of chronic pain (Taylor et al., 2007). Furthermore, sleep and pain share several comorbidities, including depression, Type 2 diabetes, and obesity (Finan & Smith, 2013; Heo, Allison, Faith, Zhu, & Fontaine, 2012; Davies, Brophy, Williams, & Taylor, 2006).

Sleep and PM

Although the relationship between sleep and pain has been extensively examined and documented, associations between sleep and PM have been less clear. A meta-analysis of research about sleep's effect on PM performance (Leong, Cheng, Chee, & Lo, 2019) indicated a significant, small-to-medium overall effect. This suggests that, broadly speaking, restful sleep improves PM performance. However, the mechanism by which this is achieved is still under investigation. Leong et al. reported that when examining only studies about sleep's effect on strategic monitoring, no significant effect was found. In studies of spontaneous retrieval processes, sleep significantly improved PM when spontaneous retrieval is highly likely compared to when its likelihood is low. These findings suggest that sleep impacts PM through processes supporting spontaneous retrieval rather than through processes supporting monitoring.

Multiple sleep deprivation studies have demonstrated that restricting sleep impairs PM performance. Esposito, Occhionero, and Cicogna (2015) examined time-based PM performance in a normal-sleep control group and a 24-hour total sleep deprivation experimental group. Participants were instructed to press a key after 20 minutes had elapsed in their session, and they

completed reasoning tasks and arithmetic problems. Participants in the experimental group did not suffer from any deficits in reasoning tasks or in time monitoring behaviors (i.e., clock-checking), but a significant difference was observed in PM task compliance such that sleep-deprived participants were less likely to remember to perform the intended PM behavior. While 80% of control group participants pressed the key at the correct time, only 32% of the experimental group participants correctly completed this task and 40% did not execute the task at all. The findings of Esposito et al. indicate that total sleep deprivation adversely affects PM performance, although time-checking remained unimpaired; this suggests that total sleep deprivation might impair the interlinking between time monitoring and the underlying reason for checking.

While Esposito et al. (2015) investigated the role of short-term total sleep deprivation on PM performance, an understanding of longer-term sleep disturbance on PM is necessary. Leong, Koh, Tandi, Chee, and Lo (2018) applied a sleep restriction manipulation to participants over five days, wherein the control group maintained nine hours of time in bed while experimental group participants were limited to five hours in bed. This design was intended to mimic a school or work week and the effects of a weeklong sleep manipulation. To test PM, participants were told to press a key when they saw the words *table* or *horse* on their screen, and they completed a semantic categorization task as an ongoing task in which they decide whether a presented word fits into a presented category. For example, the category word *VEHICLES* might appear on screen, and then the word *airplane* might then appear, in which case the participant should respond that the word does match the category. No difference was observed between groups in successful response proportion, suggesting that five days of partial sleep deprivation does not significantly impair PM performance. However, a floor effect was observed for both groups;

Leong et al. stated that this perhaps reflected an overlong delay between instructions for the PM intention and the ability to execute intentions (five days). This floor effect might mask an effect of sleep restriction on PM. The authors also noted that the task might not have been sensitive enough to detect group-level differences, and it is also possible that five days of sleep restriction (but not total sleep deprivation) was an insufficient sleep manipulation to produce differences even if the encoding stage was temporally proximal to retrieval. Despite these criticisms, the study design is likely more ecologically valid than total sleep deprivation studies, and might better reflect sleep disturbance in academic and vocational schedules.

Outside of sleep restriction studies, research about subjective evaluations of sleep variables has suggested that subjective sleep quality is not related to PM. Böhm, Bayen, and Schaper (2020) applied a computerized PM task to investigate whether subjective sleep variables are related to PM performance in two studies. The ongoing task asked participants to view four rectangles of different colors and then to decide whether a presented word stimulus matches one of the four preceding rectangle colors. The non-focal PM task was to respond whenever the presented word was one previously studied for future recall. In the first study, Böhm et al. asked participants to complete the Karolinska Sleepiness Scale, a one-item, ten-point Likert scale about sleepiness with anchors from 1 (*extremely alert*) to 9 (*extremely sleepy – fighting sleep*); after completing this item, they completed the color-matching task. In the second study, sleepiness was experimentally manipulated during the color-matching task by having participants complete measures in either an upright (seated in a chair) or supine (lying down face-up) position. Neither sleepiness nor subjective sleep quality were associated with PM performance in the studies, although a moderation effect for posture was observed in the second study: For those in a supine posture (lying on their back), a stronger relationship between poor subjective sleep quality and

the prospective PM component of the computerized task was observed than for those in an upright posture. Although these results could suggest that subjective sleep variables are unrelated to PM, it is possible that the restricted range of scores reflects the authors' exclusion of participants with sleep disorders. Taken together with an understanding that sleep deprivation negatively influences PM performance (Esposito et al., 2015; Leong et al., 2018), these results might instead indicate that subjective sleepiness does not impact PM performance at mild or moderate levels but does impair performance at more severe levels. However, given the limited nature of this research and the heterogeneous study designs, the overall effect of sleep functioning as a multivariate construct on PM performance is unclear.

Study Goals

To date, there is little substantive research involving objective measurement of PM for participants with pre-established chronic pain conditions. Furthermore, while neurobiological research and sleep deprivation studies have examined the effect of sleep restriction on PM, the complex interrelationships between pain, sleep disturbance, and PM generate several new lines of inquiry.

The present study endeavored to investigate whether the experience of chronic pain differentially affects PM performance and to examine how sleep-related variables might be associated with both pain and PM performance. Miller et al. (2014) administered the MIST to multiple sclerosis patients with chronic pain and healthy controls to examine PM performance in chronic pain, but the present study was the first to apply a computerized PM design to chronic pain and control groups; this knowledge both extends the research from Miller et al. and clarifies the effect of longstanding chronic pain on PM performance in an objective PM paradigm.

Hypotheses

Hypothesis 1: Participants with chronic pain will have significantly poorer PM performance than participants without chronic pain as measured by PM target hit rate.

Hypothesis 2: Participants with chronic pain will have significantly poorer sleep functioning than those without chronic pain as measured by PSQI global score.

Hypothesis 3a: Sleep functioning, as measured by PSQI global score, will moderate the relationship between pain status and PM performance such that those with chronic pain who experience poorer sleep functioning will have significantly larger impairments in PM performance.

Hypothesis 3b: Sleep functioning, as measured by PSQI global score, will significantly mediate the relationship between pain status and PM performance.

II. METHODS

Participants

Participants for this study were recruited through Prolific Academic (herein Prolific; www.prolific.co), an online recruitment platform that uses common qualifiers to capture target participants for academic research (Palan & Schitter, 2018). Prolific has been used as a participant pool in research from diverse fields of inquiry such as psychology (Callan, Kim, Gheorghiu, & Matthews, 2017) and economics (Marreiros, Tonin, Vlassopoulos, & Schraefel, 2017). Compared to other similar platforms such as Mechanical Turk, Prolific is more user-friendly and has greater functionality (Palan & Schitter). In addition, the ability to recruit participants based on chronic pain status is an important aspect of data collection in this study. Prolific has an existing pool of more than 25,000 participants with chronic pain active in the previous 90 days, while other platforms often require additional screening measures to find participants with added time and monetary cost. Prolific has also exhibited relatively fast data collection compared to Mechanical Turk with less dishonesty in responses (Peer, Samat, Brandimarte, & Acquisti, 2017).

For this study, participants were required to be at least 18 years old to participate, which is a requirement to hold a Prolific account; participants also confirmed that they were at least 18 years old in the consent form and reported their age. A maximum age limit was set at 50 years to reduce aging effects observed in memory processes. All participants were compensated through the Prolific system for their participation in online tasks. Due to a qualifier system on Prolific that allows access to different participant characteristics (like chronic pain), this study was

provided separately to a non-pain pool and a chronic pain pool through Prolific. Participants reported this information about themselves to gain access to studies relevant to the qualifiers. The exclusion criteria for this study were: English as a non-primary language; residence outside the United States; visual or physical impairment such that the participant is unable to respond via computer; recent major physical injury (e.g., broken bone); severe psychiatric illness (e.g., schizophrenia); multiple sclerosis; and history of dementia or memory impairment. These items were assessed in the health and demographics questionnaire, and participants were excluded after being paid for their completed work.

In order to allow participants on Prolific to complete the cognitive task portion of this study, the computerized task was created and hosted on Gorilla. Gorilla is an online platform that allows for the design and administration of complex research designs beyond surveys and questionnaires, and it is integrated with Prolific so that participants are able to complete tasks seamlessly without requiring additional recruitment (Anwyl-Irvine, Massonié, Flitton, Kirkham, & Evershed, 2020). After completing informed consent and introductory questionnaires, participants in this study were connected to the cognitive tasks. Gorilla has been applied to topics as diverse as the McGurk effect (Brown et al., 2018) and expectations about lifting COVID-19 restrictions (Belton et al., 2020).

To determine sample size required for the primary hypothesis (H1), an *a priori* power analysis for an independent samples *t*-test was conducted ($\beta = .20$, $\alpha = .05$, $d = 0.50$). To reach sufficient power, a sample size of 64 participants per chronic pain status was required (pain and no-pain; target total $N = 128$). Because data are more easily obtained in online data collection but data quality is more difficult to ensure, recruitment continued until there are at least 64 valid cases in each group with a target of approximately 100 cases per group.

Materials

Ongoing Task

Participants completed a sentence-judgment task as the ongoing task during performance trials. In this task, participants see sentences on their computer screen one at a time, and they are instructed to make a judgment about whether each sentence is most likely true or most likely false. For example, if the sentence "Cats eat mice" is presented, the sentence should be judged as most likely true, but the sentence "Cats eat dogs" should be judged as most likely false. To respond that a sentence is most likely true, participants pressed the *T* key on their computer keyboard. To respond that a sentence is most likely false, participants pressed the *F* key. The performance trials of the ongoing task take approximately 10 minutes to complete. The sentence list to be used in performance trials can be found in Appendix A.

PM Task

In the PM task, participants were asked to respond when they saw any of the four PM target words by pressing the *1* (one) key on their keyboard. These four words are: *spinach*, *volleyball*, *tails*, and *sour*. The PM task was embedded in the ongoing task at the same point for all participants, such that the target words appeared at trials 25, 50, 75, and 100.

Health and Demographics Questionnaire

The Health and Demographics Questionnaire (HDQ) is a 28-item questionnaire that assesses demographic information psychiatric history, and medical history. The HDQ includes questions about participants' age, sex, current medications, socioeconomic status, race and ethnicity, and level of educational attainment. The HDQ was presented as a screener measure for Prolific participants to complete, and takes approximately two minutes to complete. This measure can be found in Appendix B.

Chronic Pain Assessment Questionnaire

All participants completed a pain assessment questionnaire as the second screener measure to determine whether they experience chronic pain and how they are affected by it. Pain variables such as intensity, location, and quality were assessed using an adaptation of the Breakthrough Pain Semi-Structured Questionnaire (adapted from Portenoy et al., 2006; Hagen et al., 2008). Participants were asked to provide: whether the pain occurs most of the day on most days; a current 0-10 pain intensity rating; bodily location of the pain; chronicity of pain (*for how long have you been experiencing this pain?*); and opioid or other analgesic medication use. This measure takes approximately two minutes to complete, and it can be found in Appendix C.

Post-Task Questionnaire

This questionnaire serves as a manipulation check to query participants' recall of the tasks from the experiment and the strategies that they employed to complete task trials. The post-task questionnaire was administered to participants immediately after the computerized experimental tasks and takes approximately two minutes to complete. It can be found in Appendix D.

PSQI

The PSQI is a measure that is commonly administered to assess individuals on seven functional components of sleep: subjective sleep quality, sleep duration, habitual sleep efficiency, sleep latency, use of sleeping medication, sleep disturbances, and daytime dysfunction. Given that sleep can be unstable on a day-to-day basis due to a host of external factors, the PSQI asks respondents to provide estimates for their experience for "the majority of days and nights" over the previous month. Participants are asked to provide estimated values for items such as time of going to bed and getting out of bed, as well as how long it takes them to

fall asleep; in this sense, the PSQI is sometimes referred to as an objective measure of sleep functioning because many of its variables could be objectively measured. However, subjective sleep quality is an aspect of the PSQI and participants are given a 4-point scale for many items, so the information retrieved from participants must be checked for impossible or highly unusual values. Notably, the PSQI includes an item requesting that respondents ask their bed partner about the respondent's sleep functioning if they have a bed partner, meant to add supplemental information about the respondent's sleep from a collateral source. This item is not included in the computation of component scores, however, and because the administration of this measure was online, the item was not administered to participants in this study.

The PSQI demonstrates acceptable internal homogeneity and validity, and high diagnostic specificity and sensitivity (Buysse et al., 1989). Cronbach's alpha for the global PSQI score has been indexed at .87 for individuals with primary insomnia (Backhaus, Junghanns, Broocks, Riemann, & Hohagen, 2002), indicating that the PSQI demonstrates high internal consistency. One consideration for the PSQI is that it tends to exhibit a restricted range of scores when clinical subpopulations are excluded, which limits the utility of the PSQI as a representation of all sleep functioning ratings. The PSQI takes approximately five minutes to complete. The PSQI can be found in Appendix E, and its scoring algorithm can be found in Appendix F.

Hamilton Anxiety Rating Scale

The Hamilton Anxiety Rating Scale (HAM-A) is a 14-item scale that is widely administered in anxiety research and in clinical assessment (Hamilton, 1959). It assesses somatic and psychological anxiety symptoms on a five-point scale. Although it is sometimes used as an outcome variable in research settings, the HAM-A was not designed as a diagnostic measure for

anxiety concomitant with other psychiatric conditions, and it is typically ineffective at discerning somatic symptoms from anxiolytic and antidepressant side effects (Thompson, 2015). Despite these criticisms, the HAM-A provides a relatively condensed assessment of anxiety as compared to diagnostic measures, and it has demonstrated sufficient inter-rater reliability and good one-week retest reliability (Maier, Buller, Philipp, & Heuser, 1988). Because the HAM-A includes "behavior at interview" as a final item, this item was not provided to participants. The HAM-A takes approximately one minute to complete, and can be found in Appendix G.

Patient Health Questionnaire

The Patient Health Questionnaire (PHQ-9) is a nine-item self-report measure comprising the diagnostic criteria of major depression found in the DSM-IV (Kroenke, Spitzer, & Williams, 2001). Each item is scored on a four-point scale of symptom frequency from *Not at all* to *Nearly every day.* The PHQ-9 has demonstrated excellent reliability and validity as a brief measure of depression symptom severity, and it is commonly administered as a screener for depression in clinical settings. As with many clinical measures, PHQ-9 scores are increasingly interpreted as a continuous variable despite its nominal scale (Kroenke et al., 2001). The PHQ-9 takes less than five minutes to complete, and can be found in Appendix H.

Letter-String Filler Task

In real-world instances of PM, an interval of time must exist between when a PM intention is formed and when it can be carried out; during this interval, distractions frequently occur, and it is more likely that a person forgets to carry out the intention. To mimic these distractions, two filler tasks were added between the PM task practice trials and performance trials. The first filler task was a modified letter-string task, in which participants were presented with 96 sequential trials, each with two strings of capital letters separated by an underscore

(Salthouse & Babcock, 1991). Participants were asked to decide if the strings are identical and respond with the *T* and *F* keys. The number of letters in each string increased as participants completed trials, such that the first 32 trials displayed strings of three letters, the next 32 trials were six-letter strings, and the final 32 trials were nine-letter strings.

Vocabulary Filler Task

The second filler task was a vocabulary task (Gardner & Monge, 1977), in which participants were presented with 30 sequential trials, each with a word appearing in the center of the screen in uppercase letters and five lowercase words below it numbered one through five. Participants were asked to pick the response option that was the closest synonym of the word in the center of the screen. The vocabulary filler was designed to be sufficiently challenging to prevent ceiling and floor effects.

Procedure

Participant compensation was provided through Prolific; participants received approximately $8.00 per hour for completing these measures (set for an expected study time of 45–60 minutes). The study was posted on Prolific in blocks of 20–60 available slots which were then booked by participants. When these submissions were completed, they were then checked for problems until the target of 200 total participants was reached.

Upon enrolling in this study, participants were provided a Gorilla link where the study was hosted. Participants viewed an informed consent page that confirmed their age and willingness to participate and then completed the HDQ, PSQI, HAM-A, PHQ-9, and CPAQ. Following these questionnaires, participants immediately received instructions for the sentence-judgment task to be used as the ongoing task in the PM paradigm. Participants completed four practice trials of this task to ensure that they understood and could complete it reliably. Once

they completed the practice sentence-judgment trials, participants were given practice instructions for the PM task (responding when they see target words) with two practice PM targets, *green* and *toaster*. Participants then completed practice trials of the sentence-judgment task and the PM task together by responding *T* or *F* until they saw a target, and then pressing the *1* key on their keyboard when a PM target appeared. After the practice trials were complete, participants were then presented with the four performance PM targets: *spinach, volleyball, tails,* and *sour*.

Immediately after the true PM targets were presented, participants completed two short filler tasks: a letter-string comparison task and a vocabulary task. These tasks were presented after PM task encoding to impose a delay between when participants formed the PM intention and when they could carry out the intention during performance trials. The filler tasks occupied participants with activities other than the PM task so that it left consciousness, and then the PM intentions were retrieved during performance trials. After the filler tasks were completed, participants began performance trials of the sentence-judgment and PM tasks. Following completion of the performance trial interval, participants completed the post-task questionnaire. Participant submissions were then automatically sent to Gorilla for data collection and Prolific for payment. Upon receipt of the data, participant submissions were checked to ensure that participants had consented to the study and that they had satisfactorily completed all tasks provided to them; if so, the submission was approved, and participants were awarded payment.

III. RESULTS

The output data was inspected for accuracy of entry, missing or extreme-outlier values, and violations of assumptions for variables included in statistical analyses. Preliminary analyses included descriptive statistics of demographics for the sample and the two pain groups. For Hypothesis 2, a Welch's *t*-test was conducted to examine group differences on PSQI global scores. For Hypothesis 3, a moderation analysis and a mediation analysis were conducted to explore whether sleep functioning exerts an influence on the relationship between pain and PM performance, or whether pain status transmits its effect on PM through sleep. All primary and secondary analyses will be conducted using SPSS with $\alpha = 0.05$.

Data Preparation

Two hundred twenty-seven participants completed eligible submissions. In total, 39 of these submissions were excluded from analysis as explained here.

Eleven participants were excluded for health factors. Five participants were excluded for reporting that they had been diagnosed with schizophrenia; as a serious mental illness, schizophrenia was viewed as having the potential to severely disrupt cognitive, affective, and behavioral functioning beyond the scope of this project. Three participants reported a diagnosis of multiple sclerosis; although relatively common and heterogeneous in presentation, multiple sclerosis was excluded because it is a demyelinating disorder causing systemic impairment. Despite the age range restriction for this study (18–50 years), two participants reported a diagnosis of dementia and were thus excluded because of probable memory concerns. One participant was excluded because they reported currently receiving chemotherapy, which might

affect their overall pain level, sleep functioning, and cognitive functioning.

Fifteen participants were excluded based on failures to follow task instructions, with 14 excluded for having PM false alarm responses (FARs) on more than 5% of ongoing task trials, meaning that the participant was pressing the *1* key much more often than expected and committing many false alarms. In addition, one participant was excluded because they responded *T* on every ongoing task trial.

Twelve additional participants were excluded due to outlier levels of ongoing task performance. One participant was excluded from analysis because they demonstrated an overall extreme accuracy on the ongoing task, meaning that their overall accuracy was more than 2.5 *SD* from participant accuracies in their pain group. Four participants demonstrated extreme response times (RTs) compared to their group's mean RTs, meaning that their personal mean RT was more than 2.5 *SD* away from the mean RT for their pain group, and were thus excluded from analysis. Eight participants were excluded for having intra-participant outlier RTs (i.e., more than 2.5 *SD* away from their individual RT mean) on more than 10% of ongoing task trials following RT trimming procedures as described below.

Pain and No-Pain Group Coding

These above exclusions left 188 participants eligible for data analyses. Of these, 95 participants were coded as being in the pain group, and the remaining 93 participants were coded as being in the no-pain group. Participants reported whether they experience chronic pain as a qualifier on the Prolific platform before beginning this study, and qualifiers such as pain experience and duration were used to recruit participants on Prolific, but pain was reassessed with the CPAQ in the study to ensure that participant pain status had not changed. Coding was determined by germane variables from the CPAQ; specifically, the item asking participants

whether they consider their pain to be chronic was used as the main discriminative variable for group coding, although items asking about the pain's continuousness, severity, and duration were examined to ensure that participants who considered their pain to be chronic were indeed experiencing chronic pain.

Participant Demographics

The demographic characteristics of the final sample are presented in Table 1, displayed by pain group status. One hundred eight participants (57.45%) reported that they were assigned female sex at birth; 95 participants identified as women (50.53%). The majority (69.68%) of the sample was white, with 10.64% identifying as Asian/Pacific Islander; 8.51% of participants were Hispanic, 5.85% of participants were Black, 2.65% were biracial, 1.60% were multiracial, and less than 2% of the sample identified as Indigenous Peoples or Middle Eastern.

Regarding education, 38.30% of participants had a high school degree or equivalent as their highest level of education, with nearly all (97.87%) participants attaining at least high school equivalence. Two participants had earned doctorates, eighteen (9.57%) had earned a master's degree, and 71 (37.77%) had earned a bachelor's degree. A Mann-Whitney *U*-test indicated a nonsignificant difference in educational attainment between the pain and no-pain groups, $U = 3653.50$, $p = .052$.

The reported socioeconomic status of participants was also diverse. Although definitions for the classes were not provided, 17.55% of participants identified as *lower class*. Nearly one-third of the sample identified as *lower-middle class* (31.91%) and as *middle class* (32.98%). Fewer participants identified as *upper-middle class* (15.96%), and only two participants (1.06%) identified as *upper class*. A Mann-Whitney *U*-test indicated a nonsignificant difference in socioeconomic status between the pain and no-pain groups, $U = 3841.50$, $p = .136$.

Group Differences in Pain Variables

Several pain variables of interest were captured by the CPAQ, including medication use, pain location, duration, continuousness, baseline severity, and disruption of daily functionality. On the baseline severity item, participants were asked to rate their average pain over the past week on an 11-point scale from 0 to 10. As expected, a significant difference was found in baseline pain rating, $t(134.424) = -14.511$, $p < .001$, $d = -2.102$, such that the pain group's mean pain rating of 3.35 ($SE = .19$) was significantly higher than the no-pain group's mean rating of 0.35 ($SE = .09$). The median rating for the pain group was 3 out of 10 with a mode of 2, while the no-pain group's median and mode rating were each 0. Ratings in the pain group ranged from 0 to 8, while ratings in the no-pain group ranged from 0 to 4. Notably, the central tendency of the pain group's baseline ratings roughly maps onto overall mild pain severity. Although the defining feature of the pain group is longstanding pain, we are nonetheless recruiting from a largely nonclinical participant pool, so we expected to observe more mild and moderate cases of chronic pain.

Opioids are occasionally prescribed as an analgesic in cases of otherwise unresponsive or severe chronic pain. Given their typical side effects (especially at higher doses), it is important to assess the proportion of participants on opioid treatment. Because they are prescribed in cases of more severe pain yet the doses necessary to provide analgesia are higher and thus side effects are more likely, it can be difficult to disentangle whether cognitive functioning is impaired by the pain alone, by the opioid effects and side effects, or both. However, only three participants reported on the CPAQ that they were currently taking opioids for their pain, and all three were coded as being in the pain group. None of the three named the medication and dosage as requested, limiting our understanding of the scale of opioid effects. The open responses for

"other medications" were also checked to investigate whether participants were naming opioid medications while reporting that they do not take them. One such participant who was coded as being in the pain group was identified as having denied taking opioids but reporting the use of tramadol, an opioid medication that is less well-known. Thus, only four participants out of the 95 pain group participants (4.21%) were currently prescribed opioid medications, supporting the expectation of a nonclinical sample with less severe pain than observed in research with clinical recruitment.

Group Differences in Psychiatric Symptoms

Rather than excluding potential participants for exhibiting depressive or anxiety symptoms, these variables were instead measured via the PHQ-9 and HAM-A measures, respectively, and considered in relation to the primary variables of interest. The pain groups differed significantly on depression scores, $t(177) = -5.212$, $p < .001$, $d = -.779$, such that the pain group reported a more severe depressive symptomatology than the no-pain group. Similarly, the groups differed on HAM-A anxiety scores, $t(165.741) = -6.889$, $p < .001$, $d = -1.030$, such that the pain group reported significantly worse anxiety symptoms than the no-pain group. These large effects in a pain group with relatively low pain severity indicate that chronic pain is strongly associated with more severe anxiety and depression, especially with binary group coding. Relevant descriptive and test statistics are presented in Table 2.

Hypothesis 1: Group Differences in PM Performance

To test Hypothesis 1, a *t*-test was planned to determine whether the pain and no-pain groups differed in their PM performance as measured by PM hit rate. Levene's Test for Equality of Variances was nonsignificant, $p = .914$, indicating that variances can be assumed to be equal between groups; thus, an independent samples *t*-test was conducted. The hypothesis was

supported, $t(186) = 2.550$, $p = .012$, suggesting that chronic pain was associated with impaired PM performance: The pain group mean hit rate was approximately one-and-a-half hits per four available targets ($SE = .14$), while the no-pain group mean hit rate was nearly two hits per four targets ($SE = .14$), avoiding both ceiling effects and floor effects.

Because chronic pain is often comorbid with anxiety, depression, or both, exploration of these variables in the context of pain group coding was warranted. Analyses of covariance (ANCOVAs) were conducted to consider these effects while comparing pain groups on PM performance. The relationship between pain status and PM performance remained significant when adjusting PM performance by HAM-A sum score, $F(1,177) = 4.653$, $p < .05$, $\eta^2 = .026$, with the pain group ($M = 1.44$, $SE = .14$) performing significantly worse than the no-pain group ($M = 2.03$, $SE = .14$). Likewise, an ANCOVA was conducted to consider depression's effect on PM performance. This ANCOVA was also significant, $F(1,176) = 4.747$, $p < .05$, $\eta^2 = .026$, such that the pain group ($M = 1.48$, $SE = .14$) performed significantly worse than the no-pain group ($M = 2.03$, $SE = .14$) when adjusting PM performance for depression scores. Depression and anxiety scores in this study were highly correlated, $r = .849$, $p < .001$, which dovetails with clinical literature demonstrating that anxiety and depression are often comorbid with each other as well as with chronic pain (Pollack, 2005; IsHak et al., 2018; Dahan, van Velzen, & Niesters, 2014). No ANCOVA was thus conducted with both anxiety and depression as covariates because of this high collinearity.

In addition to these analyses, it was important to determine whether group differences were observed on PM task FARs or RTs on PM hits. We did not expect differences on these variables on the basis of pain status. An independent samples *t*-test indicated that the two groups did not significantly differ on FAR counts, $p = .389$, nor did the groups differ on mean RTs for

PM hits, $p = .928$. It does not appear that the experience of pain influences the number of false alarms or the amount of time it takes to respond when a PM target is presented.

Hypothesis 2: Group Differences in Sleep Functioning

To test Hypothesis 2, a *t*-test was planned to determine whether the pain and no-pain groups have equal means for their PSQI global score. Levene's Test for Equality of Variances was significant, $p = .016$, indicating that variances were unequal between groups. Because of the violated assumption of homoscedasticity, a more conservative test of difference of means, Welch's *t*-test, was conducted rather than an independent samples *t*-test. Hypothesis 2 was supported, $t(152.599) = -5.680$, $p < .001$, suggesting that the experience of chronic pain was significantly associated with impairments in sleep functioning. The PSQI is scaled such that a lower score is indicative of less sleep dysfunction, and a higher score suggests more dysfunction. The pain group's mean PSQI global score of 9.35 ($SE = .49$) was significantly higher than the no-pain group's mean of 5.88 ($SE = .37$) with a large effect size, $d = -.882$, which means that the pain group experienced poorer sleep functioning than the no-pain group. Given that pain status was significantly associated with the summed global score and the global score is an aggregation of seven components, we would also expect to see significant group differences among individual component scores as well. Supporting this expectation, the pain and no-pain groups differed significantly on all seven component scores. PSQI component and global scores are presented in Table 3.

We also examined whether sleep functioning was associated with PM performance with a simple linear regression. This regression was nonsignificant, $F(1,166) = 3.049$, $p = .083$, $r^2 = .018$. Thus, it does not appear that one's sleep functioning predicts PM performance in a meaningful way, which is an important consideration for the mediation and moderation analyses

for Hypothesis 3. Although manipulations of sleep have previously demonstrated decrements in PM performance (e.g., total sleep deprivation in Esposito et al., 2015), such effects appear to be driven by the magnitude of the manipulation. In the present study, sleep was not manipulated but instead measured through self-report, and even with more severe PSQI global scores, all participants in this study reported getting at least some sleep.

Because other variables can affect sleep, we investigated whether depression and anxiety were associated with sleep functioning. Simple linear regressions were conducted with PHQ-9 and HAM-A scores as predictor variables and PSQI global scores as the outcome variable. Regardless of group, higher levels of anxiety significantly predicted poorer sleep functioning, $F(1,159) = 210.059$, $p < .001$, $r^2 = .569$, and higher levels of depression significantly predicted poorer sleep functioning, $F(1,158) = 141.066$, $p < .001$, $r^2 = .472$. Nearly half of the variance in sleep functioning among participants was accounted for by depression (47.2%), and more than half was accounted for by anxiety (56.9%). These findings speak to the complexity of sleep functioning as a construct and suggest that research concerning sleep functioning ought to consider the role of psychiatric symptoms on holistic sleep assessment.

Hypothesis 3a and 3b: Sleep Functioning as Moderator and Mediator

To test Hypothesis 3a (sleep functioning as a moderator), a simple moderation analysis was conducted using the PROCESS macro for SPSS (Hayes, 2017) with pain status as the independent variable, PSQI global score as the moderator, and PM hit rate as the dependent variable. Moderation analyses attempt to determine if the size, sign, or strength of a relationship is altered by a third variable (Hayes, 2017), and they are similar to testing for an interaction effect between pain status and sleep quality on PM performance through factorial ANOVA in concept and interpretation. This simple moderation analysis was nonsignificant, $p = .572$; thus,

we did not find evidence that sleep functioning significantly alters the magnitude or direction of the relationship between pain status and PM performance, and Hypothesis 3a was not supported. Table 4 contains the PROCESS output for Hypothesis 3a, with the relevant test statistic emphasized with a box around it.

To test Hypothesis 3b (sleep functioning as a mediator), a simple mediation analysis was conducted using PROCESS with pain status as the independent variable, PSQI global score as the mediator, and PM hit rate as the dependent variable. Mediation analyses attempt to determine if the independent variable influences the mediator which in turn influences the dependent variable. In the context of Hypothesis 3b, this mediation analysis tested the idea that, while pain is significantly associated with PM performance, chronic pain might be transmitting its effect on PM performance through sleep functioning. As noted above, PSQI global scores do not significantly predict PM performance. However, significant effects between the independent and mediator variables and between the mediator and dependent variables are not required to establish a significant mediation effect (Hayes, 2017).

Figure 1 includes a graphical representation of this simple mediation analysis, with *a* referring to the relationship between pain and sleep, *b* referring to the relationship between sleep and PM performance, *c´* as the direct effect of pain on PM performance, and *c* as the total effect of the model. In order to determine whether there is a significant mediation, a bootstrapped 95% confidence interval for the indirect effect *ab* was computed, as the indirect effect represents how much the groups are estimated to differ in PM performance as a result of pain's influence on sleep which in turn influences PM performance. Unstandardized indirect effects were computed for each of 10,000 bootstrapped samples, and the 95% confidence interval was computed by determining the indirect effects at the 2.5th and 97.5th percentiles.

Table 5 contains the PROCESS output for Hypothesis 3b, with the relevant test statistics emphasized with boxes around them. The indirect effect was (3.4699)(-0.236) = -0.0819, with the 95% confidence interval ranging from -0.246 to 0.089. Because this confidence interval contained zero, we found no evidence that the indirect effect is significantly different from zero. Thus, Hypothesis 3b is not supported.

Overall, we did not find evidence that sleep functioning significantly alters the relationship between pain status and PM performance or that sleep functioning explains how or why pain status is related to PM performance. Although large group differences were observed between the pain groups on sleep functioning, this variable does not appear to be related to pain's association with PM performance. It is possible that pain impairs many psychological functions, such as cognitive processes like PM or biopsychological processes like sleep, but that these processes are not entirely interlinked. It is also possible that sleep functioning influences both PM performance and the pain-PM relationship but only in cases of severe sleep dysfunction or deprivation, which the present study did not capture.

Ongoing Task Performance

Ongoing task performance was not a primary focus of this study, but it was analyzed in keeping with the majority of contemporary studies of PM. Performance on the ongoing task was measured by recording accuracy and RT for sentence-judgment task trials. If participants divert cognitive resources away from the ongoing task to monitor for PM target words, they may show poorer ongoing task performance if the ongoing task itself requires cognitive resources. Participants with better PM performance would therefore be expected to demonstrate slower RTs or poorer accuracy for the ongoing task. As discussed above, there is evidence that clinical levels of chronic pain can affect information processing speed (Sjøgren et al. 2005) and such findings

can complicate the interpretation of ongoing task RT and accuracy differences between the pain and no-pain groups, because we might expect that participants with chronic pain from a clinical sample would have higher baseline RTs, poorer accuracy, or both apart from any difference related to PM performance. Due to concerns about fatigue, we did not include a baseline measure of ongoing task performance, which would have lengthened the experiment. Instead, the speeded filler task provides a measure of RTs separate from the ongoing task.

Accuracy

Ongoing task accuracy was computed as a percentage with correct ongoing task responses as the numerator and total ongoing task trials as the denominator. Accuracy for the sentence-judgment task was expected to be high overall given that the sentences are constructed to be clearly true or false (Bowden, Smith, & Loft, 2017). A 2X2 mixed ANOVA with group status as the between-subjects factor, trial type (true or false) as the within-subjects factor, and mean accuracy as the dependent variable produced a significant main effect of group, $F(1,186) = 4.058$, $p < .05$, $\eta_p^2 = .021$, and a main effect of trial type, $F(1,186) = 20.866$, $p < .001$, $\eta_p^2 = .101$, both of which were qualified by a significant trial-type-by-group interaction, $F(1,186) = 4.522$, $p < .05$, $\eta_p^2 = .024$. When examining only trials that were true, the pain group ($M = 95.07\%$, $SE = .45\%$) was significantly more accurate than the no-pain group ($M = 92.97\%$, $SE = .74\%$), $t(151.58) = -2.428$, $p = .016$. However, no difference in accuracy was observed between the pain group ($M = 95.98\%$, $SE = .32\%$) and the no-pain group ($M = 95.47\%$, $SE = .53\%$) for false trials, $p = .409$, although ceiling effects on accuracies for false trials might have attenuated the effect and prevented us from detecting a significant difference.

Response time

To remove RT outliers, ongoing task RT data were trimmed as follows. First, we

excluded trials with a RT of less than 200 msec, trials with inaccurate ongoing task responses, and the performance trial immediately following each PM target. After these exclusions, individual participant means and *SD*s were computed separately for true and false sentences. Finally, any ongoing trial with a RT that was more than 2.5 *SD* away from the individual's mean RT value for that trial type (true or false) was removed from the ongoing task analysis (e.g., Smith, 2003).

Similar to the analysis for accuracy, a 2X2 mixed ANOVA with group status as the between-subjects factor, trial type as the within-subjects factor, and mean RT as the dependent variable was conducted. A significant main effect of trial type was observed, $F(1,186) = 9.596$, $p < .01$, $\eta_p^2 = .049$, such that responses on false trials ($M = 1583.19$, $SE = 27.70$) were slower than those on true trials ($M = 1549.36$, $SE = 28.45$). No significant main effect of group on mean RT was found between the pain group ($M = 1527.46$, $SE = 36.15$) and no-pain group ($M = 1606.08$, $SE = 42.82$), $F(1,186) = 2.047$, $p = .154$, $\eta_p^2 = .011$, and the trial-type-by-group interaction was also nonsignificant, $F(1,186) = 1.701$, $p = .194$, $\eta_p^2 = .009$.

Post-Task Questionnaire Analysis

The post-task questionnaire was intended to provide information about participants' strategies for remembering the PM target words and to ascertain whether they understood task instructions. Participants were presented with an open-ended item asking them to type in any strategies they employed to help them complete the ongoing and PM tasks. Quantitative statistical analysis was not feasible with this type of item, so its primary benefit was to determine if common strategies are employed to help participants remember the task requirements. This item also checked for commission of invalid strategies (e.g., "I wrote down the target words on a sticky note before starting the task"), and no participants reported such strategies.

Participants overall did not consistently report the memory strategies they used. Of the participants who did respond to the open-ended strategies item, the most commonly reported memory strategy was brief rehearsal (e.g., "repeating the words in my head"), with 54 participants reporting that this was their strategy to remember the PM words. The next most common strategy reported (49 participants) was a statement of trust in their ability to remember rather than using a strategy like rehearsal; for instance, one participant wrote that their strategy to remember the PM targets was "just my memory." Thirty-six participants reported that, whether or not they employed specific strategies, they forgot the words quickly or struggled to remember them through performance trials. Eight participants stated that they used an associative strategy or added context to the words. For example, one participant wrote that "I remembered spinach as green veggie, volleyball as a sport, tails for animals and not stories, and sour as in lemons..." Six participants explicitly reported using mental imagery to help them remember the words.

Participants were also asked to type in the four PM targets they were asked to remember. Because this item was free recall, participants could enter any responses they wished, including partial answers (e.g., only two targets) or comments like "I can't remember," or leave the item blank. Appendix I contains all of the recalled words from this item. Each correctly recalled target was tallied for every respondent, and every intrusion (a response that was not a target) was tallied as well. For example, if a participant typed "volleyball, tails" as their response, this was coded as two hits and no intrusions; however, "tail, sour, alcohol, plants" was coded as two hits and two intrusions. Seven participants in the no-pain group and 17 pain group participants responded that they could not recall the targets or did not enter any text, which was coded as no hits and no intrusions. An independent samples *t*-test indicated that, on average, the no-pain group (M = 2.01, SE = .16) correctly recalled more PM targets than the pain group (M = 1.39,

SE = .14), *t*(186) = 2.974, *p* < .01, *d* = .434. However, no significant difference in number of intrusions was demonstrated between the no-pain group (*M* = 0.68, *SE* = .11) and the pain group (*M* = 0.48, *SE* = .09), *t*(172.118) = 1.358, *p* = .176, *d* = .199.

Group Comparisons on Age, Verbal Ability, and Processing Speed

Participants in the pain group (*M* = 32.92 years, *SE* = .96 years) were significantly older than those in the no-pain group (*M* = 29.37 years, *SE* = .83 years), *t*(183.022) = -2.795, *p* < .01, *d* = -.407. Age-related differences have been found in PM performance (e.g., Smith & Bayen, 2006), although the PAM theory proposes that decrements in working memory capacity associated with aging drive these differences. The age difference in this study (approximately three-and-a-half years) and the mean age of participants (young adults around 30 years old) would not provide an appreciable difference in working memory, so it is not likely that the age difference would explain the difference in PM performance between groups.

While the filler tasks were used to engage participants following the PM instructions, the particular filler tasks selected also provide additional information about the two groups. The vocabulary test provides a measure of participants' verbal ability, and the letter-string task provides a measure of group RTs for the groups when they are performing a single-choice speeded task. In keeping with contemporary studies of PM, accuracy was analyzed for both the letter-string task and the vocabulary task.

Vocabulary task accuracy as measured by total correct responses significantly differed between the groups, *t*(186) = -2.677, *p* = .008, such that the no-pain group (*M* = 15.37, *SE* = .48) correctly responded to fewer vocabulary words than the pain group (*M* = 17.09, *SE* = .44). As the no-pain group performed significantly better on the PM task than the pain group, the direction of

this difference in vocabulary task accuracy indicates that PM deficits for the pain group are unlikely to be due to verbal ability differences.

No significant group differences in mean accuracy on the letter-string task were observed, $p = .766$, indicating that the pain and no-pain groups were equally accurate. No group RT differences were found when the letter-string task was decomposed into correct and incorrect responses, with nonsignificant *t*-tests for correct ($p = .386$) and incorrect ($p = .790$) responses. These findings suggest that it would be unlikely that any PM performance deficits for the pain group are due to processing speed differences.

Clinical chronic pain patients seem to experience decreases in information processing speed (Sjøgren, Christrup, Petersen, & Højsted, 2005), and pain likely competes with other processes for finite resources of attention (Eccleston, Crombez, Aldrich, & Stannard, 1997), especially at more severe intensities. However, there is little evidence that processing speed in individuals with *nonclinical* chronic pain is impaired (Hart et al., 2000). This study relied upon self-reported chronic pain status, but clinical status is not intended to be an exclusionary criterion. We expected a mix of clinical and nonclinical chronic pain participants, and self-reported patient histories bore this out; a broad and inclusive definition of chronic pain was represented, which could have obfuscated the interpretation of any RT differences in the study, but the lack of a group difference on the speeded filler task indicates that this concern is minimized in the current study. Given the overall low pain severity in the pain group, it is possible that the pain group participants' chronic pain was not severe enough to elicit observable group differences in ongoing task RT.

IV. DISCUSSION

The present study utilized an online recruitment platform to explore associations between pain and PM performance, as well as to investigate whether sleep functioning influences a pain-PM relationship. Hypotheses 1 and 2 were supported, indicating that chronic pain is significantly associated with both poorer PM performance and poorer sleep functioning. These findings supplement the meager extant research that has examined pain's effect on PM functioning and on sleep functioning. However, Hypotheses 3a and 3b were not supported: Sleep functioning does not appear to alter or explain the pain–PM relationship.

Pain and PM Performance

In support of our prediction that participants in the chronic pain group would exhibit poorer performance on the PM task than the no-pain group, Hypothesis 1 was significant. This aligns with the extant literature demonstrating that the experience of pain impairs PM performance, especially with non-focal PM tasks (Ling et al., 2007; Miller et al., 2014). The observed effect in the present study is notable given that larger effects are expected when the difference in pain severity between groups is larger, yet the pain group's reported experience of pain was mild overall and the difference was small. This suggests that even at mild levels of chronic pain, sleep functioning and PM performance might be greatly impaired. The association also remained significant when PM performance was adjusted for participants' depression and anxiety scores. Taken together, these results suggest that chronic pain is associated with poorer PM performance even when considering psychiatric symptoms that are commonly experienced by individuals with chronic pain. Individuals with chronic pain might thus benefit from simple

modifications to their behavior that can increase daily functioning and decrease their pain severity, like consistent mild-to-moderate exercise or physical therapy, which might in turn decrease the deleterious effects of pain on PM performance.

Pain and Sleep Functioning

We expected that participants with chronic pain would have significantly poorer sleep quality as assessed by global PSQI score than those without chronic pain. Previous research supports the existence of a positive feedback loop between chronic pain and poor sleep in which pain disturbs sleep and this disturbed sleep amplifies the experience of pain (Doufas, Panagiotou, & Ioannidis, 2012). Sleep dysfunction and pain are also highly comorbid in chronic pain: More than half of chronic pain patients report sleep dysfunction, and nearly 90% have significant sleep disturbances (Atkinson, Ancoli-Israel, Slater, Garfin, & Gillin, 1988; Smith, Perlis, Smith, Giles, & Carmody, 2000). Our hypothesis was supported, as the chronic pain group reported significantly higher sleep dysfunction than the no-pain group. This adds to the existing literature documenting the relationship between pain and sleep functioning and demonstrates that even with relatively mild pain reported by the pain group in this study, a large effect was observed, which suggests that these variables are linked either directly or through the influence of unmeasured extraneous variables. Individuals with chronic pain might thus benefit from proactive sleep hygiene (e.g., keeping the bedroom cool and dark) and stimulus control modifications (e.g., going to bed only when sleepy and rising at the same time each morning) to their sleep routines. Because pain is frequently reported to interfere with sleep, individuals with chronic pain might also talk with their physicians about adjusting pain treatments to ensure some pain relief around bedtime.

Pain, Sleep Functioning, and PM Performance

Hypothesis 3 was not supported: We found no evidence that sleep functioning moderated or mediated the relationship between pain status and PM performance. Although chronic pain was associated with poorer sleep functioning, sleep functioning did not predict PM performance. We can interpret the nonsignificant moderation and mediation as evidence that, while pain is related to both sleep functioning and PM performance, sleep functioning does not significantly alter the size or direction of this effect, nor does it explain how or why pain is related to PM performance. Pain and sleep functioning did not have an interactive effect on PM performance, nor did pain transmit its effect on PM performance through sleep functioning.

Although we found wide ranges of PSQI global scores for both groups, we did not find many extreme sleep functioning scores; those that were found were almost exclusively from the pain group. For example, all but one of the no-pain participants and 82.9% of pain participants had a global score of 14 or lower out of a possible 21. Obtaining more severe sleep dysfunction measurements might have increased the likelihood of finding an association with PM performance, and re-testing a moderation or mediation model with more pronounced sleep dysfunction might clarify whether sleep modifies the pain-PM relationship only when sleep dysfunction is extreme. However, the number of individuals with both chronic pain and severe sleep dysfunction is quite small and does not represent the experiences of most people with pain or sleep concerns, so a significant mediation or moderation might have little substantive value for understanding the interconnections between pain, sleep, and PM performance in the general population.

Ongoing Task Results

Comparing the ongoing task RTs of the pain and no-pain groups revealed no significant difference in resource costs incurred by monitoring for PM target words during the sentence-judgment task, but the pain group showed a reduced level of ongoing task accuracy. The PAM theory (Smith, 2003) proposes that people must direct part of their cognitive capacity toward monitoring for the events that signal that a PM intention can be completed. When an individual engages in strategic monitoring to seek out and respond to PM targets, there is often a cost to the ongoing task RT at its expense, but this can also be reflected in differences in ongoing task accuracy.

We expected that participants would need to actively monitor for PM target words because the sentence-judgment task is non-focal (more cognitively demanding), but it was also possible that effects on the ongoing task due to devoting resources to the PM task in the no-pain group would be masked if chronic pain participants have an additional resource demand related to chronic pain. However, the speeded filler task results indicated that the relatively low level of chronic pain in our pain condition was not affecting accuracy or RTs. The pattern of poorer ongoing task accuracy, combined with better PM performance in the no-pain group relative to the pain group, is consistent with the PAM theory's proposal that resources are required to prepare for successful performance of the PM task.

Limitations and Future Directions

While the present study is strengthened by obtaining a sample size informed by an *a priori* power analysis and the use of a more objective PM paradigm, it is limited in several ways. One limitation of the study design is the use of online self-report questionnaires for data collection. Although they are cost- and time-efficient and necessary due to the pandemic-related

constraints on in-person data collection at the time of this study, self-report measures inherently involve dishonest, inconsistent, or erroneous participant responses. Future research in this arena may wish to employ in-person, laboratory data collection for quality control of participant responses. With this said, collecting responses online allowed for a larger age range and a more diverse sample than would have been likely at a university setting.

In the present study, we capture participant data at only one time point, limiting our ability to draw stronger conclusions about the direction and robustness of observed effects. Chronic pain is a set of conditions defined by their persistence, but chronic pain conditions might also resolve due to treatment or healing over time. Sleep dysfunction can also be dependent on other factors like pain conditions, and transient sleep dysfunction is exceedingly common. Performance on cognitive tasks might also vary across time based on pain, sleep, or situational factors like time of day. Repeated measures assessment of pain, sleep, and PM performance might resolve this concern, or a behavioral paradigm such as daily diaries for pain and sleep could be applied to determine whether the observed effects in the present study are robust across contexts.

An additional limitation of this project is the inability to comprehensively assess participants for pain and sleep conditions. In addition to the financial cost involved in providing multiple converging assessments when participants are paid for their time, we also did not want to make the study overlong and accidentally induce participant fatigue. Although an average completion time for the study was unavailable from Gorilla or Prolific, most participants completed the questionnaires more quickly than estimated yet still provided quality responses. This might be explained by participants on Prolific being experienced with online questionnaires and the general format of research, and the estimated time might have been inflated due to an

assumption that completion would take a similar amount of time as it would in a laboratory setting with instructions and transitions between tasks.

Future research might build off of the present study's results by extending the samples to either specific pain conditions or different types of pain (e.g., neurological, musculoskeletal). This would clarify the role of pain on PM across pain profiles and contexts, which could support differential intervention based on diagnostic classifications. For example, if this study's methodology was carried out using a no-pain group, a mechanical low back pain group, and a neuropathic pain group, the results of this research would indicate whether PM deficits are observed for each of these conditions and whether these deficits are the same. These results might then affect treatment selection, as groups or conditions with larger PM deficits might benefit from cognitive-behavioral intervention to learn about PM and how to improve their memory functioning. However, assuming that the severity of the pain is equal across groups, we would not expect differences in PM performance based solely on the pain type, because whether the pain is neurological or musculoskeletal, the result is still the same: the experience of pain. We would expect instead that participants in the two pain groups would describe the quality of their pain quite differently (e.g., tingling and dull, sharp and stabbing). A complication with this line of inquiry is the variability in systemic effects across conditions: Mild low back pain and demyelinating disorders like multiple sclerosis might both fit the label of chronic pain and affect daily functioning, but multiple sclerosis often causes central nervous system impairments including loss of balance and sensation, visual disabilities, and fatigue, while low back pain might simply make strenuous activity more difficult. This would make comparison between these conditions challenging, because it would be difficult to determine whether it is the pain in multiple sclerosis that is affecting PM performance instead of fatigue, trouble with vision, or

nerve damage causing RT delays. Studies that aim to disentangle the role of pain type in PM performance should consider the level of systemic impairments in conditions of interest, how those impairments might confound cognitive research, and if feasible, which conditions might be more readily comparable in their level of dysfunction.

Qualitative responses to items in the post-task questionnaire indicated that several participants believed that their memory was poor or had little confidence in their ability to remember the targets, even if they were able to recall and accurately respond to the targets in performance trials. Cognitive concerns are frequently reported by individuals with chronic pain (McCracken & Iverson, 2001), whether they reflect true deficits or perceptions due to hypervigilance. If measuring a participant's confidence in their memory is possible in the context of future post-task questionnaires, it would be of interest to consider how beliefs match up with task performance and whether these beliefs explain observed group differences.

Research with pain groups and clinical sleep disorders could be conducted to assess whether samples of clinical pain or clinical sleep dysfunction replicate the present results. The present study did not recruit from pain or sleep clinics, so while the results are more applicable to the general young-and-middle adult population, observed effects must be considered in a nonclinical context. More severe forms of sleep disturbance as seen in disorders such as insomnia, sleep apnea, and narcolepsy might present an avenue of study to investigate whether sleep functioning moderates or mediates a relationship between pain and PM performance when sleep dysfunction is more profound. Additional research might also focus on constructs such as fatigue that are associated with both chronic pain and with sleep dysfunction to determine whether fatigue explains some of the relationship between pain and PM performance.

Summary

Limited extant research indicates that chronic pain and PM performance are associated, especially when the PM task is more cognitively demanding. The results of the present study support this association. Pain was also associated with poorer sleep functioning, although sleep functioning did not influence the magnitude or direction of the pain-PM relationship. Furthermore, sleep functioning did not explain how or why chronic pain is associated with PM performance. The present study thus provides additional evidence of chronic pain's association with PM performance and of pain's relationship with sleep functioning, and both findings might be useful for improving quality of life for individuals with chronic pain by improving sleep and PM functioning.

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LIST OF APPENDICES

Table 1

Demographic Characteristics of the No-Pain and Pain Groups

	No-Pain (*n* = 93)	Pain (*n* = 95)	*p*-value
Mean age *(SE)*	29.37 *(.83)*	32.92 *(.96)*	.006
% White	58.06	81.05	.003
% Female	45.16	69.47	.001
% Woman	44.09	56.84	.032
% Bachelor's degree or higher	58.06	38.95	.074
% Middle class SES or higher	55.91	44.21	.153

Table 2

Descriptive Statistics and t-Tests for HAM-A and PHQ-9 by Pain Group

Measure	No-Pain		Pain		*t*(df)	*p*	*Cohen's d*
	M	*SE*	*M*	*SE*			
HAM-A sum	8.53	.77	17.27	1.01	-6.889 (165.741)	< .001	-1.030
PHQ-9 sum	6.57	.66	11.95	.80	-5.212 (177)	< .001	-.779

Note: Because of infrequent omitted responses on the HAM-A and PHQ-9 measures, summed scores could not be generated for all participants in each pain group. In the no-pain group, there were 91 valid cases for both the HAM-A and the PHQ-9; in the pain group, there were 89 for the HAM-A and 88 for the PHQ-9. A Welch's *t*-test was conducted for HAM-A scores because Levene's Test was significant, $p = .007$. Partial degrees of freedom are provided for this test above.

Table 3

Descriptive Statistics and t-Tests for PSQI Components by Pain Group

Component Score	No-Pain		Pain		*t* (df)	*p*	*Cohen's d*
	M	*SE*	*M*	*SE*			
Global Score	5.88	.37	9.35	.49	-5.680 (152.599)	< .001	-.882
C1: Sleep Quality	1.03	.07	1.53	.07	-4.851 (185.153)	< .001	-.708
C2: Latency	1.20	.10	1.72	.11	-3.540 (185)	.001	-.518
C3: Duration	0.61	.07	1.01	.09	-3.479 (185)	.001	-.509
C4: HSE	0.55	.08	1.11	.12	-3.876 (162.314)	< .001	-.566
C5: Disturbances	1.03	.05	1.42	.07	-4.535 (153.300)	< .001	-.696
C6: Medications	0.47	.10	0.90	.13	-2.607 (172.706)	.01	-.381
C7: Daytime	0.99	.07	1.57	.09	-4.911 (172.190)	< .001	-.722

Note: The global score is the principal sleep functioning variable used in the present study, and is calculated by summing the seven component scores (listed here as C1–7). Latency is the time required to fall asleep; HSE = habitual sleep efficiency, which is a metric defined as the time spent sleeping divided by total time in bed; and the Daytime component describes daytime sleepiness or fatigue.

Table 4

PROCESS for SPSS Output for Hypothesis 3a: Moderation

********** PROCESS Procedure for SPSS Version 3.5.3 **********

Written by Andrew F. Hayes, Ph.D. www.afhayes.com
Documentation available in Hayes (2018). www.guilford.com/p/hayes3

****
Model : 1
Y : PMsum
X : Group
W : PSQIgbl

Sample Size: 168

Custom Seed: 53091

****
OUTCOME VARIABLE:
PMsum

Model Summary

R	**R^2**	**MSE**	***F***	**df1**	**df2**	***p***
.1942	.0377	1.7820	2.1428	3.0000	164.0000	.0968

Model

	coeff	**se**	***t***	***p***	**LLCI**	**ULCI**
constant	2.0515	.2878	7.127	.0000	1.483	2.620
Group	-.1710	.4511	-.3792	.7051	-1.062	.7196
PSQIgbl	-.0048	.0424	-.1133	.9099	-.0885	.0789
Int_1	-.0307	.0541	-.5669	.5716	-.1375	.0761

Product terms key:
Int_1 : Group x PSQIgbl

Level of confidence for all confidence intervals in output:
95.0000

------ END MATRIX -----

Table 5

PROCESS for SPSS Output for Hypothesis 3b: Mediation

********** PROCESS Procedure for SPSS Version 3.5.3 **********

Written by Andrew F. Hayes, Ph.D. www.afhayes.com
Documentation available in Hayes (2018). www.guilford.com/p/hayes3

****
Model : 4
Y : PMsum
X : Group
M : PSQIgbl

Sample Size: 168

Custom Seed: 53091

****
OUTCOME VARIABLE:
PSQIgbl

Model Summary

R	**R^2**	**MSE**	***F***	**df1**	**df2**	***p***
.4054	.1644	15.48	32.651	1.00	166.00	.0000

Model

	coeff	**se**	***t***	***p***	**LLCI**	**ULCI**
constant	5.8837	.4243	13.868	.0000	5.0461	6.7214
Group	3.4699	.6073	5.7141	.0000	2.2710	4.6689

a path

****
OUTCOME VARIABLE:
PMsum

Model Summary

R	**R^2**	**MSE**	***F***	**df1**	**df2**	***p***
.1893	.0358	1.7747	3.0662	2.0000	165.0000	.0493

Model

	coeff	**se**	***t***	***p***	**LLCI**	**ULCI**
constant	2.1622	.2111	10.2446	.0000	1.7455	2.5789
Group	-.3925	.2249	-1.7451	.0828	-.8366	.0516
PSQIgbl	-.0236	.0263	-.8986	.3702	-.0755	.0283

c' path

b path

********** TOTAL EFFECT MODEL **********
OUTCOME VARIABLE:
PMsum

Model Summary

R	R^2	MSE	*F*	df1	df2	*p*
.1764	.0311	1.7726	5.3310	1.0000	166.0000	.0222

Model

	coeff	se	*t*	*p*	LLCI	ULCI
constant	2.0233	.1436	14.093	.0000	1.7398	2.3067
Group	-.4745	.2055	-2.309	.0222	-.8802	-.0687

c path

********** TOTAL, DIRECT, AND INDIRECT EFFECTS OF X ON Y **********

Total effect of X on Y

Effect	se	t	p	LLCI	ULCI	c_ps
-.4745	.2055	-2.3089	.0222	-.8802	-.0687	-.3518

Direct effect of X on Y

Effect	se	t	p	LLCI	ULCI	c'_ps
-.3925	.2249	-1.7451	.0828	-.8366	.0516	-.2911

Indirect effect(s) of X on Y:

	Effect	BootSE	BootLLCI	BootULCI
PSQIgbl	-.0819	.0842	-.2461	.0887

a•*b*

Normal theory test for indirect effect(s):

	Effect	se	Z	p
PSQIgbl	-.0819	.0937	-.8747	.3817

Partially standardized indirect effect(s) of X on Y:

	Effect	BootSE	BootLLCI	BootULCI
PSQIgbl	-.0608	.0628	-.1844	.0655

********** ANALYSIS NOTES AND ERRORS **********

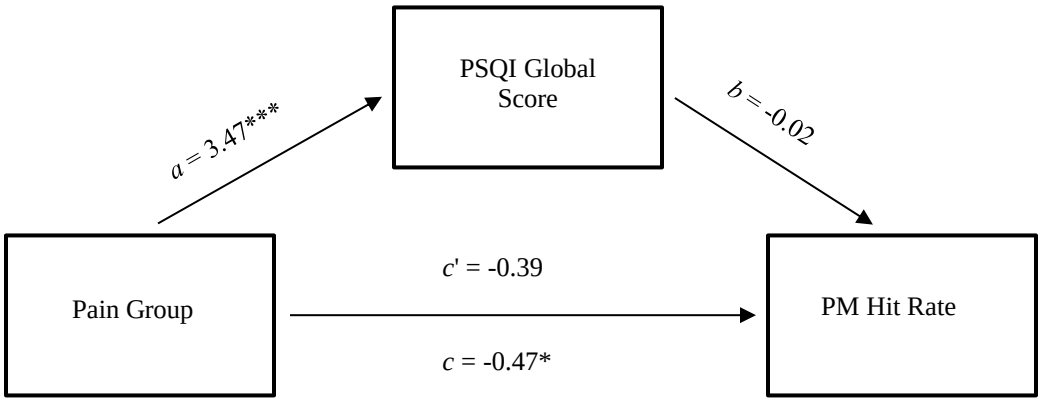
Level of confidence for all confidence intervals in output:
95.0000

Number of bootstrap samples for percentile bootstrap confidence intervals:
10000

------ END MATRIX -----

Figure 1

Visualization of Simple Mediation and Unstandardized Coefficients



Note. * $p < .05$; *** $p < .001$. The *a* path is the effect of pain on sleep functioning; the *b* path is the effect of sleep functioning on PM performance; *a* multiplied by *b* is the indirect effect of pain on PM through sleep; the *c*' path is the direct effect of pain on PM accounting for sleep; and *c* is the total effect of this model (the simple regression of PM on pain). Mathematically, this mediation is described by the formula $c = c' + ab$, as the indirect effect is equivalent to the direct effect of pain on PM subtracted from the total effect.

APPENDIX A

Ongoing Task Sentence List

America is a country	TRUE	Children can grow bigger	TRUE
Ants are living creatures	TRUE	Chili is hot	TRUE
Architects are people	TRUE	Chocolates are sweet	TRUE
Beavers can hear sounds	TRUE	Clocks can tell time	TRUE
Beds are furniture	TRUE	Crows have two eyes	TRUE
Beer contains alcohol	TRUE	Cupboards are used for storage	TRUE
Bees are small	TRUE	Daisies grow in gardens	TRUE
Bells make loud noises	TRUE	Doctors are people	TRUE
Birds have feathers	TRUE	Dogs can hear sounds	TRUE
Bishops give sermons	TRUE	Dolls wear clothes	TRUE
Boats are used for transport	TRUE	Dolphins have fins	TRUE
Books are manufactured goods	TRUE	Dragonflies have wings	TRUE
Boots are footwear	TRUE	Drills are tools	TRUE
Boxes are used for storage	TRUE	Ducks have wings	TRUE
Bread can be eaten	TRUE	Eagles have feathers	TRUE
Brothers are family members	TRUE	England is a country	TRUE
Cakes are sweet	TRUE	Fire is hot	TRUE
Candles can shine brightly	TRUE	Fish have fins	TRUE
Captains can sail ships	TRUE	Frogs are small	TRUE
Carrots come from plants	TRUE	Hammers are tools	TRUE
Cars have engines inside	TRUE	Hollywood has buildings	TRUE
Cats have teeth	TRUE	Ice is cold	TRUE
Chairs are furniture	TRUE	Jackets are clothing	TRUE

Jeans are clothing	TRUE	Snow is cold	TRUE
Juice is a liquid	TRUE	Stars can shine brightly	TRUE
Meats are sold by butchers	TRUE	Telephones make loud noises	TRUE
Mice can run fast	TRUE	Tigers can run fast	TRUE
Months measure time	TRUE	Tomatoes can be eaten	TRUE
Mothers often have husbands	TRUE	Trees can grow bigger	TRUE
New York has buildings	TRUE	Trucks have engines inside	TRUE
Nurses wear clothes	TRUE	Turtles move slowly	TRUE
Pasta is a food	TRUE	Vans are used for transport	TRUE
Pencils are manufactured goods	TRUE	Vodka contains alcohol	TRUE
Penguins have feet	TRUE	Watches can tell time	TRUE
People run countries	TRUE	Water is a liquid	TRUE
Pineapples come from plants	TRUE	Whales are living creatures	TRUE
Potatoes are vegetables	TRUE	Wives often have husbands	TRUE
Presidents run countries	TRUE	Women can sail ships	TRUE
Priests give sermons	TRUE	Years measure time	TRUE
Rabbits have feet	TRUE	America is a food	FALSE
Radishes are vegetables	TRUE	Ants are furniture	FALSE
Rice is a food	TRUE	Architects are manufactured	FALSE
Roses grow in gardens	TRUE	Beavers give sermons	FALSE
Sausages are sold by butchers	TRUE	Beds can hear sounds	FALSE
Sharks have teeth	TRUE	Beer is a country	FALSE
Shoes are footwear	TRUE	Bees move slowly	FALSE
Sisters are family members	TRUE	Bells are living creatures	FALSE
Snails move slowly	TRUE	Birds run countries	FALSE
Snakes have two eyes	TRUE	Bishops are sold by butchers	FALSE

Boats are sweet	FALSE	Ducks can sail ships	FALSE
Books are family members	FALSE	Eagles wear clothes	FALSE
Boots come from plants	FALSE	England is a liquid	FALSE
Boxes are sweet	FALSE	Fire is cold	FALSE
Bread contains alcohol	FALSE	Fish are used for storage	FALSE
Brothers are manufactured	FALSE	Frogs have engines inside	FALSE
Cakes are used for transport	FALSE	Hammers can grow bigger	FALSE
Candles are family members	FALSE	Hollywood is a food	FALSE
Captains are used for transport	FALSE	Ice is hot	FALSE
Carrots give sermons	FALSE	Jackets have feet	FALSE
Cars are people	FALSE	Jeans move slowly	FALSE
Cats come from plants	FALSE	Juice is a country	FALSE
Chairs have engines inside	FALSE	Meats grow in gardens	FALSE
Children have wings	FALSE	Mice wear clothes	FALSE
Chili is clothing	FALSE	Months can be eaten	FALSE
Chocolates are people	FALSE	Mothers are footwear	FALSE
Clocks have two eyes	FALSE	New York is a liquid	FALSE
Crows have teeth	FALSE	Nurses have fins	FALSE
Cupboards are footwear	FALSE	Pasta is cold	FALSE
Daisies can hear sounds	FALSE	Pencils have two eyes	FALSE
Doctors have fins	FALSE	Penguins can shine brightly	FALSE
Dogs are clothing	FALSE	People grow in gardens	FALSE
Dolls are vegetables	FALSE	Pineapples run countries	FALSE
Dolphins have feathers	FALSE	Potatoes can tell time	FALSE
Dragonflies have teeth	FALSE	Presidents are used for storage	FALSE
Drills are vegetables	FALSE	Priests have wings	FALSE

Rabbits are tools	FALSE
Radishes can shine brightly	FALSE
Rice has buildings	FALSE
Roses are furniture	FALSE
Sausages can run fast	FALSE
Sharks measure time	FALSE
Shoes are living creatures	FALSE
Sisters are sold by butchers	FALSE
Snails often have husbands	FALSE
Snakes measure time	FALSE
Snow has buildings	FALSE
Stars make loud noises	FALSE
Telephones can run fast	FALSE
Tigers can sail ships	FALSE
Tomatoes can tell time	FALSE
Trees make loud noises	FALSE
Trucks are small	FALSE
Turtles often have husbands	FALSE
Vans can be eaten	FALSE
Vodka is hot	FALSE
Watches can grow bigger	FALSE
Water contains alcohol	FALSE
Whales are small	FALSE
Wives are tools	FALSE
Women have feathers	FALSE
Years have feet	FALSE

APPENDIX B

Health and Demographics Questionnaire

Instructions: We know that our health can sometimes affect how we perform on different tasks. We would therefore like to ask you some questions about your health. We will also ask for information regarding ethnicity, race and gender. This information is collected to ensure that our studies provide an adequate reflection of the general population. Please keep in mind that all of your answers will be kept strictly confidential. Your name will not be connected with your responses in any way.

1. Please select your age (in years): DROP-DOWN MENU
2. Please select your gender (if *other*, please type your gender): DROP-DOWN MENU
3. Please select one of the following that bests describes your ethnicity. DROP-DOWN MENU
4. Please select one of the following that bests describes your race. DROP-DOWN MENU
5. Are you fluent in written and spoken English? YES/NO
6. How would you rate your health at this time? DROP-DOWN MENU
7. Have you been diagnosed with any of the following? Dementia, Schizophrenia, Huntington's Disease, Parkinson's Disease, or Multiple Sclerosis? YES/NO
8. Have you ever had a heart attack or stroke? YES/NO
9. Do you take insulin for diabetes? YES/NO
10. Are you receiving kidney dialysis? YES/NO
11. Have you had cancer for which you received chemotherapy in the past year?
12. Do you have emphysema?
13. Have you ever suffered from a disease or injury which might have caused brain damage?
14. Is there anything that could affect your performance on tests of problem solving, memory, or the use of words in this session? For example, less than 3 hours of sleep last night, hangover, consumption of more that 4 alcoholic beverages in the last 24 hours, medication or other drugs affecting your alertness (e.g., Benadryl, codeine, sudafed), a history of alcohol or substance abuse?
15. Are you currently taking medication for depression?

16. Do you have ADHD or ADD? If so, are you currently taking medications for this?
17. Did you have problems seeing or hearing any of the materials in this study?
18. Did you have problems concentrating during this study?
19. What level of education have you completed?
20. Are you currently a student or will you be enrolled as a student in the next semester?
21. If you are currently a student, what is your GPA?
22. Did you take the SAT or the ACT?
23. Are you currently employed? (If Yes, please report the number of hours you usually work each week.)
24. Do you participate in any volunteer activities? (If yes, please report the number of hours you usually volunteer each month.)
25. What is the highest level of education completed by your father?
26. What is the highest level of education completed by your mother?
27. How would you describe your family's economic situation?
28. In comparison to others in your community, how would you rate your family's social status?

APPENDIX C

Chronic Pain Assessment Questionnaire

1. Throughout our lives, most of us have had pain from time to time, such as minor headaches, sprains, or toothaches. Other than these, do you currently experience pain?.....YES/NO

2. On a 0 to 10 scale, with 0 being *no pain* and 10 being *the worst pain imaginable*, how would you rate the pain you currently feel? 0 (no pain) 1 2 3 4 5 6 7 8 9 10 (worst pain imaginable)

2. Do you consider this pain to be chronic pain?.....YES/NO

2. Has this chronic pain been diagnosed by a physician?.....YES/NO

3. For how long have you experienced this pain?..... __ years, __ months, __ weeks

4. During the past week, have you had any pain or would you have had pain if not for the treatment you are receiving?.....YES/NO

5. Is this pain present continuously (most of the day) on most days, or would the pain persist if not for the treatment you are receiving?.....YES/NO

6. During the past week, on average, how would you rate your baseline pain on a scale of 0 to 10?..... 0 (no pain) 1 2 3 4 5 6 7 8 9 10 (worst pain imaginable)

7. Where in your body do you experience this pain?..... drop-down: head, neck, back, etc.

8. Are you currently taking opioid medications for your pain?.....YES/NO IF YES: type Rx, dose

9. Are you currently taking any other medications for your pain?.....YES/NO IF YES: type Rx, dose

10. How much has your chronic pain affected your performance at work?... 0 (none) 1 2 3 4 5 (unable to perform)

11. How much has your chronic pain affected activities in your daily life, such as errands or housework?..... 0 (none) 1 2 3 4 5 (unable to perform)

APPENDIX D

Post-Task Questionnaire

1. While performing the sentence judgement task, you were supposed to press a different key when you saw the special words. Please press that key now. [text box]

2. Did you remember to press the *1* key when you saw the special words? [yes/no]

3. Please list the four words you were asked to remember for this task: [text box]

4. Please describe any strategies you used to help you remember these words: [text box]

APPENDIX E

Pittsburgh Sleep Quality Index

INSTRUCTIONS:

The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

1. During the past month, what time have you usually gone to bed at night?

BED TIME _____

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?

NUMBER OF MINUTES _____

3. During the past month, what time have you usually gotten up in the morning?

GETTING UP TIME _____

4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.)

HOURS OF SLEEP PER NIGHT _____

For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you . . .

a) Cannot get to sleep within 30 minutes

Not during the past month _____ Less than once a week _____ Once or twice a week _____ Three or more times a week _____

b) Wake up in the middle of the night or early morning

Not during the past month _____ Less than once a week _____ Once or twice a week _____ Three or more times a week _____

c) Have to get up to use the bathroom

Not during the past month _____ Less than once a week _____ Once or twice a week _____ Three or more times a week _____

d) Cannot breathe comfortably

Not during the past month _____ Less than once a week _____ Once or twice a week _____ Three or more times a week _____

e) Cough or snore loudly

Not during the past month _____ Less than once a week _____ Once or twice a week _____ Three or more times a week _____

f) Feel too cold

Not during the past month _____ Less than once a week _____ Once or twice a week _____ Three or more times a week _____

g) Feel too hot

Not during the past month _____ Less than once a week _____ Once or twice a week _____ Three or more times a week _____

h) Had bad dreams

Not during the past month _____ Less than once a week _____ Once or twice a week _____ Three or more times a week _____

i) Have pain

Not during the Less than Once or twice Three or more

past month _____ once a week _____ a week _____ times a week _____
j) Other reason(s), please describe
_____
How often during the past month have you had trouble sleeping because of this?
Not during the Less than Once or twice Three or more
past month _____ once a week _____ a week _____ times a week _____
6. During the past month, how would you rate your sleep quality overall?
Very good _____
Fairly good _____
Fairly bad _____
Very bad _____

7. During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")?
Not during the Less than Once or twice Three or more
past month _____ once a week _____ a week _____ times a week _____
8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?
Not during the Less than Once or twice Three or more
past month _____ once a week _____ a week _____ times a week _____
9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?
No problem at all _____
Only a very slight problem _____
Somewhat of a problem _____
A very big problem _____

10. Do you have a bed partner or room mate?
No bed partner or room mate _____
Partner/room mate in other room _____
Partner in same room, but not same bed _____
Partner in same bed _____

If you have a room mate or bed partner, ask him/her how often in the past month you have had…
a) Loud snoring
Not during the Less than Once or twice Three or more
past month _____ once a week _____ a week _____ times a week _____
b) Long pauses between breaths while asleep
Not during the Less than Once or twice Three or more
past month _____ once a week _____ a week _____ times a week _____
c) Legs twitching or jerking while you sleep
Not during the Less than Once or twice Three or more
past month _____ once a week _____ a week _____ times a week _____
d) Episodes of disorientation or confusion during sleep
Not during the Less than Once or twice Three or more
past month _____ once a week _____ a week _____ times a week _____
e) Other restlessness while you sleep; please describe_____
Not during the Less than Once or twice Three or more
past month _____ once a week _____ a week _____ times a week _____

APPENDIX F

PSQI Scoring Algorithms

Component 1: Subjective sleepiness

= **Item 6 score.**

Very good = 0
Fairly good = 1
Fairly bad = 2
Very bad = 3

Component 2: Sleep latency

Item 2 score:

≤ 15 minutes = 0
16-30 minutes = 1
31-60 minutes = 2
> 60 minutes = 3

Item 5a score:

Not during the past month = 0
Less than once a week = 1
Once or twice a week = 2
Three or more times a week = 3

Component score = Sum of scores from items 2 and 5a.

If sum is 0, component score is 0.
If sum is 1-2, component score is 1.
If sum is 3-4, component score is 2.
If sum is 5-6, component score is 3.

Component 3: Sleep duration

= **Item 4 score:**

> 7 hours = 0
6-7 hours = 1
5-6 hours = 2
< 5 hours = 3

Component 4: Habitual sleep efficiency

= **(Item 4 hours / [Item 3 – Item 1]) x 100** = habitual sleep efficiency percentage

Component score as follows:

> 85% = 0
75-84% = 1
65-74% = 2
< 65% = 3

Component 5: Sleep disturbances

For each Item from 5b – 5j:
Not during the past month = 0
Less than once a week = 1
Once or twice a week = 2
Three or more times a week = 3

= **Sum of Items 5b – 5j.**

Component score is as follows:
Sum of 0 = 0
Sum of 1-9 = 1
Sum of 10-18 = 2
Sum of 19-27 = 3

Component 6: Sleeping medication use

= Item 7 score:
Not during the past month = 0
Less than once a week = 1
Once or twice a week = 2
Three or more times a week = 3

Component 7: Daytime dysfunction

Item 8 score:
Never = 0
Once or twice = 1
Once or twice each week = 2
Three or more times each week = 3

Item 9 score:
No problem at all = 0
Only a very slight problem = 1
Somewhat of a problem = 2
A very big problem = 3

= **Sum of Items 8 and 9.**

Component score is as follows:
Sum of 0 = 0
Sum of 1-2 = 1
Sum of 3-4 = 2
Sum of 5-6 = 3

Global score = **Sum of Component scores 1–7.**

APPENDIX G
Hamilton Anxiety Rating Scales

	Not present	*Mild*	*Moderate*	*Severe*	*Very Severe*
1. **Anxious mood**: worries, irritability, Anticipation of the worst	0	1	2	3	4
2. **Tension**: Feeling restless, tense, fatigued, Trembling, can't relax, crying easily	0	1	2	3	4
3. **Fears**: of dark, strangers, animals, traffic, Crowds, being left alone	0	1	2	3	4
4. **Insomnia**: hard to fall asleep, broken sleep, dreams, nightmares, unsatisfying sleep, tired upon waking	0	1	2	3	4
5. **Intellectual**: poor memory, Hard to concentrate	0	1	2	3	4
6. **Depressed mood**: Loss of interest, lack of pleasure in hobbies, depression, waking early	0	1	2	3	4
7. **Bodily symptoms**: Pains and aches, twitching, stiffness, grinding teeth, unsteady voice	0	1	2	3	4
8. **Sensory symptoms**: Ringing in ears, blurry vision, hot and cold flashes, feeling weak, prickling sensation	0	1	2	3	4
9. **Cardiovascular symptoms**: Palpitations, fast heartbeat, chest pain, throbbing veins or blood vessels, fainting, heart skipping beats	0	1	2	3	4
10. **Respiratory symptoms**: Pressure or tightness in chest, choking feelings, trouble breathing	0	1	2	3	4

| | *Not present* | *Mild* | *Moderate* | *Severe* | *Very Severe* |

11. **Gastrointestinal symptoms**:
Hard to swallow, gas cramps, burning pain in stomach, abdominal fullness, nausea, vomiting, diarrhea, constipation, weight loss. 0 1 2 3 4

12. **Genitourinary symptoms**:
frequent urination, urgent urination, lack of monthly period, heavy periods, premature ejaculation, loss of libido, erectile dysfunction 0 1 2 3 4

13. **Autonomic symptoms**: Dry mouth, flushing, pale skin, sweatiness, feeling giddy or excited, headache, goosebumps 0 1 2 3 4

14. **Behavior at interview**:
Fidgeting, restlessness or pacing, tremor of hands, furrowed brow, strained face, sighing or rapid respiration, facial pallor, swallowing, etc. *Not provided*

APPENDIX H

Patient Health Questionnaire – Depression

	Not at all	*Several days*	*More than half of days*	*Nearly every day*
1. Little interest or pleasure in doing things	0	1	2	3
2. Feeling down, depressed, or hopeless	0	1	2	3
3. Trouble falling or staying asleep, or sleeping too much	0	1	2	3
4. Feeling tired or having little energy	0	1	2	3
5. Poor appetite or overeating	0	1	2	3
6. Feeling bad about yourself, or that you are a failure, or have let your family or yourself down	0	1	2	3
7. Trouble concentrating, such as when reading or watching television	0	1	2	3
8. Moving or speaking noticeably slowly, or being fidgety and restless	0	1	2	3
9. Thoughts that you would be better off dead or of hurting yourself	0	1	2	3

APPENDIX I

Post-Task Questionnaire PM Targets Recalled

On the post-task questionnaire, participants were asked to recall the four PM target words (*spinach*, *volleyball*, *tails*, and *sour*) in a text box. This table provides all of the words submitted by participants and the number of participants recalling each word. Words in bold did not appear in any task or trial of the present study, while words in italics were the PM targets during practice trials.

Word Recalled	Number of Participants
Spinach	88
Volleyball	84
Sour	81
Tails	66
Green	10
Vegetable(s)	7
Snail	5
Sail(s); Juice; Nurse; Ant(s); Lemon(s)	3
Building(s); Dolphin; Fin(s); *Toaster/toast*; Turtle; Sweet; Garden; **Flower**; Sermon; **Spaghetti**	2
Dolls; Snake; **Spinal**; Liquid; Tiger; **Stress**; Pencil; **Tennis**; **Oil**; **Soccer**; **Shovel**; Rabbit; President; Star; Child; **Sun**; Candles; Dog; Ship; **Blue**; Shoes; **Spaceship**; **Spicy**; Radish; **Short**; Feather; **Sailboat**; **Stuck**; Time; Vans; **Umbrella**; Mice; **Summer**; **Gorilla**; **Maple**; Hollywood; Sausage; Transport; **Insect**; Living; Pasta; Frog; **Grass**; **Feet**; **Squish**; Alcohol; Plants; Dragonflies; Tree; Tool; **Flag**	1

VITA

Education:

Minnesota State University, Mankato: Mankato, MN (August 2013–May 2015)

- Clinical Psychology Master's Program
- GPA: 3.96/4.00

Ball State University: Muncie, IN (August 2009–May 2013)

- Baccalaureate major: Psychological Science
- Minor: Interpersonal Relations (Counseling Psychology)
- GPA: 3.79/4.00

Research Experience:

08/2015–08/2021 Supervised Empirical Research Experience

- Memory, Intentions, and Development Lab (Rebekah Smith, PhD)
- Migraine and Behavioral Health Lab (Todd Smitherman, PhD)
- Assisted third-year colleague with thesis data collection, Fall 2015-Spring 2016

08/2013–04/2015 Master's Thesis Project

- *The Relationship between Sexual Functioning and Sleep Quality in A Female Undergraduate Sample*
- Created online surveys with Qualtrics and SONA
- Research concerning relationship between sleep quality and sexual functioning in undergraduate females

08/2013–04/2015 Empirical Research Experience

- Sexual Health research group (Eric Sprankle, PsyD)
- Synthesized research with colleagues
- Assisted colleague with thesis data collection, 11/2013

08/2012–04/2013 Ball State University Departmental Honors Thesis

- *Integrating the Marginalized: A Neuropsychosocial Perspective of Autism Spectrum Disorders in American Society*
- Synthesis of literature on autism spectrum disorders

Clinical and Practical Experience:

08/2016–05/2019 Clinical Psychotherapy Experience

- Psychological Services Center, Kinard Hall, University of Mississippi
- Campus clinic serving university students and community members with presenting concerns such as depression, anxiety, and emotion dysregulation
- Caseload of 2-4 clients per week
- Treat occasional referral clients for insomnia and migraine with behavioral medicine protocols

08/2017–05/2018 Supervised Clinical Practicum Placement

- University Counseling Center: Oxford, MS
- Provide individual and group therapy sessions for undergraduate students
- Caseload of 10 repeating clients, 2 intakes, and 1 group session per week
- Application of CBT, ACT, and interpersonal therapy packages

06/2016–06/2017 Supervised Clinical Practicum Placement

- The North Mississippi Regional Center: Oxford, MS
- Severe/profound IDD, medically fragile, and Prader-Willi syndrome clients
- ABA, CBT, and mindfulness therapy for 5 clients per week
- Administered functional behavior assessments, adaptive behavior interviews, and full battery assessments for diagnosis

06/2014–07/2014 Supervised Summer Practicum

- University of Nebraska Medical Center and Munroe-Meyer Institute: Omaha, NE
- Observed clinical pediatric behavioral health patient sessions
- Discussed diagnoses with patients and caregivers
- Conducted ABA therapy with toddlers in early intervention Autism program

06/2013–06/2013 Teacher-Therapist at Englishton Park Summer Camp

- Conducted behavioral therapy with 8-to-13-year-old at-risk children in three 10-day intensive sessions
- Guided groups of eight children through highly structured summer camp stays
- Created and administered schedules of reinforcement

Teaching Experience:

08/2018–07/2021 Graduate Instructor, University of Mississippi

- Undergraduate introductory psychology course (PSY 201) for five semesters
- Undergraduate cognitive psychology course (PSY 320) for one semester
- Designed curriculum, planned lessons, created and graded assignments and exams

08/2018–04/2021 Statistics Tutor, University of Mississippi

- Fall 2018, Spring 2019, Spring 2020, Fall 2020, Spring 2021
- Provided 4-5 hours per week of walk-in and online tutoring
- Topics included: distributions, central tendency, statistical analyses with R or SPSS, effect sizes, correlation, *t*-tests, ANOVA, chi-square

02/2020–03/2020 R Workshop for Graduate Students, University of Mississippi

- Led an after-hours seminar for R basics
- Three one-hour sessions
- Topics included: installing R, RStudio, tidyverse; reading datasets into R; data wrangling and tidying; basics of data visualization using ggplot2

March 2017 Guest Lecture, University of Mississippi

- One-hour lecture in Honors Introductory Psychology Course
- Discussed sleep disorders, maintenance of healthy sleep

08/2013–05/2015 Graduate Instructor Assistantship, MN State University, Mankato

- Fall 2014 and Spring 2015
- Taught Introductory Statistics for Psychology to undergraduates
- Designed curriculum, online learning platform site for in-person lectures

Publications:

Ahrendt, A., Sprankle, E., **Kuka, A. J.**, & McPherson, K. (2017). Staff member reactions to same-gender, resident-to-resident sexual behavior within long-term care facilities. *Journal of Homosexuality, 64*(11), 1502-1518. doi:10.1080/00918369.2016.1247533

Seng, E. K., **Kuka, A. J.**, Mayson, S. J., Smitherman, T. A., & Buse, D. C. (2018). Acceptance, psychiatric symptoms and migraine disability: An observational study in a headache center. *Headache, 58,* 859-872. doi:10.1111/head.13325

Smitherman, T. A., **Kuka, A. J.**, Buse, D. C., & Penzien, D. B. (2018). Recurrent headache disorders. In D. C. Turk & R. J. Gatchel (Eds.), *Psychological approaches to pain management: A practitioner's handbook (3rd Ed). New York: Guilford.*

Smitherman, T. A., **Kuka, A. J.**, Calhoun, A. H., Walters Pellegrino, A. B., Davis-Martin, R. E., Ambrose, C. E. … & Houle, T. T. (2018). Cognitive-behavioral therapy for insomnia to reduce chronic migraine: A sequential Bayesian analysis. *Headache.* https://doi.org/10.1111/head.13313

Honors and Scholarships:

Fall 2015–August 2021	University of Mississippi Graduate Research Assistantship
Fall 2015–Spring 2020	University of Mississippi Psychology Fellowship
Summer 2018	Department of Psychology Dissertation Fellowship
Fall 2013–Spring 2015	MNSU Department of Psychology Graduate Assistantship
Spring 2013	BSU Departmental Finalist, Academic Honors in Writing
Fall 2010–Spring 2013	BSU Dean's List
Fall 2009–Spring 2013	BSU Honors Distinction Scholarship
Fall 2009–Spring 2013	Member of Ball State University Honors College