2022

An Exploration of the Effects of Mindfulness on Pain: The Role of Pain Catastrophizing

Ilana Haliwa
ih0010@mix.wvu.edu

An Exploration of the Effects of Mindfulness on Pain: The Role of Pain Catastrophizing.

Ilana Haliwa, M.P.H., M.S.

Dissertation submitted to the Eberly College of Arts and Sciences at West Virginia University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Psychology

JoNell Strough, Ph.D., Chair
Cole Vonder Haar, Ph.D.
Natalie Shook, Ph.D.
Julie Brefczynski-Lewis, Ph.D.

Department of Psychology
Morgantown, West Virginia 2022

Keywords: mindfulness, app-based intervention, pain, headspace

ABSTRACT

An Exploration of the Effects of Mindfulness on Pain: The Role of Pain Catastrophizing.

Ilana Haliwa

Chronic pain is a complex global public health concern associated with a host of negative outcomes, including loss of productivity, decreased quality of life, and greater likelihood of developing a mental health disorder. Initial evidence indicates that mindfulness-based interventions (MBIs) improve pain symptomatology. However, most MBIs are time and resource intensive, and it is unclear how mindfulness may improve the pain experience. The purpose of the present set of studies was to test the effects of a brief, app-based MBI on pain experience, and to examine whether pain catastrophizing was a statistical mediator of any effect. Two studies were conducted using samples of healthy adults recruited through West Virginia University (N = 118) and adults reporting chronic low back pain (N = 78), respectively. Participants were randomly assigned to either a 10-day app-based MBI or an active control condition. Pain-catastrophizing, fear of pain, pain sensitivity, and pain severity (Study 2 only) were assessed pre- and post-intervention. We hypothesized that participants in the mindfulness condition, but not the active control condition, would demonstrate decreased pain experience post-intervention. Further, we expected that the effect of the app-based MBI on pain experience would be statistically accounted for by decreases in pain catastrophizing. Decreases in pain sensitivity (Study 1), fear of pain (Study 1), and pain severity (Study 2) were observed pre- to post-intervention, regardless of condition. There was no evidence of an effect of condition or statistical mediation by pain catastrophizing. Overall, the present findings suggest that a 10-day app-based MBI is not sufficient to elicit changes in pain experience among individuals with or without chronic pain. It remains unknown whether pain catastrophizing statistically mediates the effect of an MBI on pain experience. Future research may assess the use of longer app-based interventions or the inclusion of face-to-face intervention components in order to improve pain outcomes.

Acknowledgements

I have received a great deal of support in the development, proposal, implementation, and writing of this dissertation project. This research was made possible by funding from the WVU Department of Psychology Graduate Research Fund Award, the Eberly College of Arts and Sciences Doctoral Research Award, the WVU Behavioral and Biomedical Sciences' Dr. James Stevenson Scholarship Award, and funding by Dr. Natalie Shook. First and foremost, I would like to thank my research mentor, Dr. Shook, whose expertise, mentorship, and guidance was invaluable in not only the development of this dissertation project but also in overcoming novel challenges posed by conducting a dissertation in the context of a global pandemic. Thank you for your patience, support, and willingness to help problem solve as we delved into new territory conducting fully remote research study sessions. I would also like to sincerely thank my advisor and dissertation chair, Dr. JoNell Strough, for consistent support and encouragement throughout this process and my committee members, Drs. Cole Vonder Haar and Julie Brefczynski-Lewis for their contributions to this research project. I have been fortunate to have the help of several wonderful research assistants in preparing materials for the study, data collection, and data entry. I want to give a special thanks to Hunter Barnetta, Luke Frashure, Kelly Smith, Sherley Vasquez-Colon, Cal Benitex, Meghan Jerrild, Sophia Kammerman, Cyrus Smith, Andrew Tsao, and Melanie Wellman who assisted with running study sessions. Lastly, I am eternally grateful to my friends and family for their support and encouragement in completing this project during a uniquely challenging global context.

Table of Contents

An Exploration of the Effects of Mindfulness on Pain: The Role of Pain Catastrophizing

Chronic pain is a significant global public health concern (Goldberg & Mcgee, 2011). Indeed, pain and pain-related disorders have been named a leading cause of global disability and disease burden, affecting over 50 million U.S. adults, and incurring national costs of up to $650 billion per year in health care and loss of productivity (GBD 2016 Disease and Injury Incidence and Prevalence Collaborators, 2017; Institute of Medicine, 2011; Yong et al., 2022). In addition to the aversive symptomatology associated with pain disorders, downstream effects of chronic pain include decreased quality of life and increased likelihood of developing a mental health disorder (Mayer et al., 2019), which may further exacerbate pain experience (Hilton et al., 2017; Woo, 2010).

The most common treatments for chronic pain are analgesics, particularly opioids, but they often come with negative side effects (e.g., sedation, physical dependence, tolerance) and are not necessarily effective (Ballantyne & Shin, 2008; Benyamin et al., 2008; Reinecke et al., 2015). Given the wide-ranging and detrimental impacts of chronic pain and the high addiction potential of opioid pain-therapy, there has been a push to identify alternative therapies for pain management (Dowell et al., 2016; Majeed et al., 2018). Mindfulness-based interventions (MBIs) have demonstrated initial success in the attenuation of pain symptomatology, including decreased pain intensity and maladaptive pain-related cognition (Majeed et al., 2018; Zeidan & Vago, 2016). However, traditional MBIs are time-intensive and require resources (e.g., transportation, childcare) not available to all individuals. Further, little is known about how mindfulness may function to improve pain experience. As such, the purpose of the present set of studies was to test the effects of a brief app-based MBI on pain experience and to assess maladaptive cognition (i.e., pain catastrophizing) as a potential statistical mediator of any effect.

Pain

Pain is a multi-dimensional, subjective experience, involving unpleasant physiological, affective, cognitive, and behavioral processes associated with existing or impending tissue damage (Garland et al., 2013; Merskey et al., 1979; Zeidan & Vago, 2016). Pain can be characterized as acute or chronic, where acute pain is generally restricted in duration (e.g., moments to weeks) and results from a readily identified physical insult that can fully heal. Chronic pain is recurring and persists past the healing time of the initial insult (generally, more than three months; Treede et al., 2015). Although both acute and chronic pain can negatively impact physical and psychological health, the effects of chronic pain are often more detrimental given the longer duration, and chronic pain is more challenging to manage using traditional pharmacotherapy (Grichnik & Ferrante, 1991; Mayer et al., 2019; Smith & Torrance, 2012).

From a physiological standpoint, pain occurs in response to the detection of a potential physical insult by specialized peripheral sensory neurons called nociceptors, which transmit sensory information up to the brain for processing via afferent nerve fibers. Signaling from nociceptors can trigger immune and glial cells in the peripheral nervous system and neurons in the central nervous system to secrete inflammatory proteins, such as C-reactive protein (CRP), which initiate the inflammatory response to localize and eliminate noxious stimuli and remove components of damaged tissue in the body (Kandel et al., 2013; Wojdasiewicz et al., 2014). Further, circulating inflammatory proteins promote the production of neuropeptides, such as nerve growth factor (NGF; Kandel et al., 2013, Zhang & An, 2007). These neuropeptides bind to nociceptors and increase the transcription of genes that promote nociceptor sensitivity and increased pain sensation (Kandel et al., 2013, Zhang & An, 2007).

There is, however, significant individual variability in pain responses to a similar nociceptive stimulus. Thus, researchers have begun to consider the physiological components of pain in the context of broader psychological processes (Crombez et al., 2012; Vlaeyen et al., 2016). Specifically, the fear-avoidance model of pain depicts a process by which cognitive responses to injury and the immediate pain experience influence the long-term perception of pain, resultant functional disability, and potential for recurring pain (see Figure 1; Lethem et al., 1983; Vlaeyen & Linton, 2000). Central to this model is pain catastrophizing, which is characterized by an overestimation of the gravity and duration of the effects of pain (e.g., "I worry all the time about whether the pain will end"; Sullivan et al., 1995). Vlaeyen and Linton (2000) proposed that if pain is interpreted through catastrophic cognitions (i.e., pain catastrophizing), fear of pain (i.e., an anticipatory affective response to real or perceived imminent pain) may evolve. Fear then becomes a learned response associated with situations or activities perceived as having the potential to induce pain (e.g., exercising, lifting a heavy object; Vlaeyen & Linton, 2000). Individuals may then avoid these situations or behaviors, thus promoting greater functional disability (avoidance of daily activities) and disuse of affected body parts, which has been shown to worsen physical disability by detrimentally affecting both the musculoskeletal and cardiovascular systems (Bortz, 1984; Vlaeyen & Linton, 2000). Withdrawal from activities may decrease opportunities to contact reinforcers associated with daily living, thus leading to affective disturbances, such as increased negative affect and depression (Vlaeyen & Linton, 2000). Finally, disability, disuse, and depression all lead to greater likelihood of reinjury or prolonged pain experience (i.e., chronic pain; Vlaeyen & Linton, 2000).

Empirical evidence has supported the fear-avoidance model of pain in a variety of chronic pain populations, including chronic back pain, headache, and fibromyalgia (Crombez et

al., 1999; Crombez et al., 2012; Keefe et al., 2004; Leeuw et al., 2007; Pincus et al., 2002; Pincus et al., 2010). Together, this work highlights the fundamental role of pain catastrophizing in shaping the pain experience. For example, greater pain catastrophizing is associated with greater pain intensity (i.e., magnitude of experienced pain; Cook et al., 2013) and pain sensitivity (i.e., anticipated magnitude of pain; Melzack, 1987; Ruscheweyh et al., 2009).

Despite evidence supporting the psychological components of pain, pharmacotherapy with analgesics, such as non-steroidal anti-inflammatory drugs (NSAIDs) and opioids, remain the front-line treatments for chronic pain (Jackson, 2006; Kroenke et al., 2009). However, the effectiveness of these treatments is generally poor (Chapparo et al., 2014; Gaskell et al., 2009; Kissin, 2013; Noble et al., 2010; Teater, 2014). For example, a Cochrane review assessing treatment of post-operative pain found that only 22% of patients treated with oxycodone received adequate pain relief (Gaskell et al., 2009). Additionally, opioid analgesics have been found to be no more effective than placebo in the treatment of chronic pain for longer than four months (Chapparo et al., 2014; Kissin, 2013; Noble et al., 2010). Furthermore, there are a number of negative side effects associated with continuous use of many analgesic pharmacotherapies (e.g., sedation, respiratory depression, renal dysfunction, hypertension), as well as concerns regarding addiction with opioids (Teater, 2014). As such, additional effective interventions are needed to address chronic pain (Ballantyne & Shin, 2008; Benyamin et al., 2008; Reinecke et al., 2015). One such category of treatment, which has displayed promising initial results, is MBIs (Majeed et al., 2018; Zeidan & Vago, 2016).

Mindfulness

Mindfulness is defined as awareness through purposeful, non-judgmental attention to the present moment (Kabat-Zinn et al., 1985) and can be conceptualized as both a state and a

dispositional trait (Kiken et al., 2015). State mindfulness refers to an intentionally induced mindset through exercises or practices, such as meditation (Lau et al., 2006), whereas dispositional mindfulness refers to a trait level predisposition (Baer et al., 2006). State and dispositional mindfulness are positively related, as consistent practice of state mindfulness can lead to increased dispositional mindfulness, which is associated with a host of psychological and physical benefits (Baer et al., 2006; Brown & Ryan, 2003; Greeson, 2009; Kiken et al., 2015). As such, a variety of MBIs have been developed to address a range of health issues, with generally positive results (Baer, 2003; Creswell, 2017; Cullen, 2011).

Most MBIs consist of 6-8 weeks of regular in-person training and daily engagement in mindfulness practices. Participants are taught a set of specific exercises aimed at inducing state-level mindfulness, with the ultimate goal of increasing an individual's dispositional propensity to be mindful. These exercises generally focus on the ability to engage in non-judgmental, present-focused attention to the physical body, emotions, and thoughts (Moore, 2008). Three common exercises are body scan, yoga, and sitting meditation. During a body scan exercise, participants are instructed to lie down with their eyes closed and sequentially direct their attention to particular areas of the body (e.g., feet, calves, abdomen, chest; Baer, 2006; Creswell, 2017; Cullen, 2011). Throughout the exercise, participants are guided to notice sensations in each area, in turn, while refraining from assigning affective labels to these sensations (e.g., "my arm hurts, and that is bad"). Yoga is another body-focused mindfulness exercise, in which participants focus on physical sensations that arise during guided gentle movement or stretching (Cullen, 2011). Finally, sitting meditation practices entail participants being guided to focus their attention on a specific stimulus, such as their breath, thoughts, or affective experience, while in a sitting position (Baer, 2006; Creswell, 2017; Cullen, 2011; Moore, 2008). Throughout the

duration of these exercises, participants are encouraged to observe internal and external sensations non-judgmentally and to simply redirect their attention back to the focal stimulus when they find themselves distracted or engaging in judgment (Baer, 2006; Creswell, 2017; Cullen, 2011; Moore, 2008). These practices have been shown to independently improve state mindfulness, as well as dispositional mindfulness, and both physical and psychological well-being when practiced collectively in the form of an MBI package (Baer, 2006; Creswell, 2017; Cullen, 2011).

Although generally effective, there are several limitations inherent in the use of traditional MBIs. First, many RCTs looking at the effects of MBIs have failed to use active control conditions, instead using treatment-as-usual or waitlist controls, which may be susceptible to the influence of factors unrelated to treatment (e.g., placebo effects, demand characteristics; Baer 2003; Goldberg, 2017). This limitation can be addressed by implementing more rigorous control groups in order to determine the unique benefits of MBIs after accounting for these non-treatment specific effects. Further, the most common MBIs used in RCTs are modeled after the prototype of Mindfulness Based Stress Reduction (MBSR; Kabat-Zinn, 1990), an 8-week mindfulness intervention consisting of 2 – 2.5 hours of weekly group mindfulness instruction and 45 minutes per day of guided home practice (Baer et al., 2006; Creswell, 2017). Initially developed for the treatment of chronic pain, the MBSR framework has been adapted for application to a variety of disorders in which stress is considered a hallmark symptom, including issues relating to substance-use relapse prevention, healthy eating, and relationship enhancement (Bowen et al., 2014; Carson et al., 2004; Creswell, 2017; Mason et al., 2015). While these interventions are effective in improving pain symptomatology, dependence on pain medication, and cognition with medium effect sizes (Baer et al., 2006; Creswell, 2017), the time and resource

intensive nature of these interventions may be prohibitive for many populations, including individuals with low socioeconomic status (SES) and those residing in rural areas, with limited access to transportation, childcare, or providers with mindfulness training. Indeed, time commitment has been cited as a common barrier to completion of MBSR programs (Chang et al., 2004; Morone et al., 2008; Simpson et al., 2019).

These barriers to traditional MBI programming may be surmounted by using mobile-based MBI applications (apps) with the capability to offer mindfulness training exercises (e.g., body scans, sitting meditation) guided by experienced instructors to a wider and more varied audience (Cavanaugh et al., 2014; Flett et al., 2019). This method of delivery is especially promising, given that on average 81% of U.S. adults own a smartphone (Taylor & Silvier, 2019). While initial research has found app-based MBIs to be acceptable to participants (e.g., engaging, easy to use) and effective in increasing self-reported mindfulness, research is needed to further test the effects of these interventions (Bennike et al, 2017; Flett et al., 2019; Haliwa et al., 2021a; Mistler et al., 2017; Wen et al., 2017). Overall, existing barriers associated with traditional MBIs may be addressed via the use of mobile-based intervention delivery, thus expanding the potential to implement MBIs with a larger portion of individuals suffering from chronic pain.

Mindfulness and Pain

A growing body of research has linked mindfulness with pain-related outcomes. Dispositional mindfulness, in the absence of any training, has been inversely associated with both self-reported (McCracken et al., 2007; Schutze et al., 2010; Zeidan et al., 2018) and behavioral pain outcomes (Harrison et al., 2019; Petter et al., 2013). Two cross-sectional studies with adult chronic pain samples found that those with higher levels of dispositional mindfulness reported lower levels of pain intensity (McCracken et al., 2007; Schutze et al., 2010) and pain

interference (Schutze et al., 2010). The inverse relation between dispositional mindfulness and pain intensity was also replicated among a sample of healthy adults (Zeidan et al., 2018). Petter and colleagues (2013) utilized a cold pressor task to measure pain tolerance (i.e., how long pain can be endured) and pain intensity (i.e., self-reported magnitude of experienced pain) among healthy adolescents. Participants with higher levels of dispositional mindfulness demonstrated greater pain tolerance (i.e., longer latency to remove their hand from cold water) and reported lower levels of pain intensity. This pattern was also found with a thermal pain task, in which participants (healthy adults with no prior history of mindfulness practice) experienced progressively increased thermal stimulation ranging from 89.6°F to 104°F applied to the calf (Harrison et al., 2019). More mindful individuals demonstrated higher pain-thresholds (i.e., identified the sensation as painful at higher temperatures).

A few studies have evaluated the effects of mindfulness training on behavioral measures of pain, suggesting that mindfulness training increases pain tolerance and threshold. For example, Grant and Rainville (2009) found that trained meditators with over 1000 hours of practice demonstrated significantly lower pain sensitivity and greater pain tolerance to thermal stimuli compared to matched control volunteers without meditation training. Zeidan and colleagues (2010, 2011, 2015) found that even brief mindfulness interventions (4 sessions, 20 minutes each) among healthy adults decreased pain sensitivity and pain intensity, and increased pain thresholds during acute laboratory induced pain via both electrical and thermal stimuli. Similarly, undergraduate students who were assigned to meditation training for 25-minutes per day across 2-weeks demonstrated higher pain thresholds during a thermal pain task than those in a passive control condition (Reiner et al., 2016). Further, upon repeated exposure to thermal

stimuli, participants in the mindfulness training condition demonstrated a more rapid habituation effect than those in the control condition.

Evidence generally supports the utilization of MBIs for pain-management, such that individuals who participate in MBIs demonstrate improved pain experience (e.g., reduced self-reported pain intensity, severity, interference) compared to controls (Hilton et al., 2017; Kabat-Zinn et al., 1985; Merkes, 2010; Reiner et al., 2013). A recent meta-analysis of 30 randomized controlled trials (RCTs) using MBI in the treatment of various types of chronic pain, including fibromyalgia, back pain, rheumatoid arthritis, migraine headache, and irritable bowel syndrome, found that, overall, participants who participated in an MBI reported greater improvements in self-reported pain severity, intensity, and interference compared to controls (i.e., waitlist control, treatment-as-usual, cognitive behavioral therapy (CBT), psycho-education/support group) with a small effect size (SMD = 0.32; Hilton et al., 2017). Taken together, these results suggest that mindfulness may attenuate acute and chronic responses to pain among both healthy adults and those experiencing chronic pain and that these effects can be induced via mindfulness training. However, the mechanisms or statistical mediating factors through which this occurs remain unclear.

Mindfulness and Pain Catastrophizing

Some researchers have suggested that one mechanism by which mindfulness may improve psychological and physical health outcomes is by altering cognitive processes (Dahl et al., 2015; Ford et al., 2021a; Ford & Shook, 2019). That is, mindfulness may change what information is attended to (Brown et al., 2007; Garland et al., 2015; Ford et al., 2021b), how information is processed or interpreted (Grabovac et al., 2011; Segal et al., 2002), and what information is remembered (Alberts & Thewissen, 2011; Roberts-Wolfe et al., 2012). In

particular, mindfulness may reduce tendencies toward negativity bias in cognitive processes, or the tendency for negatively valenced stimuli to exert greater effects on cognitive processes compared to positively valenced or neutral stimuli (Baumeister et al., 2001). For example, greater mindfulness has been associated with less catastrophic thinking, a type of negatively biased cognition characterized by an overestimation of the negative consequences of an event (Beck et al., 1979), which is considered maladaptive given its associations with worse outcomes including worse depression, anxiety, and pain experience (see Gellalty & Beck, 2016, for a review).

According to the fear-avoidance model of pain, pain catastrophizing represents a negatively biased pain-related cognition, which serves as the precursor to prolonged or chronic pain experience (Hoffman et al., 2007; Vlaeyen & Linton, 2000; Quartana et al., 2009). As such, researchers have recently proposed that mindfulness may influence pain catastrophizing, thereby improving pain experience (see Figure 2; Schutze et al., 2010). Indeed, dispositional mindfulness has been associated with a lower likelihood of engaging in pain catastrophizing (Paul et al., 2013; Prins et al., 2014). Furthermore, dispositional mindfulness may be indirectly associated with lower pain sensitivity through reduced pain-catastrophizing (Haliwa & Shook, 2020). Additional support for pain catastrophizing as a statistical mediator of this effect comes from experimental work assessing the effects of MBIs on pain catastrophizing among individuals with chronic pain (Day et al., 2014; Garland et al., 2012). Day and colleagues (2014) found that adults with chronic headache pain receiving Mindfulness Based Cognitive Therapy (MBCT) experienced a significant reduction in pain catastrophizing compared to wait-list controls. Additionally, Garland and colleagues (2012) assessed the effects of either an 8-week MBI or support group on intensity of symptoms and pain catastrophizing in women with irritable bowel

syndrome (IBS) and found that those in the MBI condition reported significantly greater improvements in IBS-related pain intensity compared to the control group. This effect was statistically mediated by change in pain catastrophizing (Garland et al., 2012). Taken together, existing evidence suggests that one way mindfulness may improve pain experience is by attenuating pain catastrophizing.

Present Research

Existing research indicates that MBIs may be a promising therapy for pain management and that its effects may be due, in part, to improvements in pain catastrophizing. However, research is needed to further evaluate the efficacy of more accessible interventions, such as shorter, app-based trainings. Additionally, more work is needed to address gaps in the existing literature on the relations among MBI, pain catastrophizing, and pain experience. Specifically, further research is needed to experimentally test a model of the effect of app-based MBIs on pain with maladaptive cognition as a statistical mediator. Thus, the purpose of the proposed set of studies was to test the effect of a brief app-based MBI on pain experience, and to test pain catastrophizing as a statistical mediator of the effect of the brief app-based MBI on pain experience. [1]

Participants were randomly assigned to either a mindfulness condition or an active control condition. The first study utilized a sample of healthy adults recruited through West Virginia University. Although this sample consisted of largely young adults without chronic

[1] The originally proposed studies also involved the examination of inflammation as a potential mediator between mindfulness and pain experience, as well as behavioral assessment of pain. However, due to the emergence and continued spread of the COVID-19 virus during data collection, modifications to the research protocol were made to ensure participant and researcher safety. Rather than conducting the research study in-person, data collection was completed using a remote protocol that was pre-approved by committee members during the proposal meeting. As such, blood sampling and cold-pressor procedures were excluded from the protocol, and thus measurement and analyses of inflammation and cold-pressor outcomes (i.e., pain tolerance, pain intensity, and pain threshold) were not conducted.

pain, this convenience sample allowed for a large sample size with sufficient power to test our hypotheses. Further, as similar patterns have been observed in studies assessing the effects of mindfulness on pain among both healthy and chronic pain samples (e.g., McCracken et al., 2007; Petter et al., 2013; Schutze et al., 2010; Zeidan et al., 2018), we expected few differences in results based on pain status. The second study utilized a chronic pain sample to determine whether findings from Study 1 generalized to a chronic pain population. We hypothesized that participants who engaged in an MBI would demonstrate greater reductions in pain experience than those in the control condition and that these effects would be statistically accounted for by decreases in pain catastrophizing.

Study 1

Participants

Students, faculty, and staff at West Virginia University were recruited through multiple sources, including listserv emails, flyers, and the Department of Psychology's subject pool. Participants had to be 18 years or older and fluent English speakers, as the measures utilized in this study were validated in adult, English-speaking samples. Individuals were excluded if they did not possess a mobile phone with the capacity to run the experimental applications, or if they reported regularly using the experimental app (Headspace) more than twice per week.

An a priori power analysis for a repeated measures ANOVA measuring within-between interaction effects was conducted using G*Power (Faul et al., 2007). The power analysis indicated that a sample size of 90 participants was required to detect small to medium effects (F=.15, α = .05, β = .80) comparing pre- and post-intervention measures of pain-related outcomes. Small to medium effects were expected based on prior studies testing the effects of mindfulness on the primary outcomes of interest (Baer et al., 2006; Creswell, 2017; Hilton et al.,

2017). To account for unusable data and participant attrition, 133 participants were enrolled in the study (Headspace = 67; Evernote = 66). One hundred and twenty of these participants completed both Sessions 1 and 2 (n = 60 for each condition). There was no significant difference in attrition between conditions, $X^2(1) = .07$, $p = .79$. Completers did not significantly differ from non-completers on age, race/ethnicity, mindfulness experience, or on any of the primary study variables (mindfulness, pain catastrophizing, pain outcomes) at Session 1, ps > .05.

Of the participants who completed both sessions, two participants were excluded for missing data on key study outcomes. Further, two participants reported significant life events occurring between Sessions 1 and 2 (i.e., birth of a child and surgery) that could affect pain ratings, and two participants were identified as multivariate outliers. Excluding participants reporting significant life events during the study and multivariate outliers did not affect the pattern of results (see Appendix B), so data were analyzed including these four participants. Thus, the final sample consisted of 118 participants (n = 59 for each condition). Excluded participants did not significantly differ from the final sample on age, race/ethnicity, mindfulness experience, or any of the primary study variables at Session 1, ps > .05. The mean age of participants was 21.34 years (SD = 5.74; range 18 – 64 years); 80.5% were White; and 77.1% were female (see Table 1 for a more detailed breakdown of demographic information). There were no significant condition differences for any primary study variables at Session 1, ps > .05.

Measures and Materials

Cognitive and Affective Mindfulness Scale – Revised (CAMS – R; Feldman et al., 2007). The CAMS-R is a 12-item scale measuring the cognitive and affective components of mindfulness. Participants indicate the extent to which statements apply to them (e.g., “I try to notice my thoughts without judging them”) on a 4-point scale (1 = rarely/not at all, 4 = “almost

always"). After appropriate items are reverse scored such that higher values indicate greater levels of mindfulness, a composite score is computed by summing values for all items. The CAMS-R has demonstrated good internal consistency in prior research (α = .74 - .85; Baer et al., 2006; Feldman et al., 2007). Good convergent validity has been demonstrated via significant inverse correlations between CAMS-R scores and depression (*rs* = -.30 to -.44, *p*s < .001), anxiety (*r*s = -.23 to - .24, *p*s < .01), and maladaptive emotion regulation (*rs* = -.28 to -.52, *p*s < .001; Feldman et al., 2007). Additionally, CAMS-R scores are generally positively associated with alternate measures of mindfulness (*r*s = .51 to .66, *p*s < .001), well-being (*r* = .47, *p* < .001), and adaptive emotion regulation (*rs* = .14 to .53, *p*s < .05; Feldman et al., 2007).

Mindful Attention Awareness Scale (MAAS; Brown & Ryan 2003). The MAAS is a 15-item scale measuring present moment awareness in daily life. Participants respond to questions regarding the frequency with which they engage in certain behaviors (e.g., "I do jobs or tasks automatically, without being aware of what I'm doing.") on a 6-point scale (1= "almost always", 6 = "almost never"). A composite score is computed by averaging all 15 items, where higher scores indicate higher levels of dispositional mindfulness. The MAAS has generally demonstrated good internal consistency (α = .87) and test-retest reliability (ICC = .81; Brown & Ryan 2003). Further, convergent validity for the MAAS has been demonstrated via positive associations with openness to experience (*r* = .18), and internal state awareness (*r* = .23), and negative associations with depression (*r* = -.41), trait-level anxiety (*r* = -.40), and rumination (*r* = .23; Brown & Ryan, 2003).

Five-Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2006). The FFMQ is a 39-item scale measuring dispositional mindfulness. The FFMQ can be measured as a composite score, as well as broken up into five subscales: nonreactivity, observing, acting with awareness,

describing, and nonjudging. Participants respond to questions on the degree to which statements (e.g., "I find myself doing things without paying attention.") are true for them on a 5-point scale (1 = "rarely" or "never true", 5 = "very often" or "always true"). For the purpose of this study, there were no hypotheses specific to FFMQ subscales; however, descriptive statistics and correlations for the FFMQ subscales can be found in Appendix C. The FFMQ composite score was the primary index of focus for the present study. To calculate this score, appropriate items are reverse scored, so that higher scores for each question indicate higher levels of dispositional mindfulness, and items are summed. The FFMQ has been found to have good internal consistency (α = .75 - .91; Baer et al., 2006). Prior studies have demonstrated evidence of convergent validity, as the FFMQ has been found to relate positively to psychological well-being (*r*s = .34 to .52) and meditation experience (*r*s = .14 to .35; Baer et al., 2008).

Pain Catastrophizing (PCS; Sullivan et al., 1995). The PCS is a 13-item questionnaire measuring the extent to which individuals engage in catastrophic thinking in relation to their pain experience. Participants respond to questions on the frequency with which they engage in certain patterns of thought (e.g., "I worry all the time about whether the pain will end") on a 5-point scale (0 = "not at all", 4 = "all the time"). A composite PCS score is derived by summing all items, where higher values indicate greater levels of pain catastrophizing. PCS subscales include magnification, rumination, and helplessness. The PCS has been found to have strong internal consistency (α = .92) and test-retest reliability (*r* = .88; Sullivan et al., 1995; Wheeler et al., 2019). Convergent validity of this scale has been demonstrated via moderate associations with negative thoughts in relation to pain (*r* = .56), anxiety (*r*s = .36 to .37), and depression (*r*s = .17 to .21; Osman et al., 1997).

Fear of Pain Questionnaire – 9 (FPQ-9; McNeil et al., 2018). The FPQ-9 is a shortened version of the Fear of Pain Questionnaire – III (McNeil & Rainwater, 1998), consisting of nine questions. Participants rate the extent to which they fear the pain associated with various events (e.g., breaking your arm, getting a papercut on your finger) on a 5-point scale from 1 ("not at all") to 5 ("extreme"). A total score is obtained by summing responses to all nine items, and higher scores indicate greater fear of pain. The FPQ-9 was found to have good internal consistency ($\alpha = .83$), and convergent validity as evidenced by moderate correlations with measures of pain anxiety symptoms (*r*s = .34 to .50; McNeil et al., 2018).

Pain Sensitivity Questionnaire (PSQ; Ruscheweyh et al., 2009). The PSQ is a 17-item questionnaire, assessing participants' reactions to a series of situations (14 painful, 3 non-painful). For each question, participants are asked to imagine a scenario (e.g., "Imagine you burn your tongue on a very hot drink"), and then rate how painful they imagine these situations would be for them on an 11-point scale from 0 ("not at all painful") to 10 ("most severe pain imaginable"). Total scores are calculated by averaging responses from the 14 pain-related items, and higher values reflect greater sensitivity to pain. The PSQ has strong internal consistency ($\alpha = 0.92$), and test-retest reliability (ICC = 0.83; Ruscheweyh et al., 2009). Generally, PSQ scores are significantly correlated with pain specific measures, such as the PCS ($r = .45$), and not correlated with non-pain specific measures of depression ($r = .24$), and anxiety (*r*s = .15 to .19; Ruscheweyh et al., 2009).

Demographic Questionnaire. Participants responded to a questionnaire containing several demographic variables, including age, gender, occupation, sexual orientation, political orientation, marital status, ethnicity/race, socioeconomic status, and health history, and pain

status. Participants were also asked about their experiences with mindfulness-related activities, such as yoga, tai chi, or meditation.

Brief Mindfulness-Based Intervention. Participants in the mindfulness experimental condition participated in a free, 10-day mindfulness program via the Headspace application (https://www.headspace.com, Santa Monica, CA, USA). Of the many app-based MBIs on the market, the Headspace app is commonly used, with over 30 million users in 190 countries at the time of writing (Headspace Inc., 2021) and holds the highest score on the Mobile Application Rating System, which assesses app quality using measures of user engagement, functionality, information quality, visual aesthetics, and satisfaction (Mani et al., 2015). Further, prior work has successfully implemented the Headspace 10-day free trial as a brief mindfulness-based intervention with low rates of attrition (10%), no differential attrition or exclusion between Headspace and control conditions, and significantly greater increases in self-reported mindfulness across intervention days compared to active controls (Haliwa et al., 2021a).

The intervention consisted of one introductory video and 10 guided mindfulness meditation exercises. The application was designed such that participants were instructed to complete one 10-minute guided mindfulness meditation exercise per day, across the 10 days. On Day 1, they viewed an introductory animated video that encouraged participants to complete the mindfulness exercises at a similar time each morning and provided basic introductory meditation techniques (e.g., using quiet space, sitting upright in a comfortable seat). Daily mindfulness exercises were generally consistent across days, and entailed a brief body scan, focused breathing, mind-wandering, and practice viewing thoughts as an impartial observer. Participants downloaded and subscribed to the app on their personal mobile device by providing a functional

email address. Participants were instructed to complete one 10-minute exercise daily for 10 days and to set a daily reminder to complete the exercise on their phone.

Active Control Condition. As in prior work with the Headspace app, the Evernote app (https://evernote.com, Evernote Corporation, Redwood, CA, USA) was used as an active control condition (Flett et al., 2019), to control for placebo attention effects. Participants were instructed to download the free app and "jot down all the things you can remember doing on this day last week" (Flett et al., 2019) for 10-minutes per day, throughout the 10-day study. Similar to participants in the mindfulness condition, participants in the active control condition were instructed to use the application for 10-minutes per day and to set a daily reminder for the exercise in their phone. Prior work has successfully implemented the Evernote app as an active control condition (Flett et al., 2019).

Procedure

The study involved two online sessions via Zoom video call. Sessions were separated by 10-14 days and participants were randomly assigned to one of two experimental conditions in the first study session: brief mindfulness-based intervention or active control. At the first study session, participants were provided with a brief overview of the study and electronic informed consent was obtained. Then, participants completed the CAMS-R, MAAS, FFMQ, PCS, FPQ-9, and the PSQ in a random order (see Appendix A for all measures). Three measures of mindfulness were used to ensure that we were able to capture multiple conceptualizations of the construct, as some measures (e.g., CAMS-R) focus on the cognitive and affective components of mindfulness while others (e.g., MAAS) capture the attention and awareness component (Brown & Ryan, 2003; Feldman et al., 2007). Following completion of these measures, participants filled out a demographic questionnaire and were randomly assigned to one of the two experimental

conditions. Upon randomization, research assistants helped participants to download either the Headspace or Evernote app on their mobile device. Participants then engaged in Day 1 exercises for their assigned app over the video call. For privacy, participants were asked to mute themselves and turn off video while they completed the 10-minute exercise. Participants were then given the opportunity to ask questions about using the app and ensure that they were comfortable with the app interface. Participants were then instructed to complete one exercise per day for the next 10-days within two hours of waking up and to set a daily reminder for the exercise in their phone. Additionally, participants in both conditions were provided with daily email reminders containing a survey link, through which they were instructed to complete a daily online log of the exercises (i.e., exercise completed, length of time spent on the exercise, reactions to the exercise). Participants were reminded about their compensation options, thanked for their time, and provided with either one hour of course credit or $10 for completion of the first session. The study session generally lasted between 60 to 90 minutes.

The second online study session took place approximately 10-14 days after the first study session. As in the first session, participants completed the CAMS-R, MAAS, FFMQ, PCS, FPQ-9, and PSQ in a random order. Then, participants were compensated for their participation and debriefed. The second study session generally lasted between 30 to 60 minutes. Participants received either one hour of course credit or financial compensation of $10 for session completion, as well as any bonus research credits for completion of daily surveys (up to 2.5 additional credits or $10).

Results

Each measure was examined for normality before statistical analysis. Pain sensitivity scores at both sessions were mildly skewed (skewness/*SD* skewness > 3.2). A square root

transformation successfully normalized the distribution of pain sensitivity scores. However, as the general pattern of results was the same whether the transformed or non-transformed measure was used (see Appendix B), results are reported with the original untransformed scores. Descriptive statistics and internal consistency for all measures at Session 1 and Session 2 are presented in Tables 2 and 3, respectively.

Bivariate correlations were conducted to explore whether any demographic variables were related to the primary outcome measures (i.e., pain catastrophizing, pain sensitivity, fear of pain) and should be included as covariates in the main analyses. Identifying as non-White was associated with greater pain sensitivity at both sessions (*r*s = .24 and .21, respectively, *ps* < .05) and males reported lower levels of pain catastrophizing (r = -.22, p = .018) and fear of pain (r = -.25, p = .006) than females at Session 1. Analyses were conducted with and without race and gender as covariates (see Appendix B). The pattern of results did not differ, so results are reported for analyses conducted without covariates.

Adherence

Overall, participants demonstrated high adherence across both conditions. Participants spent an average of 89.71 minutes (out of a recommended 100 minutes) engaging with their app across the intervention (range = 11 – 135 minutes, SD = 24.08)[2]. On average, participants in the Headspace condition spent 91.64 minutes engaging with the app (SD = 24.01), and participants in the Evernote condition spent 87.71 minutes using the app (SD = 24.22). There was no significant difference in participant engagement between conditions, p = .19.

[2] Four participants did not report minutes spent meditating across the 10-day intervention. Thus, adherence data is provided for a sample of 114 participants.

Correlations

To assess simple associations between the primary variables of interest, Pearson bivariate correlations were tested for mindfulness (CAMS-R, MAAS, FFMQ composite), pain catastrophizing, pain sensitivity, and fear of pain at both time points. Associations between variables at Session 1 and Session 2 are presented in Tables 2 and 3, respectively. Overall, at Session 1, all three composite measures of mindfulness were strongly positively correlated. Greater mindfulness was also significantly inversely associated with pain catastrophizing across all three measures of mindfulness. Greater mindfulness as assessed by the CAMSR was significantly associated with lower fear of pain, and greater mindfulness as assessed by the CAMSR and FFMQ was significantly associated with less pain sensitivity. Pain catastrophizing, fear of pain, and pain sensitivity were positively correlated with one another.

Similarly, at Session 2, all three composite measures of mindfulness were strongly positively correlated. Greater mindfulness was significantly inversely associated with pain catastrophizing across all three measures of mindfulness at Session 2. Greater mindfulness as assessed by the CAMSR and the MAAS was significantly associated with lower fear of pain, and greater mindfulness as assessed by the FFMQ was significantly associated with less pain sensitivity. Pain catastrophizing, fear of pain, and pain sensitivity were positively correlated with one another.

Change Over Time

To test whether the mindfulness intervention affected mindfulness, pain catastrophizing, or pain experience, a series of 2 x 2 repeated-measures within-between subject analyses of variance (ANOVAs) were conducted (see Table 4). The between-subject factor was condition (Headspace or Evernote), and the within-subject factor was time (Session 1 and Session 2).

There was a significant main effect of time for the FFMQ composite score, such that mindfulness was significantly higher at Session 2 (M = 125.47, SE = 1.65) compared to Session 1 (M = 122.49, SD =1.73), regardless of condition. No other significant main or interaction effects were observed for dispositional mindfulness with the FFMQ, MAAS, or CAMSR scores.

No significant main or interaction effects were observed for pain catastrophizing scores. Significant effects of time were observed for both fear of pain and pain sensitivity, such that both were significantly higher at Session 1 (Ms = 24.77 and 3.55, SEs = .67 and .15, respectively) compared to Session 2 (Ms = 23.38 and 3.20, SEs = .63 and .14, respectively), regardless of condition. No other main or interaction effects were observed for pain outcomes.

Mediation Analyses

Two mediation models (see Figures 3 & 4) were tested using SPSS PROCESS macro to assess whether associations between study condition and pain outcomes (fear of pain, pain sensitivity) at Session 2 were mediated by pain catastrophizing at Session 2, controlling for pain catastrophizing at Session 1. Though both model summaries were significant (ps < .05), neither the direct effects of condition on fear of pain or pain sensitivity were significant (ps = .30 and .75, respectively). Similarly, the indirect effects of pain catastrophizing on fear of pain (95% CI = - 1.11, .46) and pain sensitivity (95% CI = - .13, .05) were not significant.

Two exploratory mediation analyses were conducted to test whether pain catastrophizing at Session 2 significantly mediated the association between dispositional mindfulness at Session 1 and pain outcomes at Session 2 (i.e., fear of pain and pain sensitivity; see Figures 5 & 6). In order to reduce the number of exploratory analyses conducted (reduced from 6 models to 2 models), a composite mindfulness score was created by standardizing and averaging all three measures of mindfulness at Session 1. Both model summaries were significant (ps < .05), but no

significant direct effects were revealed for the effect of dispositional mindfulness at Session 1 on either fear of pain or pain sensitivity at Session 2 (*ps* > .05). However, both indirect effects were significant, such that pain catastrophizing at Session 2 significantly mediated the effects of dispositional mindfulness at Session 1 on fear of pain (β = -1.07, *SE* = .40, 95% CI = -1.96, -.38) and pain sensitivity (β = -.13, *SE* = .07, 95% CI = -.29, -.01) at Session 2.

Study 1 Discussion

The purpose of Study 1 was to test the effect of a 10-day app-based MBI on pain experience and to determine whether pain catastrophizing served as a statistical mediator of this effect. We hypothesized that participants in the experimental (Headspace), but not the control (Evernote) condition, would demonstrate significantly lower levels of fear of pain and pain sensitivity at Session 2 compared to Session 1. We also hypothesized that these effects would be mediated by pain catastrophizing. However, data from the present sample did not support these hypotheses.

Though correlational analyses demonstrated that greater mindfulness was associated with lower fear of pain and pain sensitivity, there was no evidence that the MBI significantly impacted pain outcomes compared to the control condition. Instead, decreases in fear of pain and pain sensitivity were observed, regardless of condition. While it is possible that both interventions improved pain outcomes, these effects of time may also be attributed to a digital placebo effect, by which the act of regularly engaging with a digital app leads to improved outcomes regardless of content (Torous & Firth, 2016).

Mediation models demonstrated no significant indirect effect of the MBI on pain outcomes through pain catastrophizing. However, the function of MBIs is to increase dispositional mindfulness (Kiken et al., 2015), which is associated with benefits including

improved pain experience. As the proposed MBI had no effect of dispositional mindfulness or pain experience, we were unable to test our hypothesized mediation. In order to test for theorized associations between dispositional mindfulness, pain catastrophizing, and pain experience in the present sample, we ran exploratory correlational and mediation analyses. These exploratory analyses revealed that pain catastrophizing at Session 2 consistently mediated the relation between dispositional mindfulness at Session 1 and both pain outcomes at Session 2. This provides some evidence for our hypothesized mediation model with dispositional mindfulness. Given these findings, it is possible that 10-days of repeated state mindfulness inductions was not sufficient to produce changes in dispositional mindfulness, and thus in pain-related outcomes.

Notably, Study 1 tested the hypothesized model within a convenience sample of healthy adults, rather than targeting individuals experiencing chronic pain. We originally hypothesized that the effects of mindfulness on pain outcomes would generalize across samples with and without chronic pain, given research demonstrating associations between mindfulness and pain outcomes within healthy samples (Harrison et al., 2019; Petter et al., 2013; Zeidan et al., 2018). However, it is possible that intervention effects may be better observed within a sample of participants with chronic pain. These individuals may experience higher baseline fear of pain and pain sensitivity, and thus may experience pain as a more salient aspect of their lives.

Study 2

The purpose of Study 2 was to replicate Study 1 within a sample of individuals reporting chronic lower back pain, in order to assess whether findings generalized from healthy to chronic-pain samples. A measure of chronic pain severity was also included to better capture the experience of chronic pain among Study 2 participants.

Participants

Adults reporting a history of chronic low back pain (for at least 3 months) were recruited through community and university listservs, social media, chronic pain support groups, and community health centers. As in Study 1, participants had to be 18 years or older and fluent English speakers, as the measures utilized in this study have been validated in adult, English-speaking samples. Individuals who did not possess a mobile phone with the capacity to run the experimental applications were ineligible to participate. Individuals who participated in Study 1 were not eligible to participate in Study 2.

An a priori power analysis indicated a minimum sample size of 90 (see Study 1). However, there were anticipated logistical constraints on recruiting and maintaining this sample size with the specific patient population. For example, as the adult prevalence of low back pain in industrialized countries is between 15% - 45% (Duthey, 2013), the pool of potential participants for this study was more limited than for Study 1. Further, attrition rates for chronic pain treatments range from 5% to 46% (Oosterhaven et al., 2019). Thus, using a conservative estimate of recruitment success within the community, we proposed a sample size of 60 participants for Study 2. The purpose of this proposed sample size was to strike a balance between power and feasibility.

To account for unusable data and participant attrition, 120 participants were enrolled in the study (Headspace = 65; Evernote = 55). Of enrolled participants, 104 completed both Sessions 1 and 2 (Headspace = 54; Evernote = 50). There was no significant difference in attrition between conditions, $X^2(1) = 1.58$, $p = .21$. Completers did not significantly differ from non-completers on age, race/ethnicity, mindfulness experience, dispositional mindfulness, pain catastrophizing, or pain outcomes at Session 1, ps $> .05$. Due to a concern regarding the validity

of responses from participants through certain recruitment sources (i.e., participants signing up for the study multiple times) and missing data on key variables, data for 26 completers were excluded from analysis (Headspace = 16; Evernote = 10). Excluded participants did not significantly differ from non-excluded participants on age, gender, mindfulness experience, mindfulness as measured by the FFMQ, or pain catastrophizing, *p*s > .05. A larger proportion of non-White participants were excluded from analysis compared to White participants, $X^2(1) = 4.15$, $p = .04$. Excluded participants also reported higher levels of dispositional mindfulness as measured by the CAMSR and MAAS, fear of pain, pain sensitivity, and pain severity at Session 1 compared to non-excluded participants, *ps* < .05.

The final sample consisted of 78 participants (Headspace = 43; Evernote = 35). The mean age of participants was 28.24 years (*SD* = 12.24; range 18 – 71 years; 71.8% White; 71.8% female; see Table 1 for a more detailed breakdown of demographic information). Participants in the Headspace condition reported significantly higher levels of pain sensitivity at Session 1 ($M = 3.79$, $SD = 1.76$) compared to participants in the Evernote condition ($M = 2.93$, $SD = 1.41$), $t(76) = 2.37$, $p = .02$. Thus, pain sensitivity at Session 1 was included as a covariate in primary study analyses. No other differences were observed by condition for key study variables at Session 1 (*p*s > .05). Based on a sensitivity analysis for a repeated measures ANOVA with a within-between interaction, the present sample is powered to detect small to medium effects ($F \geq .16$)

Measures

Participants completed the same measures and interventions described in Study 1. In addition, participants completed a third pain outcome measure.

Brief Pain Inventory – Short Form (BPI-SF; Cleeland, 1991; α = .85 - .88). An adapted version of the BPI-SF was used (see Appendix A). Participants answered four items

assessing pain severity (e.g., “worst pain in the last 24 hours”, “average pain”) on an 11-point scale from 0 (“no pain”) to 10 (“pain as bad as you can imagine”). Pain severity ($\alpha = .85$) item scores are averaged to obtain a composite score. The BPI-SF also contains a pain interference subscale. However, due to a technical error, this scale was not presented to participants in the online survey, and pain interference data were not collected. The standard BPI-SF also includes a diagram in which respondents indicate physical location of experienced pain. As only individuals with lower back pain were recruited, the question about physical location of pain was not included in the present study.

Procedure

Participants in Study 2 followed the same procedure described in Study 1, with two exceptions: 1) Participants in Study 2 also completed the BPI-SF at each study session, and 2) compensation consisted of $20 for the first session and up to $30 for the second session ($20 for completion of the second session and $1 for each short survey during the 10-day intervention). Thus, participants could receive up to $50 total.

Results

Each measure was examined for normality before statistical analysis. Pain sensitivity scores at Session 2 were mildly skewed (skewness/*SD* skewness > 3.2). A square root transformation successfully normalized the distribution of pain sensitivity scores. However, as the general pattern of results was the same whether the transformed or non-transformed measure was used, results are reported with the original untransformed scores (see Appendix B). Descriptive statistics and internal consistency for all measures at Session 1 and Session 2 are presented in Tables 5 and 6, respectively.

Bivariate correlations were conducted to explore whether any demographic variables were related to the primary outcome measures (i.e., pain catastrophizing, pain sensitivity, fear of pain, pain severity) and should be included as covariates in the main analyses. Identifying as non-White was associated with greater pain sensitivity at both sessions (*r*s = .38 and .36, respectively, *ps* < .001) and identifying as male was associated with lower levels of pain severity at both sessions (*r* = -.26 and -.27, *ps* < .05). As patterns of results differed with and without covariates included (see Appendix B), results are presented for analyses using gender and race as covariates, in addition to pain sensitivity at Session 1. Differences are noted in footnotes.

Adherence

Overall, participants demonstrated good adherence across both conditions. Participants spent an average of 87.19 minutes (out of a recommended 100 minutes) engaging with the apps across the intervention (range = 10 – 120 minutes, *SD* = 24.31). On average, participants in the Headspace condition spent 90.70 minutes engaging with the app (*SD* = 24.47), and participants in the Evernote condition spent 82.87 minutes using the app (*SD* = 23.75). There was no significant difference in participant engagement between conditions, *p* = .16.

Correlations

To assess simple associations between the primary variables of interest, Pearson bivariate correlations were tested for mindfulness (CAMS-R, MAAS, FFMQ composite), pain catastrophizing, pain sensitivity, fear of pain, and pain severity at both time points. Associations between variables at Session 1 and Session 2 are presented in Tables 5 and 6, respectively. Overall, at Session 1, all three composite measures of mindfulness were strongly positively correlated. Greater mindfulness as measured by the FFMQ was significantly associated with lower pain catastrophizing, and greater mindfulness as assessed by the CAMSR was significantly

associated with greater pain sensitivity. Pain catastrophizing was significantly positively associated with fear of pain and pain severity. Finally, fear of pain was significantly positively associated with pain sensitivity.

At Session 2, all three composite measures of mindfulness were strongly positively correlated. Greater mindfulness as assessed by the CAMSR and the FFMQ was significantly inversely associated with pain catastrophizing at Session 2. Pain catastrophizing, fear of pain, pain sensitivity, and pain severity were positively correlated with one another.

Change Over Time

To test whether the mindfulness intervention affected dispositional mindfulness, pain catastrophizing, or pain experience, a series of 2 x 2 repeated-measures within-between subject ANOVAs were conducted (see Table 7). Gender and race were included as covariates for all analyses. Pain sensitivity at Session 1 was included as a covariate for all analyses, excluding the ANOVA with pain sensitivity as the outcome. For each analysis, the between-subject factor was condition (Headspace or Evernote), and the within-subject factor was time (Session 1 and Session 2). There was a significant main effect of time for mindfulness as measured by the CAMSR, which was qualified by a significant interaction effect of condition by time (see Figure 7)[3]. Simple main effects analyses revealed that participants in the Headspace condition demonstrated significant increases in mindfulness from Session 1 (M = 29.4, SE = 0.84) to Session 2 (M = 31.38, SE = 0.95; $p < .001$). Mindfulness did not change over time in the Evernote condition (Ms = 29.59 and 29.73, SEs = 0.94 and 1.06, at Session 1 and 2 respectively, p = .82). No other significant main or interaction effects were observed for the other dispositional mindfulness measures, MAAS and FFMQ.

[3] Analyses without covariates included revealed only a significant effect of time for mindfulness as measured by the CAMSR, without a significant interaction effect of condition by time.

A significant effect of time was observed for pain severity, such that scores were significantly higher at Session 1 (M = 3.42, SE = 0.15) compared to Session 2 (M = 2.87, SE = 0.16), regardless of condition. The main effect of condition and the time by condition interaction were not significant for pain severity. There was a significant effect of condition for pain sensitivity, such that across both sessions participants in the Headspace condition demonstrated significantly higher levels of pain sensitivity (M = 3.57, SE = 0.22) compared to participants in the Evernote condition (M = 2.83, SE = 0.24). No other main or interaction effects were observed for pain sensitivity, fear of pain, or pain catastrophizing.[4]

Mediation Analyses

Three mediation models (see Figures 8-10) were tested using SPSS PROCESS macro to assess whether associations between study condition and pain outcomes (fear of pain, pain sensitivity, pain severity) at Session 2 were mediated by pain catastrophizing at Session 2, controlling for pain catastrophizing at Session 1. Gender, race, and pain sensitivity at Session 1 were included as covariates in the model. All model summaries were significant (ps < .001). No significant direct effects of condition on pain outcomes were revealed (ps > .05). Indirect effects through pain catastrophizing on fear of pain (95% CI = -.30, .38), pain sensitivity (95% CI = -.08, .17), and pain severity (95% CI = -.09, .24) were also not significant.

Three exploratory mediation analyses were conducted to test whether pain catastrophizing at Session 2 significantly mediated the association between dispositional mindfulness at Session 1 and pain outcomes at Session 2 (fear of pain, pain sensitivity, pain severity; see Figures 11-13). All three measures of mindfulness at Session 1 were standardized and averaged to create a composite measure of dispositional mindfulness. Gender and race were

[4] There was also a significant effect of time for pain sensitivity for analyses without covariates (see Appendix B).

entered as covariates. All three model summaries were significant (*p*s < .05). No significant direct effects were observed for dispositional mindfulness at Session 1 on any pain outcomes at Session 2 (*p*s > .05). An indirect effect was observed such that pain catastrophizing at Session 2 significantly mediated the relation between dispositional mindfulness at Session 1 and pain sensitivity at Session 2 (β = -.16; *SE* = .10; 95% CI = -.41, -.004). No significant indirect effect was observed for pain catastrophizing on fear of pain (95% CI = -1.36, .004) or pain severity at Session 2 (95% CI = -.45, .001).

Study 2 Discussion

The purpose of Study 2 was to replicate Study 1 within a sample of individuals reporting chronic lower back pain, in order to assess whether findings generalized from healthy to chronic-pain samples. We hypothesized that participants in the experimental (Headspace), but not the control (Evernote) condition, would demonstrate significantly lower levels of fear of pain, pain sensitivity, and pain severity at Session 2 compared to Session 1. We also hypothesized that these effects would be statistically mediated by pain catastrophizing. However, data from the present sample did not support these hypotheses.

As in Study 1, there was no evidence that the MBI significantly impacted fear of pain, pain sensitivity, or pain severity compared to the control condition. Instead, decreases in pain severity were observed pre- to post- intervention in both conditions. This effect of time may indicate that both the Headspace and Evernote interventions were effective in decreasing pain severity. Alternatively, this effect may be attributed to a digital placebo effect, as mentioned in Study 1.

It is unclear whether the app-based MBI affected dispositional mindfulness. Although participants in the Headspace condition demonstrated significant increases in mindfulness

compared to participants in the Evernote condition, this effect was observed for only one of three measures of dispositional mindfulness (i.e., the CAMSR but not the MAAS or the FFMQ). Prior research has shown that even brief, app-based MBIs are effective in increasing dispositional mindfulness compared to controls using both the CAMSR (Flett et al., 2019) and the MAAS Kirk & Axelsen, 2020, Throuvala et al., 2020). The CAMSR was developed to capture four components of mindfulness (i.e., attention, awareness, present focus, and acceptance; Feldman et al., 2007), while the MAAS focuses specifically on attention and awareness (Brown & Ryan, 2003), and the FFMQ on the skills of observing and describing the present moment, acting with awareness, nonjudging of inner experience, and non-reactivity to inner experience. It is possible that the CAMSR is more sensitive to changes in mindfulness observed in Headspace participants compared to the MAAS and the FFMQ. However, given the considerable overlap between components of mindfulness assessed across these three measures, this significant finding may simply represent a spurious effect. Indeed, these findings, in the context of non-significant interaction effects for all three pain outcomes, seem to suggest that this 10-day MBI was not sufficient to produce changes in dispositional mindfulness and thus to elicit the hypothesized condition-specific changes in pain-related outcomes.

Though correlational analyses demonstrated that greater dispositional mindfulness was associated with lower pain catastrophizing, mindfulness was not associated with fear of pain or pain severity. Further, greater dispositional mindfulness as assessed by the CAMSR was associated with greater pain sensitivity at Session 1. The absence of significant associations between mindfulness, fear of pain, and pain severity is unexpected based on existing research (McCracken et al., 2007; Haliwa & Shook, 2020; Petter et al., 2013; Schutze et al., 2010; Zeidan et al., 2018), as is the direction of the association between mindfulness and pain sensitivity.

While it is possible that Study 2 participants reporting greater levels of mindfulness *were* more sensitive to pain at Session 1, it is equally possible that this finding represents a spurious correlation explained by an unmeasured, confounding variable (Haig, 2003), particularly when considering the absence of associations between mindfulness and pain sensitivity using the other two measures of mindfulness.

These unexpected findings may be interpreted in the context of some limitations of this study sample. Notably, 25% of completers for Study 2 were excluded due to concerns regarding validity of responses and missing data. These excluded participants reported significantly higher levels of mindfulness, fear of pain, pain sensitivity, and pain severity at Session 1. As such, it is possible that excluding these participants eliminated considerable variability in mindfulness and pain-related outcomes, limiting the ability to detect existing associations. Given the proportion of excluded participants and significant differences observed between excluded and non-excluded participants, results from Study 2 should be interpreted with caution.

Exploratory analyses revealed that pain catastrophizing at Session 2 mediated the relation between dispositional mindfulness at Session 1 and pain sensitivity at Session 2. However, no significant indirect effects were observed for pain catastrophizing as a mediator of the relation between dispositional mindfulness and fear of pain or pain severity. In contrast with findings from Study 1, these exploratory mediation analyses do not consistently support pain catastrophizing as a statistical mediator of the relation between mindfulness and pain experience.

General Discussion

Across two studies, we found no evidence for the effect of a 10-day, app-based MBI on pain outcomes (i.e., fear of pain, pain sensitivity, pain severity). These findings are inconsistent with a substantial body of research demonstrating the efficacy of MBIs in improving pain

experience, including reductions in self-reported pain intensity, sensitivity, severity, and interference compared to controls (Hilton et al., 2017; Kabat-Zinn et al., 1985; Merkes, 2010; Reiner et al., 2013). Furthermore, the current MBI did not affect pain catastrophizing as expected. As such, pain catastrophizing was not a statistical mediator of any effect of the MBI on pain experience.

A primary reason for the null effects of the intervention on pain outcomes may be that the app-based MBI did not increase dispositional mindfulness. Increasing dispositional mindfulness is the primary purpose of an MBI and is thought to underlie many of the benefits associated with MBIs (Kiken et al., 2015). Thus, it is possible that the present intervention was insufficient to elicit the necessary changes in dispositional mindfulness that would drive related changes in pain outcomes. Within each study, dispositional mindfulness was assessed using three separate measures (i.e., CAMSR, MAAS, FFMQ), yet only one significant time by condition interaction effect emerged (i.e., for the CAMSR in Study 2), suggesting a spurious finding. The absence of an effect of the present MBI on dispositional mindfulness is unexpected, as several studies have demonstrated that app-based MBIs as short as 10 days can effectively increase dispositional mindfulness as measured by the CAMSR (Flett et al., 2019) and the MAAS (Kirk & Axelsen, 2020, Throuvala et al., 2020). It is unclear why the present intervention was not successful in increasing dispositional mindfulness compared to prior studies using similar methodology and measurement.

There are a few key differences between the present pair of studies and prior research demonstrating the positive effects of MBIs on pain, which may also underlie the discrepancies in our findings. Specifically, existing research on the efficacy of MBIs in improving pain experience largely centers on a traditional MBI format consisting of 8 weeks of in-person group

mindfulness instruction. These interventions are time-intensive, requiring up to 13 hours of total intervention engagement compared to the 100 minutes recommended for the experimental MBI for the present studies (Baer et al., 2006; Creswell, 2017). Indeed, in a review of the literature by Hilton and colleagues (2017), studies ranged from 3 to 12 weeks in length, the majority of which were conducted in person (35 out of 38 studies) for at least 8 weeks (32 out of 38 studies). In contrast, the present studies implemented app-based delivery and a 10-day intervention. Thus, the delivery format and "dose" in the current studies may have been insufficient to elicit change.

Still, one study demonstrated significant improvements in physical functioning among participants with chronic pain following a 6-week app-based MBI compared to a wait-list control condition (Mascaro et al., 2021). However, Forbes and colleagues (2020) found no evidence of changes in pain-related disability or pain-related functioning for women with chronic pelvic pain following a 60-day app-based MBI compared to an active control condition. It is possible that the effects observed by Mascaro and colleagues (2021) may be attributed to the use of a wait-list control rather than an active control, which may have introduced confounding factors unrelated to treatment (e.g., placebo effects, demand characteristics; Baer 2003; Goldberg, 2017). Further, while both studies implemented app-based, rather than in-person interventions, intervention length for each was considerably longer than the present 10-day Headspace intervention.

Though a few studies have tested the effects of abbreviated MBIs ($\leq$ 10 days) on pain experience, these studies implemented in-person rather than app-based interventions and yielded mixed results (Gill et al., 2021; Zeidan et al., 2010, 2011, 2015). Studies by Zeidan and colleagues (2010, 2011, 2015) have repeatedly demonstrated that in-person MBIs as short as 3-4 days can reduce pain outcomes, including pain sensitivity and pain intensity in healthy adults. However, consistent with our findings, Gill and colleagues (2021) found decreases in pain

sensitivity in a sample of healthy adults, regardless of treatment condition, following a 5-day MBI. Though it remains unclear what factors may underlie the inconsistencies between the present studies and prior research with respect to the efficacy of brief app-based MBIs in increasing dispositional mindfulness, it is worth noting that research on the efficacy of abbreviated and app-based interventions for improving pain outcomes are sparse and inconsistent. Thus, more research is needed to determine whether longer and/or in-person interventions may be necessary to confer benefits of MBIs on pain experience.

Despite a lack of observed intervention effects on pain experience, participants in both studies reported improvements in certain pain outcomes between Sessions 1 and 2, regardless of condition. Participants in Study 1 reported decreases in both pain sensitivity and fear of pain, whereas participants in Study 2 reported decreases in pain severity only. A measure of pain severity was added for Study 2 to expand the assessment of pain experienced by individuals with chronic pain. The measure was developed specifically for individuals experiencing chronic pain (Cleeland & Ryan, 1994). Given this specificity, the pain severity outcome may have better captured changes in pain experience among individuals with chronic pain (Study 2 participants) compared to measures of pain sensitivity and fear of pain, which are less specific to the chronic pain experience.

Decreases in pain experience over time across both studies may suggest that Headspace and Evernote were equally effective in improving certain pain outcomes, or they may be attributed to a digital placebo effect (Torous & Firth, 2016). The placebo effect is a well-established phenomenon by which expectations relating to the efficacy of a treatment may lead to observed clinical improvement (Miller & Rosenstein, 2006). Similar effects are hypothesized to occur in the context of digital and mobile interventions (Torous & Firth, 2016). Indeed,

participant engagement across both groups was high, and participants reported engaging with their mobile apps for an average of 89.71 minutes - 87.19 minutes in Studies 1 and 2, respectively. As such, salutary placebo effects may have been conferred to participants in both the Headspace and Evernote condition, simply by virtue of daily engagement with a smartphone app rather than due to any treatment-specific effect.

Finally, the brief, app-based MBI did not reduce pain catastrophizing in either sample. As such, mediation analyses did not reveal evidence of statistical mediation by pain catastrophizing for either study sample. Our hypothesis regarding pain catastrophizing as a statistical mediator was based on prior work indicating that dispositional mindfulness is inversely associated with pain experience through its inverse association with pain catastrophizing (Haliwa & Shook 2020; Paul et al., 2013; Prins et al., 2014; Schutze et al., 2010). MBIs are thought to improve dispositional mindfulness, which may explain experimental findings in which MBIs have been shown to reduce pain catastrophizing (Day et al., 2014) and in which the effect of the MBI on pain experience is statistically mediated by changes in pain catastrophizing (Garland et al., 2012). Null findings in the present mediation analyses may stem from the failure of the MBI to affect dispositional mindfulness and related outcomes.

Exploratory analyses in Study 1 revealed that, consistent with prior work, pain catastrophizing did mediate the effects of dispositional mindfulness at Session 1 on pain sensitivity and fear of pain at Session 2 (Haliwa & Shook, 2020; Paul et al., 2013; Prins et al., 2014; Schutze et al., 2010). The mediation finding with pain sensitivity was replicated in Study 2. However, pain catastrophizing did not mediate the effect of dispositional mindfulness on fear of pain or pain severity in Study 2. This inconsistency in associations across studies was also reflected in bivariate correlations among dispositional mindfulness and pain-related variables. In

Study 1, mindfulness was inversely associated with pain catastrophizing, fear of pain, and pain sensitivity. However, in Study 2, mindfulness was not consistently associated with pain catastrophizing or fear of pain and was positively associated with pain sensitivity with one of the mindfulness measures. As such, the pattern of associations underlying our mediation hypotheses were not consistently supported across both samples, suggesting that our hypothesized mediation model may not accurately reflect associations between mindfulness, pain catastrophizing, and pain experience.

Limitations and Future Directions

These findings should be interpreted in the context of several limitations. First, the present samples were homogeneous in nature (80.5% - 71.8% White, 71.8 – 77.1% female, 60.3% - 74.6% students). Also, although chronic pain is more common in older adults (e.g., > 50 years old; Zelaya et al., 2020), the average age of participants in Study 2 was 28.24 years. As such, findings may not generalize to a more heterogeneous population or to a sample of individuals more representative of the chronic pain population. Recruitment focused heavily on university listservs, support group listservs, and advertisements on social media platforms. Further, study procedures required reliable internet access for remote study sessions and access to smartphone to download mobile apps. This combination of recruitment methods and study procedures may have limited enrollment to individuals with reliable internet access and who regularly use email and social media, to the exclusion of individuals with lower income or who reside in rural areas with limited access to the internet. Despite incorporating some in-person methods of recruitment through community centers and doctors' offices, most participants enrolled in both studies were recruited through university listservs, resulting in relatively young and homogenous samples. Future research may benefit from diversifying recruitment

methodology to rely more heavily on in-person advertising (e.g., flyers, recruitment events), targeting locations such as community centers, recreation centers, and local health practices.

Further, recruitment for this pair of studies was conducted from August 2020 through February 2022, during the global COVID-19 pandemic. Throughout the recruitment period, the global population experienced novel and unique stressors including the physical health risk associated with COVID-19, impacts of COVID-19 on daily life (e.g., school closures, a family member contracting COVID-19; Haliwa et al., 2021b), and several studies have demonstrated worsened mental health during the pandemic (see Robinson et al., 2022, for a review). Given the unique context during which data collection took place, findings from the present study may be limited in generalizability.

The present studies also relied solely on self-reported measures of pain. While existing research has demonstrated the efficacy of MBIs in improving pain experience using self-report measures of outcomes such as fear of pain, pain sensitivity, and pain severity (Hilton et al., 2017; Kabat-Zinn et al., 1985; Merkes, 2010), these measures are vulnerable to response bias (Rosenman et al., 2011). For example, participant responses to survey questions related to mindfulness and pain experience may better reflect the way they wish to be perceived rather than their actual levels of each (i.e., social desirability bias) and/or may differ pre- to post-intervention due to changing conceptualizations of these constructs (a different conceptualization of mindfulness following the MBI; i.e., response-shift bias). Several studies have replicated the efficacy of MBIs in improving pain experience using behavioral laboratory-based pain tasks, which measure outcomes such as pain tolerance and pain threshold (Grant & Rainville, 2009; Reiner et al., 2016; Zeidan et al., 2010, 2011, 2015). The advantage of these behavioral outcomes is that they can be more objectively measured by researchers, since they do not rely on

participant self-perception, consistency, and accurate recall. Future research should consider including a mix of self-reported and behavioral pain outcomes, in order to capture both objective and self-perceived pain experience in relation to MBIs.

While maladaptive cognition (i.e., pain catastrophizing) was identified as a potential statistical mediator for both study hypotheses, there are other constructs that may also contribute to the previously established effects of MBIs on pain experience. For example, neural connectivity and decreased inflammation have both been proposed as potential mediators for the effects of MBIs on pain (Zeidan et al., 2019; Black & Slavich, 2016). Research regarding neural mechanisms of MBI-related analgesia suggests that pain relief following MBIs is associated with higher activation in the rostral anterior cingulate cortex, the orbitofrontal cortex, and insular cortexes along with decreased activation in the periaqueductal grey (Zeidan et al., 2019). Further, initial evidence supports inflammation as a potential statistical mediator of the effect of mindfulness on pain experience, such that MBIs are hypothesized to decrease inflammation levels by decreasing circulating pro-inflammatory proteins (e.g., C-reactive protein), altering transcription factors for certain inflammatory cytokines (e.g., Nuclear Factor-kB), and slowing immune cell aging (Black & Slavich, 2016; Creswell et al., 2012; Jedel et al., 2014; Malarkey et al., 2013). However, existing evidence is mixed, with many studies being underpowered and utilizing post-hoc sub-group comparisons (Black & Slavich, 2016). Thus, further research is needed to explore inflammation as a potential mediator of the effect of MBIs on pain experience. Given the multi-faceted nature of the pain experience, future research should continue to explore the pathways (e.g., affective, cognitive, physiological, neural) through which MBIs may confer benefits on pain, as well as how these may overlap or interact with one another.

Given the present findings and limited evidence for the efficacy of abbreviated and app-based MBIs in improving pain experience (Forbes et al., 2020; Gill et al., 2021; Mascaro et al., 202; Zeidan et al., 2010; Zeidan et al., 2011; Zeidan et al., 2015), future research may consider testing the necessary intervention length required to observe significant improvement in pain experience. As intervention length is a common barrier to enrollment in and completion of traditional MBIs (Chang et al., 2004; Morone et al., 2008; Simpson et al., 2019), it would be beneficial to understand the minimum effective intervention length which may confer benefits on pain experience. These studies might also systematically compare intervention delivery format (e.g., in-person versus via a mobile app) to determine whether delivery method is a factor impacting the efficacy of MBI interventions on pain experience.

Finally, future research might consider incorporating real-time app-based sessions with trained MBI professionals and/or exercises specific to pain management. These more tailored interventions may better address pain experience among individuals with chronic pain, allowing for the specialized face-to-face support available to individuals participating in traditional MBIs without the additional time and resource burden. While the 10-day Headspace intervention was selected due to its popularity and cost-free availability to participants, there are a wide variety of app-based MBI programs both within the Headspace platform and on other apps, which may incorporate real-time access to trained professionals as well as exercises specific to chronic pain (Mani et al., 2015). Future research might expand upon the present studies by testing the effects of these more tailored interventions on pain experience.

Conclusions

Overall, these studies add to a limited body of literature assessing the effects of brief app-based MBIs for pain management and potential statistical mediators of this effect. Given the high

prevalence of chronic pain and concerns with prolonged use of traditional pharmacotherapy for the treatment of pain (Dowell et al., 2016; Majeed et al., 2018), it is critical to assess the efficacy of alternative and complementary interventions for pain management which are both evidence based and accessible to a wide range of individuals. Findings from the present studies suggests that this 10-day app-based MBI was not more effective than an active control condition in improving pain experience among individuals, regardless of chronic pain status, and it remains unknown whether pain catastrophizing serves as a mediator of this effect. Future research may extend on these findings by recruiting a larger more representative sample of individuals with chronic pain, identifying the minimum MBI length necessary to confer benefits on pain experience, comparing in-person and app-based delivery methods, and exploring the effects of app-based interventions more specifically tailored to pain management.

References

Alberts, H.J.E.M., Thewissen, R. (2011). The effect of a brief mindfulness intervention on memory for positively and negatively valenced stimuli. *Mindfulness, 2,* 73–77. https://doi.org/10.1007/s12671-011-0044-7

American Psychological Association. (nd). Cognition. In *APA Dictionary of Psychology*. Retrieved February 9, 2022, from https://dictionary.apa.org/cognition

Baer, R. A. (2003). Mindfulness training and clinical intervention: A conceptual and empirical review. *Clinical Psychology: Science and Practice, 10*, 125 – 143. doi: 10.1093/clipsy/bpg015

Baer, R., Smith, G., Hopkins, J., Krietemeyer, J., & Toney, L. (2006). Using self-report assessment methods to explore facets of mindfulness. *Assessment, 13*(1), 27-45. doi: 10.1177/1073191105283504

Baer, R. A., Smith, G. T., Lykins, E., Button, D., Krietemeyer, J., Sauer, S., ... & Williams, J. M. G. (2008). Construct validity of the five facet mindfulness questionnaire in meditating and nonmeditating samples. *Assessment*, *15*, 329-342. doi: 10.1177/1073191107313003

Ballantyne, J. C. & Shin, N. S. (2008). Efficacy of opioids for chronic pain: A review of the evidence. *The Clinical Journal of Pain, 24,* 469 – 478. doi: 10.1097/AJP.0b013e31816b2f26

Baumeister, R. F., Bratslavsky, E., Finkenauer, C., & Vohs, K. D. (2001). Bad is stronger than good. *Review of General Psychology*, *5*, 323–370.

Beck, A. T., Rush, A. J., Shaw, B. F., & Emery, G. (1979). *Cognitive Therapy of Depression.* New York: Guilford Press.

Bennike, I. H., Wieghorst, A., & Kirk, U. (2017). Online-based mindful-ness training reduces behavioral markers of mind wandering. *Journal of Cognitive Enhancement, 11,* 230–210. doi: 10.1007/s41465-017-0020-9

Benyamin, R., Trescot, A. M., Datta, S., Buenaventura, R., Adlaka, R., Sehgal, N., … & Vallejo, R. (2008). Opioid complications and side effects. *Pain Physician Journal, 11,* s105-s120.

Black, D. S. & Slavich, G. M. (2016). Mindfulness meditation and the immune system: A systematic review of randomized controlled trials. *Annals of the New York Academy of Science, 1373,* 13 – 24. doi:10.1111/nyas.12998

Bortz, W. M. (1984). The disuse syndrome. *Western Journal of Medicine, 141,* 691-694.

Bowen, S. Witkiewitz, K., Clifasefi, S. L., Grow, J., Chawla, N., Hsu, S. H., … & Larimer, M. E. (2014). Relative efficacy of mindfulness-based relapse prevention, standard relapse prevention, and treatment as usual for substance use disorders: A randomized clinical trial. *JAMA Psychiatry, 71,* 547 – 556. doi: 10.1001/jamapsychiatry.2013.4546

Brindle, E., Fujit, M., Shofer, J., & O'Conner, K. A. (2010). Serum, plasma, and dried blood spot high-sensitivity C-reactive protein enzyme immunoassay for population research. *Journal of Immunological Methods, 36,* 112 – 120. doi:10.1016/j.jim.2010.09.014

Britannica, T. Editors of Encyclopedia (2021, March 2). Cognition. In *Encyclopedia Britannica*. Retrieved February 9, 2022, from https://www.britannica.com/topic/cognition-thought-process

Brown, K. W. & Ryan, R. M. (2003). The benefits of being present: Mindfulness and its role in psychological wellbeing. *Journal of Personality and Social Psychology, 84,* 822 – 848. doi: 10.1037/0022-3514.84.4.822

Brown, K. W., Ryan, R. M., & Creswell, J. D. (2007). Mindfulness: Theoretical foundations and evidence for its salutary effects. *Psychological Inquiry*, *18*, 211–237.

Carson, J. W., Carson, K. M., Gil, K. M., & Baucom, D. H. (2004). Mindfulness-based relationship enhancement. *Behavior Therapy, 35,* 471-494. doi: 10.1016/S0005-7894(04)80028-5

Cavanaugh, K., Strauss, C., Forder, L., & Jones, F. (2014). Can mindfulness and acceptance be learnt by self-help?: A systematic review and meta-analysis of mindfulness and acceptance-based self-help interventions. *Clinical Psychology Review, 34,* 118 – 129. doi: 10.1016/j.cpr.2014.01.001

Chang, V. Y., Palesh, O., Caldwell, R., Glasgow, N., Abramson, M., Luskin, F., …, & Koopman, C. (2004). The effects of a mindfulness-based stress reduction program on stress, mindfulness self-efficacy, and positive states of mind. *Stress and Health, 20,* 141-147. doi: 10.1002/smi.1011

Chapparo, L. E., Furlan, A. D., Deshpande, A., Mailis-Gagnon, A., Atlas, S., & Turk, D. C. (2014). Opioids compared with placebo or other treatments for chronic low back pain: an update of the Cochrane Review. *Spine, 39,* 556 – 563. doi: 10.1097/BRS.0000000000000249

Cook, K. F., Dunn, W., Griffith, J. W., Morrison, M. T., Tanquary, J., Sabata, D., …, & Gershon, R. C. (2013). Pain assessment using the NIH Toolbox. *Neurology, 80,* s49 – s53. doi: 10.1212/WNL.0b013e3182872e80.

Cleeland, C. S., & Ryan, K. M. (1994). Pain assessment: Global use of the Brief Pain Inventory. *Annals, Academy of Medicine, Singapore, 23*, 129–138.

Creswell, J., D. (2017). Mindfulness interventions. *Annual Review of Psychology, 68*, 491 – 516. doi: 10.1146/annurev-psych-042716-051139

Creswell J. D., Irwin M. R., Burklund, L. J., Lieberman, M. D., Arevalo, J. M. G., Ma., J., … Cole, S. W. (2012). Mindfulness-based stress reduction training reduces loneliness and pro-inflammatory gene expression in older adults: a small randomized controlled trial. *Brain Behavior and Immunity, 26*, 1095–101. doi: 10.1016/j.bbi.2012.07.006

Crombez, G., Vlaeyen, J. W., Heuts, P. H., & Lysens, R. (1999). Pain-related fear is more disabling than pain itself: evidence on the role of pain-related fear in chronic back pain disability. *Pain, 80*, 329–39. doi: 10.1016/s0304-3959(98)00229-2

Crombez, G., Eccleston, C., Van Damme, S., Vlaeyen, J. W. S., & Karoly, P. (2012). Fear-avoidance model of chronic pain: The next generation. *Clinical Journal of Pain, 28,* 475 – 483. doi: 10.1097/AJP.0b013e3182385392.

Cullen, M. (2011). Mindfulness based interventions: An emerging phenomenon. *Mindfulness, 2*, 186 – 193. doi: 10.1007/s12671-011-0058-1

Dahl, C. J., Lutz, A., & Davidson, R. J. (2015). Reconstructing and deconstructing the self: cognitive mechanisms in meditation practice. *Trends in Cognitive Sciences*, *19*, 515–523. https://doi.org/10.1016/j.tics.2015.07.001

Day M. A., Jensen, M. P., Ehde, D. M. & Thorn, B. E. Toward a theoretical model for mindfulness-based pain management. *The Journal of* Pain*, 15,* 691–703. doi: 10.1016/j.jpain.2014.03.003.

Dowell, D., Haegerich, T. M., & Chou, R. (2016). CDC Guideline for Prescribing Opioids for Chronic Pain — United States, 2016. *Morbidity and Mortality Weekly Report, 65*, 1–49. doi: 10.15585/mmwr.rr6501e1

Duthey, B. (2013). Priority medicines for Europe and the world: a public health approach to innovation. *WHO Background Paper 6.24: Low Back Pain*.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175-191.

Feldman, G., Hayes, A., Kumar, S., Greeson, J., & Laurenceau, J. P. (2007). Mindfulness and emotion regulation: The development and initial validation of the Cognitive and Affective Mindfulness Scale – Revised (CAMS – R). *Journal of Psychopathology and Behavioral Assessment, 29,* 177 – 190. doi: 10.1007/s10862-006-9035-8

Forbes, G., Newton, S., Cantalapiedra Calvete, C., Birch, J., Dodds, J., Steed, L., Rivas, C., Khan, K., Röhricht, F., Taylor, S., Kahan, B. C., & Ball, E. (2020). MEMPHIS: a smartphone app using psychological approaches for women with chronic pelvic pain presenting to gynaecology clinics: a randomised feasibility trial. *BMJ open*, *10*(3), e030164. https://doi.org/10.1136/bmjopen-2019-030164

Ford, C. G. (2019). An Investigation of the Relation between Mindfulness and Self-Esteem Stability. (Unpublished doctoral dissertation). West Virginia University, Morgantown, WV.

Ford, C.G., Haliwa, I., Shook, N. J. (2021b). Mind your gaze: Examining the relation between mindfulness and visual attention to valenced images. *Behavioral Brain Research, 401,* 113063. https://doi.org/10.1016/j.bbr.2020.113063

Ford, C. G., Kiken, L. G., Haliwa I., & Shook, N. J. (2021a). Negatively biased cognition as a mechanism of mindfulness: A review of the literature. *Current Psychology.* https://doi.org/10.1007/s12144-021-02147-y

Ford, C. G., & Shook, N. J. (2019). Negative cognitive bias and perceived stress: Independent mediators of the relation between mindfulness and emotional distress. *Mindfulness*, *10*(1), 100-110.

Flett, J. A. M., Fletcher B. D., Riordan, B. C., Patterson, T., Hayne, H., & Conner T. S. (2019). The peril of self-reported adherence in digital interventions: A brief example. *Internet Interventions, 18,* 100267. doi: 10.1016/j.invent.2019.100267

Garland, E. L., Farb, N. A., R. Goldin, P., & Fredrickson, B. L. (2015). Mindfulness broadens awareness and builds eudaimonic meaning: A process model of mindful positive emotion regulation. *Psychological Inquiry*, *26*(4), 293-314.

Garland, E. L., Froeliger, B., Zeidan, F., Partin, K., Howard, M. O. (2013). The downward spiral of chronic pain, prescription opioid misuse, and addiction: Cognitive, affective, and neuropsychopharmacologic pathways. *Neuroscience & Biobehavioral Reviews, 37,* 2597 – 2601. doi: 10.1016/j.neubiorev.2013.08.006

Garland, E. L., Gaylord, S. A., Palsson, O., Faurot, K., Douglas-Mann, J., & Whitehead, W. E. (2012). Therapeutic mechanisms of a mindfulness-based treatment for IBS: effects on visceral sensitivity, catastrophizing, and affective processing of pain sensations. *Journal of Behavioral Medicine, 35,* 591 – 602. doi: 10.1007/s10865-011-9391-z

Gaskell, H., Derry, S., Moore, R. A., & McQuay, H. J. (2009). Single dose oral oxycodone and oxycodone plus paracetamol (acetaminophen) for acute postoperative pain in adults. *Cochrane Database of Systematic Reviews,* CD002763. doi: 10.1002/14651858.CD002763.pub2

GBD 2016 Disease and Injury Incidence and Prevalence Collaborators (2017). Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet (London, England)*, *390*(10100), 1211–1259. https://doi.org/10.1016/S0140-6736(17)32154-2

Gellatly, R., Beck, A.T. (2016). Catastrophic thinking: A transdiagnostic process across psychiatric disorders. *Cognitive Therapy Research,* 40, 441–452. https://doi.org/10.1007/s10608-016-9763-3

Gill, L. N., Tabry, V., Taylor, V., Lussier, M., Martinu, K. … & Rainville, P. (2020). Effects of brief mindfulness interventions on the interference induced by experimental heat pain on cognition in healthy individuals. *Frontiers in Pain Research, 2,* 1-4. https://doi.org/10.3389/fpain.2021.673027

Goldberg, D.S., McGee, S.J. (2011). Pain as a global public health priority. *BMC Public Health* **11,** 770. https://doi.org/10.1186/1471-2458-11-770

Goldberg, S. B., Tucker, R. P., Greene, P. A., Simpson, T. L., Kearney, D. J., & Davidson, R. J. (2017) Is mindfulness research methodology improving over time? A systematic review. PLoS ONE 12(10): e0187298. https://doi.org/10.1371/journal.pone.0187298

Grabovac, A. D., Lau, M. A., & Willett, B. R. (2011). Mechanisms of mindfulness: A Buddhist psychological model. *Mindfulness*, *2*, 154-166.

Grant, J. A. & Rainville, P. (2009). Pain sensitivity and analgesic effects of mindful states in Zen meditators: a cross-sectional study. *Psychosomatic Medicine, 71,* 106 – 114. doi: 10.1097/PSY.0b013e31818f52ee

Greeson, J. M. (2009). Mindfulness research update: 2008. *Complementary Health Practice Review, 14,* 10 – 18. doi: 10.1177/1533210108329862

Grichnik, K. P. & Ferrante, F. M. (1991). The difference between acute and chronic pain. *Mount Sinai Journal of Medicine, 58,* 217 – 220.

Haig, B. D. (2003). What is a spurious correlation? *Understanding Statistics, 2*(2), 125-132. https://doi.org/10.1207/S15328031US0202_03

Haliwa, I., & Shook, N. J. (February 2020). *Mindfulness and pain sensitivity: The mediating role of pain-related cognition.* Poster presented at the Society for Personality and Social Psychology Health Preconference.

Haliwa, I., Ford, C. G., Wilson, J. M., & Shook, N. J. (2021a). A Mixed-Method Assessment of a 10-Day Mobile Mindfulness Intervention. *Frontiers in psychology*, *12*, 722995. https://doi.org/10.3389/fpsyg.2021.722995

Haliwa, I., Wilson, J., Lee, J., & Shook, N. J. (2021b). Predictors of Change in Mental Health during the COVID-19 Pandemic. *Journal of affective disorders*, *291*, 331–337. https://doi.org/10.1016/j.jad.2021.05.045

Harrison, R., Zeidan, F., Kitsaras, G., Ozceclik, D., & Salomons, T. V. (2019). Dispositional mindfulness is associated with lower pain reactivity and connectivity of the default mode network. *The Journal of Pain, 20,* 645 – 654. doi: 10.1016/j.jpain.2018.10.011

Hilton, L., Hempel, S., Ewing, B., Apaydin, E., Xenakis, L., Newberry, S., … & Maglione, M. A. (2017). Mindfulness meditation for chronic pain: Systematic review and meta-analysis. *Annals of Behavioral Medicine, 51,* 199 – 213. doi: 10.1007/s12160-016-9844-2

Hoffman, B. M., Papas, R. K., Chatkoff, D. K., & Kerns, R. D. (2007). Meta-analysis of psychological interventions for chronic low back pain. *Health Psychology, 26*, 1–9. doi: 10.1037/0278-6133.26.1.1

Institute of Medicine. (2011). *Relieving Pain in America: A Blueprint for Transforming Prevention, Care, Education, and Research.* Washington, DC: National Academies Press

Jackson, K. C. (2006). Pharmacotherapy for neuropathic pain. *Pain Practice, 6*, 27 – 33. doi: 10.1111/j.1533-2500.2006.00055.x

Jedel, S., Hoffman, A., Merriman, P., Swanson, B., Voigt, R., Rajan, K. B., … & Keshavarzian, A. (2014). A randomized controlled trial of mindfulness-based stress reduction to prevent flare-up in patients with inactive ulcerative colitis. *Digestion, 89,* 142 – 155. doi: 10.1159/000356316

Kabbat-Zinn, J. (1990). Full catastrophe living: Using the wisdom of your body and mind to face stress, pain, and illness. Dell Publishing; New York.

Kabat-Zinn, J., Lipworth, L., & Burney, R. (1985). The clinical use of mindfulness meditation for the self-regulation of chronic pain. *Journal of Behavioral Medicine, 8,* 163-190

Kandel, E. R., Schwartz, J. H., Jessell, T. M., Siegelbaum, S. A., Hudspeth, A. J., & Mack, S. (2013). Principles of neural science (5th ed.) McGraw Hill Companies.

Keefe F. J., Rumble M. E., Scipio C. D., Giordano L. A., & Perri L. M. (2004). Psychological aspects of persistent pain: Current state of the science. *The Journal of Pain*, *5*,195–211. doi: 10.1016/j.jpain.2004.02.576

Kiken, L. G., Garland, E. L., Bluth, K., Palsson, O. S., & Gaylord, S. A. (2015). From a state to a trait: Trajectories of state mindfulness in meditation during intervention predict changes in dispositional mindfulness. *Personality and Individual Differences, 81*, 4 – 46. doi: 10.1016/j.paid.2014.12.044

Kirk U., Axelsen J. L. (2020). Heart rate variability is enhanced during mindfulness practice: A randomized controlled trial involving a 10-day online-based mindfulness intervention. *PLoS One* 15: e0243488. 10.1371/journal.pone.0243488

Kissin, I. (2013). Long-term opioid treatment of chronic nonmalignant pain: unproven efficacy and neglected safety? *Journal of Pain Research, 6,* 513 – 529. doi: 10.2147/JPR.S47182

Koenig, J, Jarczok, M. N., Ellis, R. J., Bach, C. Thayer, J. F., & Hillecke, T. K. (2013). Two-week test–retest stability of the cold pressor task procedure at two different temperatures as a measure of pain threshold and tolerance. *Pain Practice, 14,* e126 – e135. doi: 10.1111/papr.12142

Kroenke, K., Krebs, E. E., & Blair, M. J. (2009). Pharmacotherapy of chronic pain: a synthesis of recommendations from systematic reviews. *General Hospital Psychiatry, 31,* 206 – 219. doi: 10.1016/j.genhosppsych.2008.12.006

Lau, M. A., Bishop, S. R., Segal, Z. V., Buis, T., Anderson, N. D., Carlson, L., ... & Devins, G. (2006). The Toronto mindfulness scale: Development and validation. *Journal of clinical psychology*, *62*, 1445-1467. doi: 10.1002/jclp.20326

Leeuw, M., Goossens, M. E., Linton, S. J., Crombex, G., Boersma, K., & Vlaeyen, J. W. 2007. The fear-avoidance model of musculoskeletal pain: current state of scientific evidence. *Journal of Behavioral Medicine, 30,* 77 – 94. doi: 10.1007/s10865-006-9085-0

Lethem, J., Slade, P. D., Troup, J. D., & Bentley, G. (1983). Outline of a fear-avoidance model of exaggerated pain perception. *Behaviour Research and Therapy, 21*, 401 – 408. doi: 10.1016/0005-7967(83)90009-8

Majeed, M. H., Ali, A. A., Sudak, D. M. (2018). Mindfulness-based interventions for chronic pain: Evidence and applications. *Asian Journal of Psychiatry, 32,* 79 – 83. doi: 10.1016/j.ajp.2017.11.025

Malarkey, W. B., Jarjura, D., & Klatt, M. (2013). Workplace based mindfulness practice and inflammation: A randomized trial. *Brain, Behavior, and Immunity, 27,* 145 – 154. doi: 10.1016/j.bbi.2012.10.009

Mani, M., Kavanagh, D. J., Hides, L., & Stoyanov, S. R. (2015). Review and evaluation of mindfulness-based iPhone apps. *JMIR mHealth and uHealth*, *3*, e82. doi: 10.2196/mhealth.4328

Mascaro, J. S., Singh, V., Wehrmeyer, K., Scott, B., Juan, J., McKenzie-Brown, A. M., Lane, O. P., & Haack, C. (2021). Randomized, wait-list-controlled pilot study of app-delivered mindfulness for patients reporting chronic pain. *Pain reports*, *6*(1), e924. https://doi.org/10.1097/PR9.0000000000000924

Mason, A. E., Epel, E. S., Kristeller, J., Moran, P. J., Dallman, M., Lustig, R. H., …, & Daubenmeier, J. (2015). Effects of a mindfulness-based intervention on mindful eating, sweets consumption, and fasting glucose levels in obese adults: data from the SHINE randomized controlled trial. *Journal of Behavioral. Medicine, 39,* 201–13. doi: 10.1007/s10865-015-9692-8

Mayer, S., Spickschen, J., Stein, V., Crevenna, R., Dorner, T. E., & Simon, J. (2019). The societal costs of chronic pain and its determinants: The case of Austria. *PLOS ONE, 14,* e0213889. doi: 10.1371/journal.pone.0213889

McCracken, L. M., Gauntlett-Gilbert, J., & Vowles, K. E. (2007). The role of mindfulness in a contextual cognitive-behavioral analysis of chronic pain-related suffering and disability. *Pain, 131*, 63–9. doi:10.1016/j.pain.2006.12.013

McDade, T. W., Burhop, J., & Dohnal, J. (2004). High sensitivity enzyme immunoassay for C-reactive protein from dried blood spots. *Clinical Chemistry, 50*, 652–654. doi: 10.1373/clinchem.2003.029488

McNeil, D. W., Kennedy, S. G., Randall, C. L., Addicks, S. H., Wright, C. D., Hursey, K. G., & Vaglienti, R. (2018). Fear of Pain Questionnaire-9: Brief assessment of pain-related fear and anxiety. *European Journal of Pain*, *22*, 39-48. doi: 10.1002/ejp.1074

McNeil, D. W. & Rainwater, A. J. (1998) - Development of the Fear of Pain Questionnaire--III. *Journal of Behavioral Medicine, 21,* 389 – 410. doi: 10.1023/a:1018782831217

Melzack, R. (1987). The short-form McGill Pain Questionnaire. *Pain, 30,* 191 – 197. doi: 10.1016/0304-3959(87)91074-8

Merkes, M. (2010). Mindfulness-based stress reduction for people with chronic diseases. *Australian Journal of Primary Health, 16*, 200–210. doi: 10.1071/PY09063.

Merskey, H., Albe Fessard, D., Bonica, J. J., Carmon, A., Dubner, R., Kerr, F. W. L., …, & Sunderland, S. (1979). Pain terms: a list with definitions and notes on usage. Recommended by the IASP subcommittee on taxonomy. *PAIN, 6,* 249 – 252.

Miller, F. G., & Rosenstein, D. L. (2006). The nature and power of the placebo effect. *Journal of Clinical Epidemiology*, *59*(4), 331–335. https://doi.org/10.1016/j.jclinepi.2005.12.001

Mistler, L. A., Ben-Zeev, D., Carpenter-Song, E., Brunette, M. F., Friedman, M. J. (2017). Mobile mindfulness intervention on an acute psychiatric unit: Feasibility and acceptability study. *Journal of Medicinal Internet Research: Mental Health, 4*, e34. doi: 10.2196/mental.7717

Modir, J. G. & Wallace, M. S. (2010) Human Experimental Pain Models 2: The Cold Pressor Model. In: Szallasi A. (eds) Analgesia. Methods in Molecular Biology (Methods and Protocols), vol 617. Humana Press, Totowa, NJ.

Moore, P. (2008). Introducing mindfulness to clinical psychologists in training: An experiential course of brief exercises. *Journal of Clinical Psychology in Medical Settings, 15,* 331 – 337. doi: 10.1007/s10880-008-9134-7

Morone, N. E., Greco C. M., Weiner D. K. (2008). Mindfulness meditation for the treatment of chronic low back pain in older adults: a randomized controlled pilot study. *Pain, 134*, 310–319. doi: 10.1016/j.pain.2007.04.038

Noble, M., Treadwell, J. R., Tregear, S. J., Coates, V. H., Wiffen, P. J., Akafomo C, & Schoelles K. M. (2010). Long-term opioid management for chronic noncancer pain. *Cochrane Database of Systematic Reviews,* CD006605. doi:10.1002/14651858.CD006605.pub2.

Oosterhaven, J., Wittink, H., Mollema, J., Kruitwagen, C., & Deville, W. (2019). Predictors of dropout in interdisciplinary chronic pain management programmes: A systematic review. *Journal of Rehabilitation Medicine, 51,* 2 – 10. doi: 10.2340/16501977-2502

Osman, A., Barrios, F. X., Kopper, B. A, Hauptmann W., Jones, J., & O'Neill, E. (1997). Factor structure, reliability, and validity of the Pain Catastrophizing Scale. *Journal of Behavioral Medicine, 20,* 589 – 605.

Ostler, M. W., Porter, J. H., & Buxton, O. M. (2014). Dried blood spot collection of health biomarkers to maximize participation in population studies. *Journal of Visualized Experiments*, e50973. doi: 10.3791/50973

Paul, N. A., Stanton, S. J., Greeson, J. M., Smoski, M. J., & Wang, L. (2013). Psychological and neural mechanisms of dispositional mindfulness in reducing depression vulnerability. *Social Cognitive and Affective Neuroscience, 8,* 56 – 64. doi: 10.1093/scan/nss070

Petter, M., Chambers, C. T., McGrath, P. J., & Dick, B. D. (2013). The role of dispositional mindfulness in the pain experience of adolescents. *The Journal of Pain, 14,* 1709-1718. doi: 10.1016/j.jpain.2013.08.015

Pincus, T., Burton, A. K., Vogel, S., & Field, A. P. (2002). A systematic review of psychological factors as predictors of chronicity/disability in prospective cohorts of low back pain. *Spine, 27,* e109 – e120. doi: 10.1097/00007632-200203010-00017

Pincus, T., Smeets, R. J. E. M., Simmonds, M. J., & Sullivan, M. J. (2010). The fear avoidance model disentangled: Improving the clinical utility of the fear avoidance model. *Clinical Journal of Pain, 26,* 739 – 746. doi: 10.1097/AJP.0b013e3181f15d45.

Prins, B., Decuypere, A., & Van Damme, S. (2014). Effects of mindfulness and distraction on pain depend upon individual differences in pain catastrophizing: An experimental study. *European Journal of Pain, 18,* 1207 – 1315. doi: 10.1002/j.1532-2149.2014.491.x

Quartana, P. J., Campbell, C. M., & Edwards, R. R. (2009). Pain catastrophizing: a critical review. *Expert Review of Neurotherapeutics*, *9*, 745–758. https://doi.org/10.1586/ern.09.34

Reinecke, H., Weber, C., Lange, K., Simon, M., Stein, C., & Sorgatz, H. (2015). Analgesic efficacy of opioids in chronic pain: recent meta-analyses. *British Journal of Pharmacology, 172,* 324 – 333. doi: 10.1111/bph.12634.

Reiner, K., Tibi, L., & Lipsitz, J. D. (2013). Do mindfulness-based interventions reduce pain intensity? A critical review of the literature. *Pain Medicine, 14*, 230–242. doi: 10.1111/pme.12006

Reiner, K. Granot, M., Soffer, E., Lipsitz, J. D. (2016). A brief mindfulness meditation training increases pain threshold and accelerates modulation of response to tonic pain in an experimental study. *Pain Medicine, 17,* 628 – 635. doi: 10.1111/pme.12883

Roberts-Wolfe, D., Sacchet, M. D., Hastings, E., Roth, H., Britton, W. (2012). Mindfulness training alters emotional memory recall compared to active controls: support for an emotional information processing model of mindfulness. *Frontiers in Human Neuroscience, https://doi.org/10.3389/fnhum.2012.00015*

Robinson, E., Sutin, A. R., Daly, M., & Jones, A. (2022). A systematic review and meta-analysis of longitudinal cohort studies comparing mental health before versus during the COVID-19 pandemic in 2020. *Journal of affective disorders*, *296*, 567–576. https://doi.org/10.1016/j.jad.2021.09.098

Rosenman, R., Tennekoon, V., & Hill, L. G. (2011). Measuring bias in self-reported data. *International journal of behavioural & healthcare research*, *2*(4), 320–332. https://doi.org/10.1504/IJBHR.2011.043414

Ruscheweyh, R., Marziniak, M., Stumpenhorst, F., Reinholz, J., & Knecht, S. (2009). Pain sensitivity can be assessed by self-rating: development and validation of the Pain Sensitivity Questionnaire. *Pain*, *146*, 65-74. doi:10.1016/j.pain.2009.06.020

Schutze. R., Rees, C., Preece, M., & Schutze, M. (2010). Low mindfulness predicts pain catastrophizing in a fear-avoidance model of chronic pain. *Pain, 148,* 120 – 127. doi:10.1016/j.pain.2009.10.030. The Creative Commons license does not apply to this content. Use of the material in any format is prohibited without written permission from the publisher, Wolters Kluwer Health, Inc. Please contact permissions@lww.com for further information

Segal, Z. V., Williams, J. M. G., & Teasdale, J. D. (2002). *Mindfulness-based cognitive therapy for depression: A new approach to preventing relapse*. New York: The Guilford Press.

Simpson, R., Simpson, S., Wood, K., Mercer, S. W., & Mair, F. S. (2019). Using normalisation process theory to understand barriers and facilitators to implementing mindfulness-based stress reduction for people with multiple sclerosis. *Chronic Illness,15*, 306-318. doi: 10.1177/1742395318769354.

Smith, B. H. & Torrance, N. (2012). Epidemiology of neuropathic pain and its impact on quality of life. *Current Pain and Headache Reports, 16,* 191 – 198. doi: 10.1007/s11916-012-0256-0.

Suchting, R., Yoon, J. H., San Miguel, G. G., Green, G., Weaver, M., Vincent, J. N., … & Lane, S. D. (2020). Preliminary examination of the orexin system on relapse-related factors in cocaine use disorder. *Brain Research,* 1731, 146359. doi: 10.1016/j.brainres.2019.146359

Sullivan, M. J., Bishop, S. R., & Pivik, J. (1995). The Pain Catastrophizing Scale: Development and validation. *Psychological Assessment*, *7*, 524-532.

Taylor, K. & Silvier, L. (2019). Smartphone ownership is growing rapidly around the world, but not always equally. Pew Research Center.

Torous J., & Firth J. (2016). The digital placebo effect: mobile mental health meets clinical psychiatry. *Lancet Psychiatry* 3, 100–102. 10.1016/S2215-0366(15)00565-9

Throuvala M. A., Griffiths M. D., Rennoldson M., Kuss D. J. (2020). Mind over matter: testing the efficacy of an online randomized controlled trial to reduce distraction from smartphone use. *International Journal of Environmental Research in Public Health* 17:4842. 10.3390/ijerph17134842

Treede, R.D., Rief, W., Barke, A., Aziz, Q., Bennett, M., Benoliel, R., … & Wang, S. J. (2015). A classification of chronic pain for ICD-11. *Pain, 156,* 1003 – 1007. doi: 10.1097/j.pain.0000000000000160

Villalba, D. K., Lindsay, E. K., Marsland, A. L., Greco, C. M., Young, S., Brown, K. W., … & Creswell, J. D. (2019). Mindfulness training and systemic low-grade inflammation in stressed community adults: Evidence from two randomized controlled trials. *PLOS ONE, 14,* e0219120. doi: 10.1371/journal.pone.0219120

Vlaeyen, J. W., Crombez, G., & Linton, S. J. (2016). The fear avoidance model of pain. *Pain, 157,* 1588-1589. doi: 10.1097/j.pain.0000000000000574. The Creative Commons license does not apply to this content. Use of the material in any format is prohibited without written permission from the publisher, Wolters Kluwer Health, Inc. Please contact permissions@lww.com for further information

Vlaeyen, J. W. & Linton, S. J. (2000). Fear-avoidance and its consequences in chronic musculoskeletal pain: a state of the art. *Pain, 85,* 317 – 332. doi: 10.1016/s0304-3959(99)00242-0

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*, 1063.

Wen, L., Sweeney, T. E., Welton, L., Trockel, M., & Katznelson, L. (2017). Encouraging mindfulness in medical house staff via smartphone app: a pilot study. *Academic Psychiatry, 41*, 646–650. doi: 10.1007/s40596-017-0768-3.

Wheeler, C. H. B., Williams, A. C. C., & Morley, S. J. (2019). Meta-analysis of the psychometric properties of the Pain Catastrophizing Scale and associations with participant characteristics. *Pain, 160,* 1946-1953. doi: 10.1097/j.pain.0000000000001494.

Wojdasiewicz, P. Łukasz, A. P., & Szukiewicz, D. (2014). The role of inflammatory and anti-inflammatory cytokines in the pathogenesis of osteoarthritis. *Mediators of Inflammation, 2014,* 561459. doi: 10.1155/2014/561459

Woo, A. K. M. (2010). Depression and anxiety in pain. *British Journal of Pain, 4,* 8 – 12. doi: 10.1177/204946371000400103

Yong, J. R., Mullins, P. M., Bhattacharyya, N. (2022). Prevalence of chronic pain among adults in the United States. *Pain,* 163, e328 – e332. doi: 10.1097/j.pain. 0000000000002291

Zeidan, F., Baumgartner, J. N., & Coghill, R. C. (2019). The neural mechanisms of mindfulness-based pain relief: a functional magnetic resonance imaging-based review and primer. *Pain reports*, *4*(4), e759. https://doi.org/10.1097/PR9.0000000000000759

Zeidan, F., Emerson, N. M., Farris, S. R., Ray, J. N., Jung, Y., McHaffie, J. G., & Coghill, R. C. (2015). Mindfulness Meditation-Based Pain Relief Employs Different Neural Mechanisms Than Placebo and Sham Mindfulness Meditation-Induced Analgesia. *The Journal of Neuroscience*, *35*(46), 15307–15325. https://doi.org/10.1523/JNEUROSCI.2542-15.2015

Zeidan, F., Gordon, N. S., Merchant, J., & Goolkasian, P. (2010). The effects of brief mindfulness meditation training on experimentally induced pain. *The Journal of Pain*, *11*(3), 199–209. https://doi.org/10.1016/j.jpain.2009.07.015

Zeidan, F., Martucci, K. T., Kraft, R. A., Gordon, N. S., McHaffie, J. G., & Coghill, R. C. (2011). Brain mechanisms supporting the modulation of pain by mindfulness meditation. *Journal of Neuroscience, 31,* 5540 – 5548. doi: 10.1523/JNEUROSCI.5791-10.2011

Zeidan, F., Salomons, T. Farris, S. R., Emerson, N. M., Adler – Neal, A., Jung, Y., & Coghill, R. C. (2018). Neural mechanisms supporting the relationship between dispositional mindfulness and pain. *Pain, 159,* 2477 – 2485. doi:10.1097/j.pain.0000000000001344.

Zeidan, F. & Vago, D. (2016). Mindfulness meditation-based pain relief: A mechanistic account. *Annals of the New York Academy of Science, 1371,* 114 – 127. doi:10.1111/nyas.13153

Zelaya, C. E., Dahlhamer, J. M., Lucas, J. W., & Connor, E. M. (2020). Chronic pain and high-impact chronic pain among U.S. adults, 2019. *National Center for Health Statistics Data Brief.* Retrieved from: https://www.cdc.gov/nchs/products/databriefs/db390.htm

Table 1. Demographic Characteristics for Studies 1 and 2.

Demographic Variable	Study 1	Study 2
	M (SD)/ *n* (%)	
Age	21.34 (5.74)	28.24 (12.24)
Gender		
Female	91 (77.10%)	56 (71.80%)
Male	25 (21.20%)	22 (28.20%)
Other	1(0.80%)	0%
Race		
White	95 (80.50%)	56 (71.80%)
Black/African American	3 (4.20%)	9 (9.00%)
Hispanic/Latinx	5 (2.50%)	2 (2.60%)
Asian	8 (6.80%)	6 (7.70%)
Native American/Pacific islander	0 (0.00%)	0 (0.00%)
Other	1 (0.80%)	1 (1.30%)
More than one	6 (5.10%)	6 (7.70%)
Employment		
Student	88 (74.60%)	47 (60.30%)
Full Time	4 (3.40%)	11 (14.10%)
Part Time	13 (11.00%)	3 (3.80%)
Unemployed	6 (5.10%)	2 (2.60%)
Self Employed	1 (0.80%)	3 (3.80%)
Retired	1 (0.80%)	4 (5.10%)
Other	1 (4.20%)	8 (10.30%)
Year in College (Students Only)		
Freshman	38 (40.90%)	3 (5.90%)
Sophomore	15 (16.10%)	7 (13.70%)
Junior	11 (11.80%)	9 (17.60%)
Senior	12 (12.90%)	13 (25.50%)
Other (e.g., Grad School)	17 (18.30%)	19 (37.70%)
Ever Practice Regularly (Y/N)		
Meditation	25 (22.00%)	31 (39.70%)
Yoga	29 (24.60%)	24 (30.80%)
Tai Chi	0 (0.00%)	3 (3.80%)
Martial Arts	3 (2.50%)	6 (7.70%)
Ever Regularly Used Headspace (Y/N)	7 (5.90%)	3 (3.80%)

Table 2. Descriptive Statistics and Bivariate Correlations for Study 1 Variables at Session 1.

Measures	1	2	3	4	5	6
1. CAMS-R	-	**.45****	**.76****	**-.40****	**-.29****	**-.30****
2. MAAS		-	**.62****	**-.25****	.02	-.12
3. FFMQ Composite			-	**-.40****	-.15	**-.28****
4. Pain Catastrophizing				-	**.25****	**.32****
5. Fear of Pain					-	**.33****
6. Pain Sensitivity						-
M	30.91	3.69	122.72	16.46	24.22	3.52
SD	(6.09)	(.78)	(18.43)	(11.33)	(7.46)	(1.54)
α	.82	.86	.89	.93	.87	.94

Note. ** $p < 0.01$; * $p < 0.05$; CAMSR = Cognitive and Affective Mindfulness Scale-Revised; MAAS = Mindful Attention Awareness Scale; FFMQ = Five Facet Mindfulness Questionnaire.

Table 3. Descriptive Statistics and Bivariate Correlations for Study 1 Variables at Session 2.

Measures	1	2	3	4	5	6
1. CAMS-R	-	**.55****	**.71****	**-.42****	**-.19***	-.17
2. MAAS		-	**.57****	**-.26****	**-.20***	-.16
3. FFMQ Composite			-	**-.26****	-.14	**-.22***
4. Pain Catastrophizing				-	**.39****	**.24***
5. Fear of Pain					-	**.56****
6. Pain Sensitivity						-
M	31.32	3.70	125.29	15.77	23.24	3.17
SD	(5.86)	(0.81)	(17.35)	(11.86)	(6.90)	(1.49)
α	.81	.88	.87	.95	.86	.93

Note. ** $p < 0.01$; * $p < 0.05$; CAMSR = Cognitive and Affective Mindfulness Scale- Revised; MAAS = Mindful Attention Awareness Scale; FFMQ = Five Facet Mindfulness Questionnaire.

Table 4. Study 1 Condition by Time ANOVA Results.

	Condition			Time			Condition x Time		
Measure	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
CAMS-R	1.42	.24	.01	1.19	.28	.01	1.00	.32	.01
MAAS	0.22	.64	.00	0.02	.88	.00	0.33	.57	.00
FFMQ Composite	0.71	.40	.01	**6.99**	**.01**	**.06**	0.60	.44	.01
Pain Catastrophizing	0.01	.94	.00	0.63	.43	.01	0.02	.88	.00
Fear of Pain	2.00	.16	.02	**5.34**	**.02**	**.04**	1.24	.27	.01
Pain Sensitivity	0.07	.79	.00	**16.28**	**.00**	**.12**	0.01	.93	.00

CAMSR = Cognitive and Affective Mindfulness Scale- Revised; MAAS = Mindful Attention Awareness Scale; FFMQ = Five Facet Mindfulness Questionnaire.

Table 5. Descriptive Statistics and Bivariate Correlations for Study 2 Variables at Session 1.

Measures	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1. CAMS-R	-	**.59****	**.76****	-.20	.17	**.25***	-.18
2. MAAS		-	**.72****	-.22	-.02	.12	-.11
3. FFMQ Composite			-	**-.28***	.07	.20	-.05
4. Pain Catastrophizing				-	**.23***	.17	**.25***
5. Fear of Pain					-	**.45****	.03
6. Pain Sensitivity						-	**.33****
7. Pain Severity							-
M	29.48	3.35	119.30	19.49	22.60	3.40	3.40
SD	(5.83)	(.84)	(17.26)	(13.04)	(6.60)	(1.66)	(1.50)
α	.81	.88	.88	.95	.82	.95	.88

Note. ** $p < 0.01$; * $p < 0.05$; CAMSR = Cognitive and Affective Mindfulness Scale- Revised; MAAS = Mindful Attention Awareness Scale; FFMQ = Five Facet Mindfulness Questionnaire.

Table 6. Descriptive Statistics and Bivariate Correlations for Study 2 Variables at Session 2.

Measures	1	2	3	4	5	6	7
1. CAMS-R	-	**.62****	**.74****	**-.32****	.10	.04	-.21
2. MAAS		-	**.71****	-.09	.19	.11	.02
3. FFMQ Composite			-	**-.23***	.04	.07	-.10
4. Pain Catastrophizing				-	**.25***	**.32****	**.29***
5. Fear of Pain					-	**.63****	**.26***
6. Pain Sensitivity						-	**.45****
7. Pain Severity							-
M	30.64	3.37	122.63	18.00	22.26	3.07	2.83
SD	(6.25)	(.78)	(18.07)	(12.42)	(6.00)	(1.60)	(1.70)
α	.85	.88	.09	.96	.82	.95	.89

Note. ** $p < 0.01$; * $p < 0.05$; CAMSR = Cognitive and Affective Mindfulness Scale- Revised; MAAS = Mindful Attention Awareness Scale; FFMQ = Five Facet Mindfulness Questionnaire.

Table 7. Study 2 Condition by Time ANOVA Results.

	Condition			**Time**			**Condition x Time**		
Measure	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
CAMS-R	0.31	.58	.00	**7.67**	**.01**	**.10**	**4.76**	**.03**	**.06**
MAAS	0.52	.47	.01	0.50	.48	.01	0.61	.44	.01
FFMQ Composite	0.53	.47	.01	2.16	.15	.03	2.13	.15	.03
Pain Catastrophizing	2.31	.13	.03	0.94	.34	.01	0.00	.96	.00
Fear of Pain	0.01	.92	.00	1.65	.20	.02	0.23	.64	.00
Pain Sensitivity	**5.29**	**.02**	**.07**	3.67	.06	.05	2.75	.10	.04
Pain Severity	3.41	.07	.05	**8.24**	**.01**	**.10**	0.25	.62	.00

CAMSR = Cognitive and Affective Mindfulness Scale- Revised; MAAS = Mindful Attention Awareness Scale; FFMQ = Five Facet Mindfulness Questionnaire.

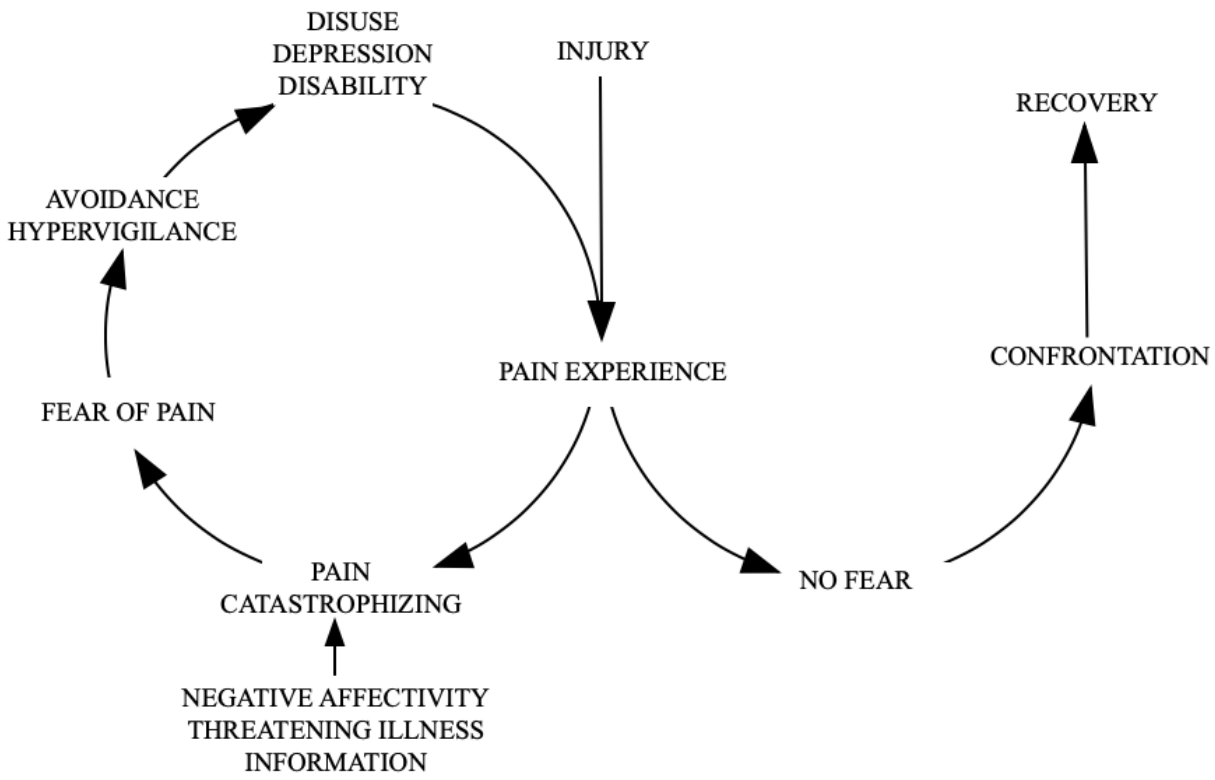


Figure 1. The adapted fear-avoidance model from "Low mindfulness predicts pain catastrophizing in a fear-avoidance model of chronic pain" by Schutze et al., 2010. Pain, 148, p. 121.

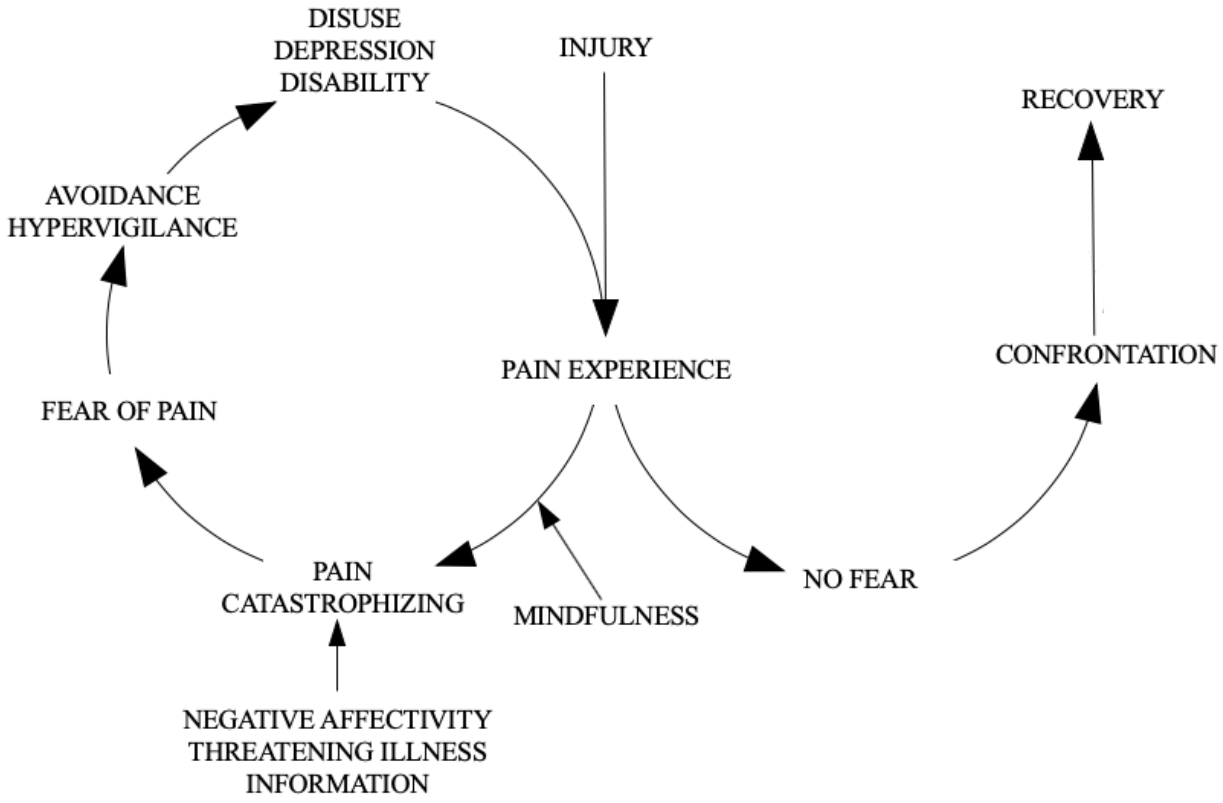


Figure 2. The adapted fear-avoidance model from "Low mindfulness predicts pain catastrophizing in a fear-avoidance model of chronic pain" by Schutze et al., 2010. Pain, 148, p. 125.

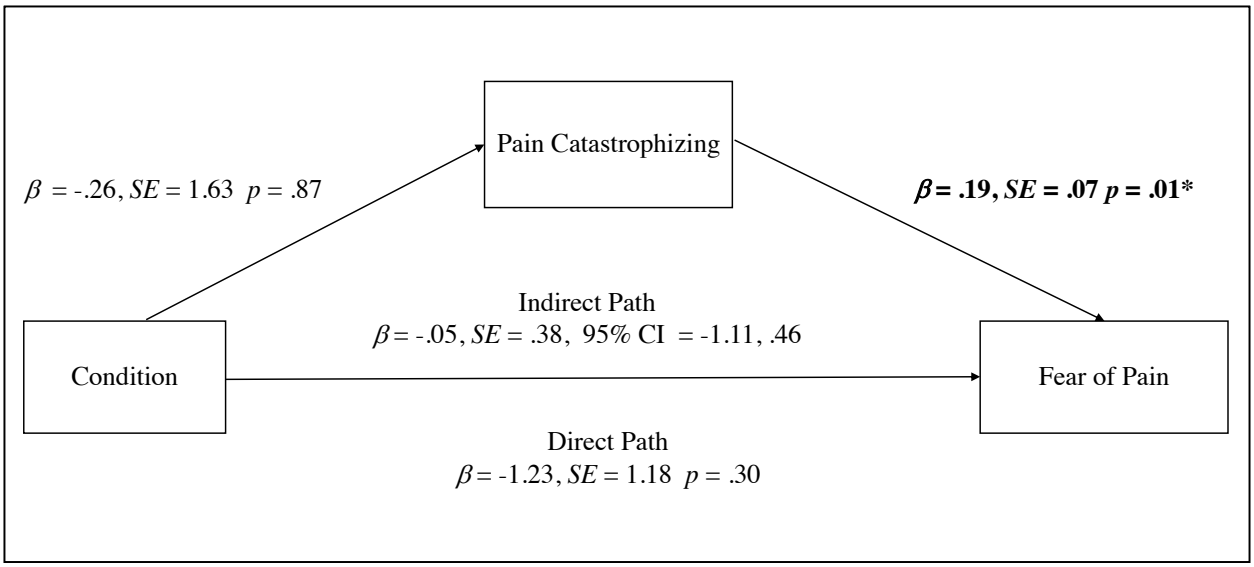


Figure 3. Mediation model depicting the effect of condition on fear of pain at Session 2 through pain catastrophizing for participants in Study 1.

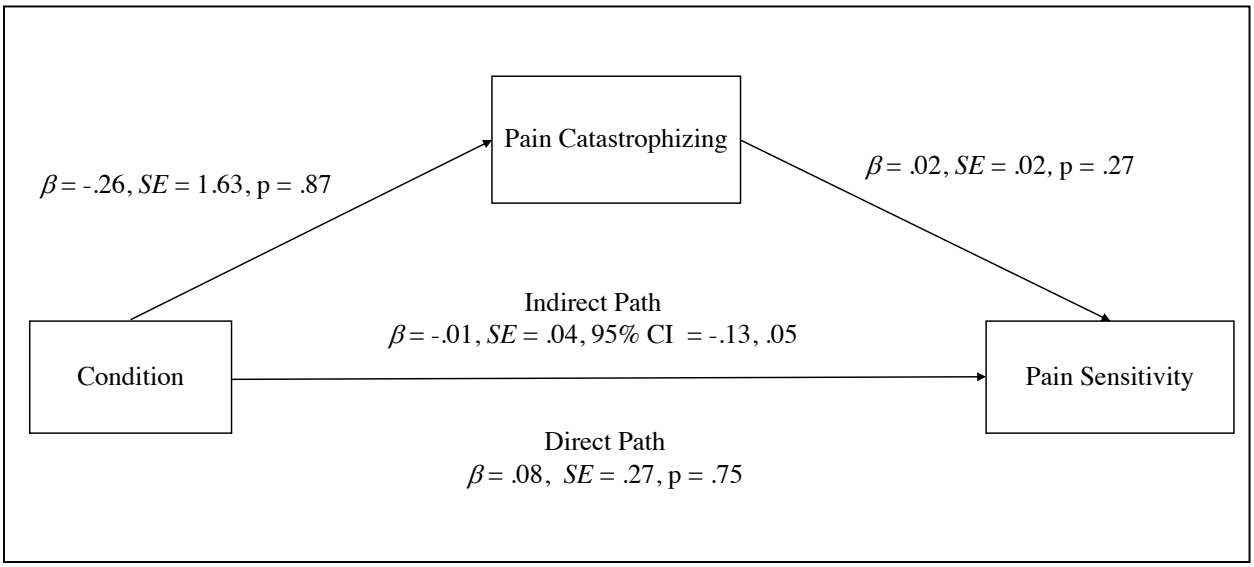


Figure 4. Mediation model depicting the effect of condition on pain sensitivity at Session 2 through pain catastrophizing for participants in Study 1.

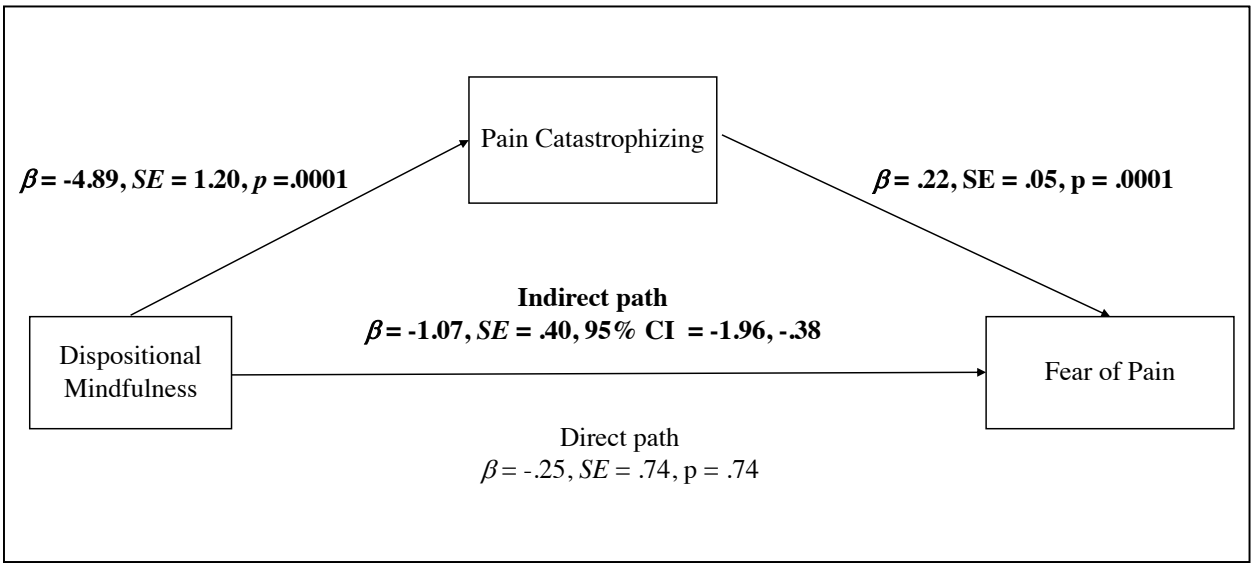


Figure 5. Mediation model depicting the effect of dispositional mindfulness at Session 1 on fear of pain at Session 2 through pain catastrophizing for participants in Study 1.

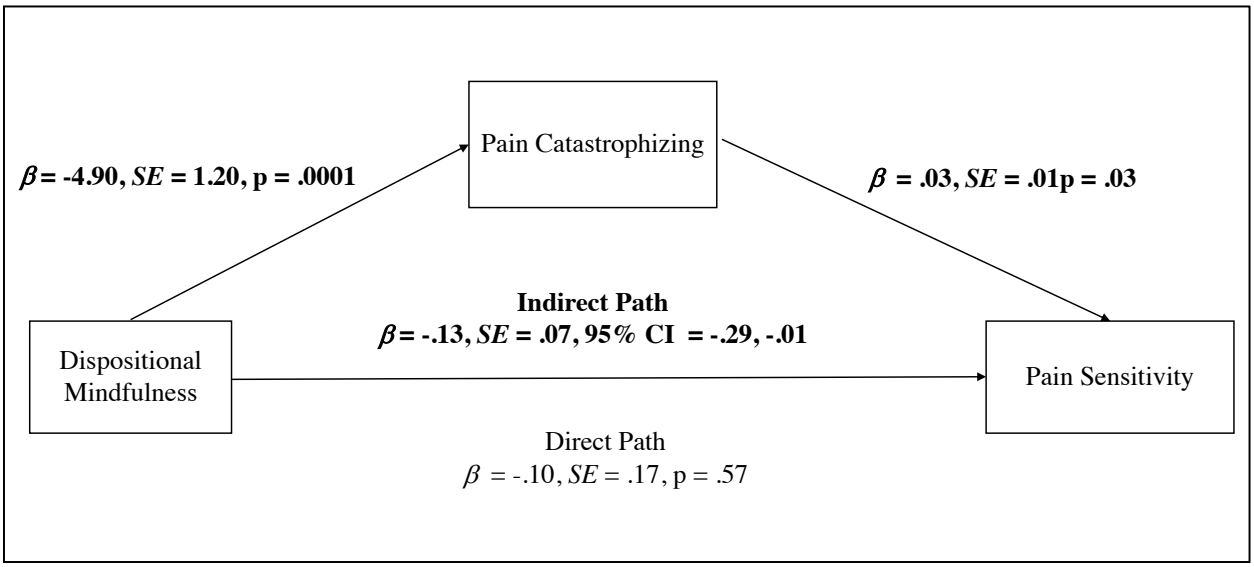


Figure 6. Mediation model depicting the effect of dispositional mindfulness at Session 1 on pain sensitivity at Session 2 through pain catastrophizing for participants in Study 1.

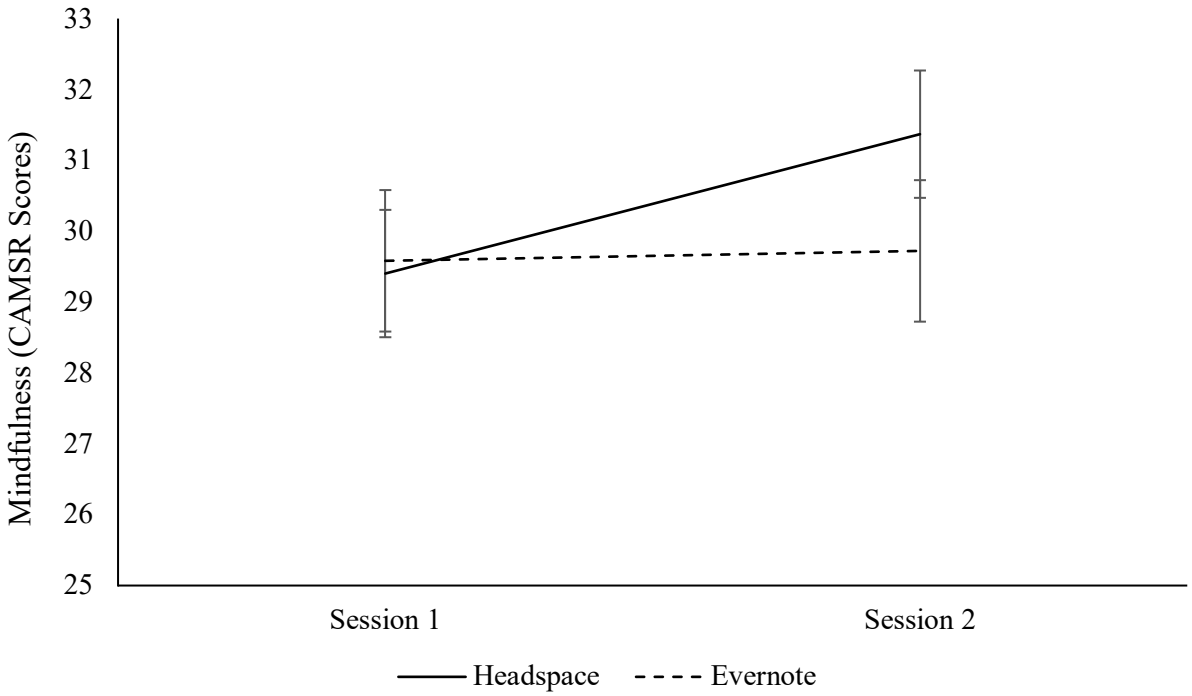


Figure 7. Change in CAMSR scores by condition from Session 1 to Session 2 for Study 2 participants

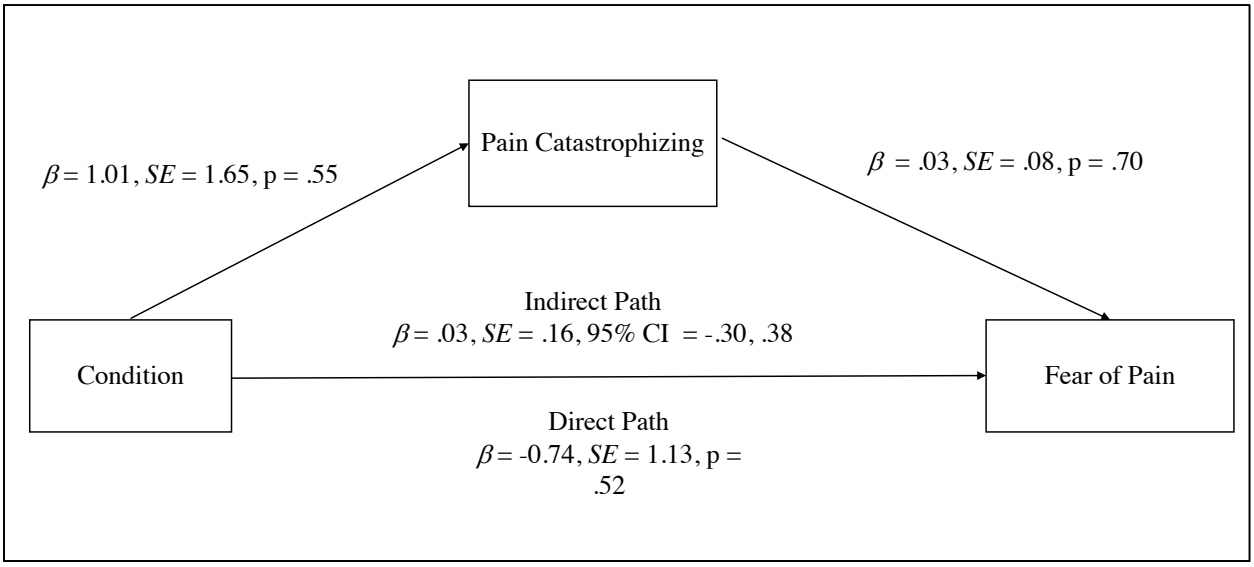


Figure 8. Mediation model depicting the effect of condition on fear of pain at Session 2 through pain catastrophizing for participants in Study 2.

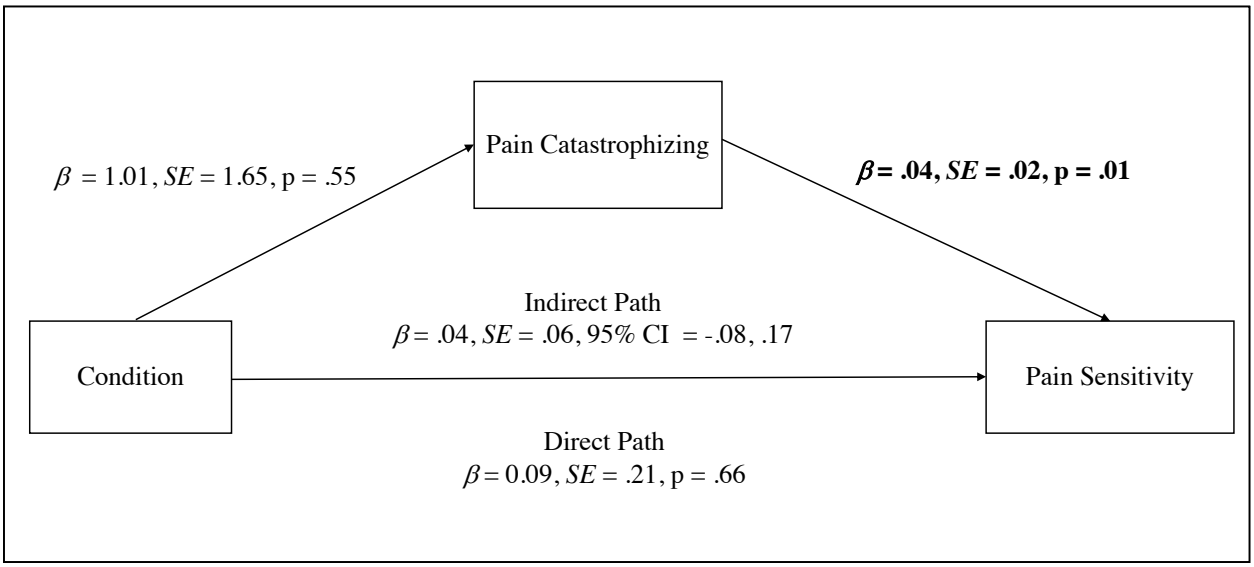


Figure 9. Mediation model depicting the effect of condition on pain sensitivity at Session 2 through pain catastrophizing for participants in Study 2.

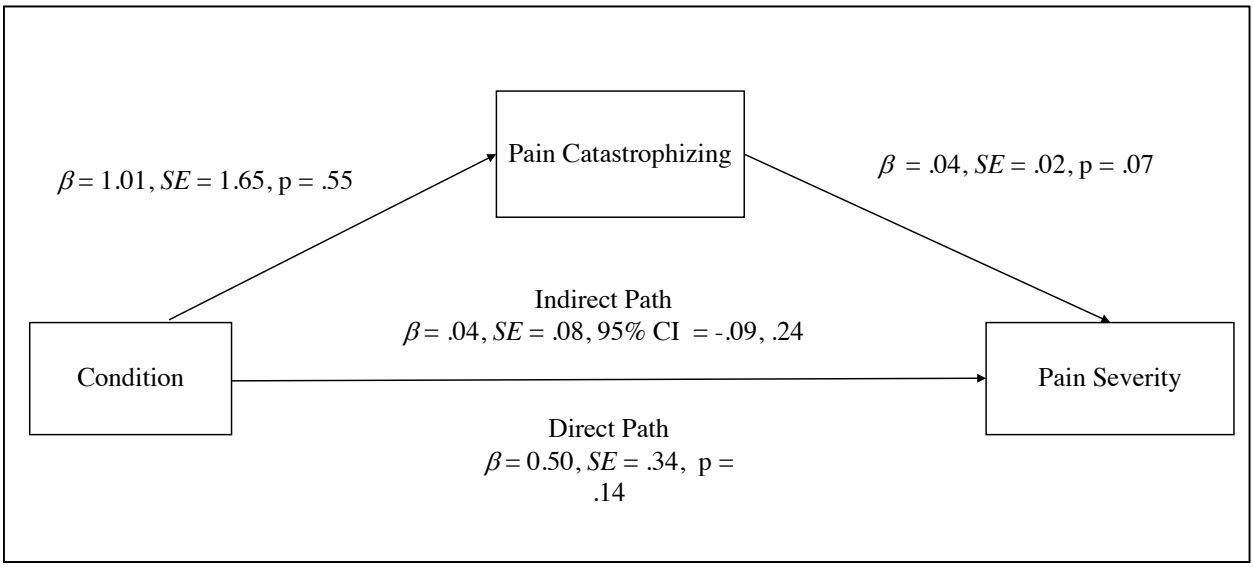


Figure 10. Mediation model depicting the effect of condition on pain severity at Session 2 through pain catastrophizing for participants in Study 2.

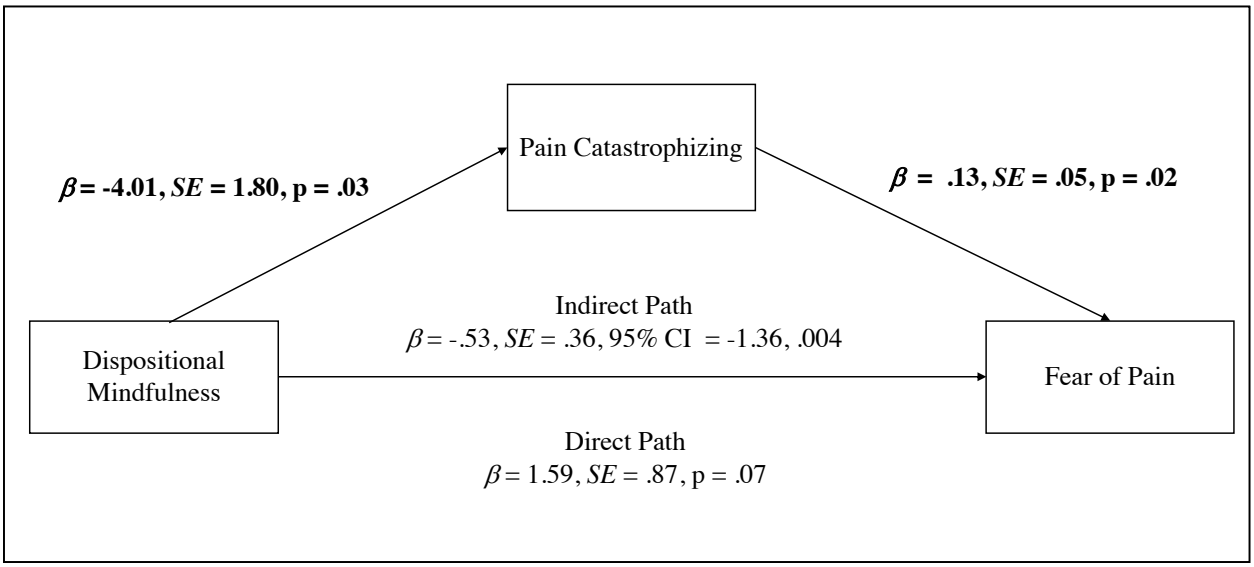


Figure 11. Mediation model depicting the effect of dispositional mindfulness at Session 1 on fear of pain at Session 2 through pain catastrophizing for participants in Study 2.

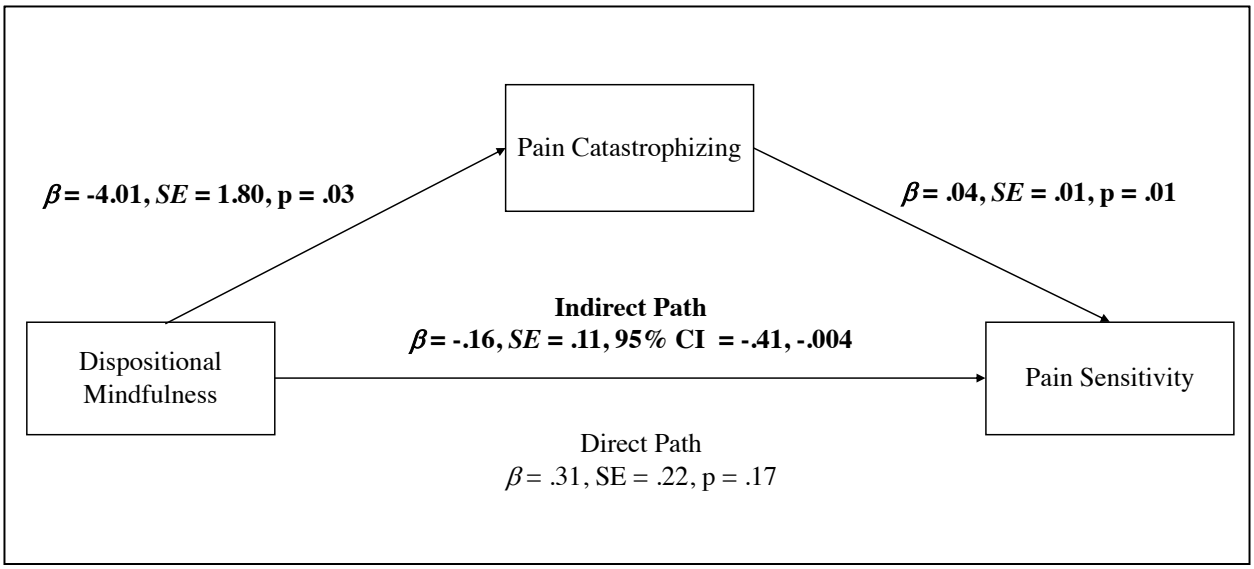


Figure 12. Mediation model depicting the effect of dispositional mindfulness at Session 1 on pain sensitivity at Session 2 through pain catastrophizing for participants in Study 2.

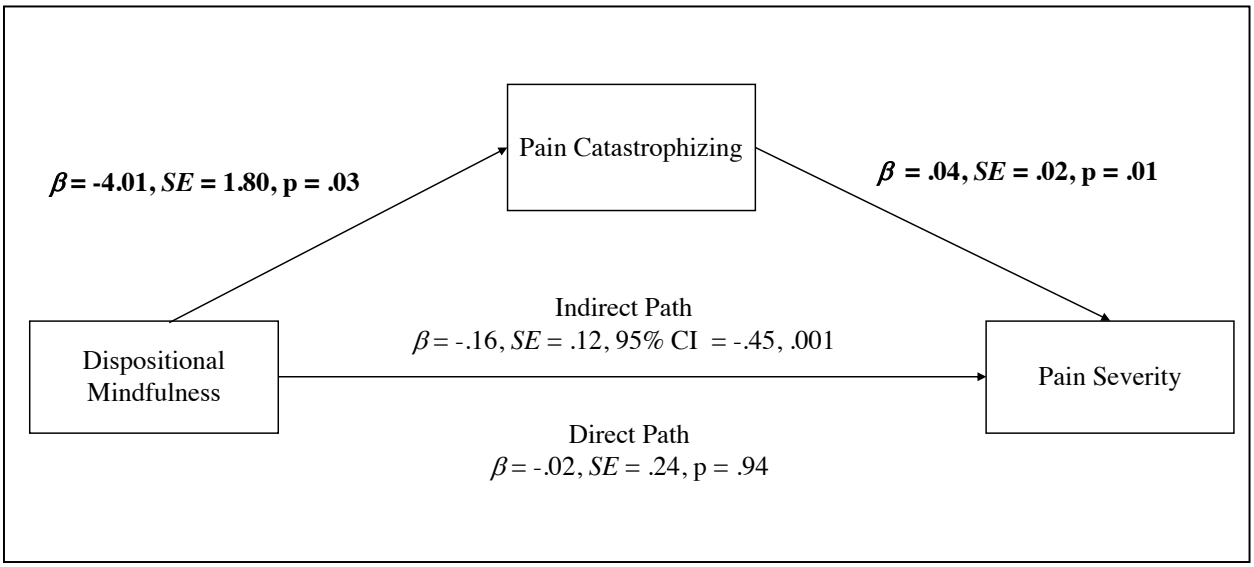


Figure 13. Mediation model depicting the effect of dispositional mindfulness at Session 1 on pain severity at Session 2 through pain catastrophizing for participants in Study 2.

Appendix A

Cognitive and Affective Mindfulness Scale – Revised
(Feldman et al., 2007)

Instructions: People have a variety of ways of relating to their thoughts and feelings. For each of the items below, rate how much each of these ways applies to you.

1	2	3	4
Rarely/ Not At All	Sometimes	Often	Almost always

It is easy for me to concentrate on what I am doing.	1	2	3	4
I am preoccupied by the future.	1	2	3	4
I can tolerate emotional pain.	1	2	3	4
I can accept things I cannot change.	1	2	3	4
I can usually describe how I feel at the moment in considerable detail.	1	2	3	4
I am easily distracted.	1	2	3	4
I am preoccupied by the past.	1	2	3	4
It is easy for me to keep track of my thoughts and feelings.	1	2	3	4
I try to notice my thoughts without judging them.	1	2	3	4
I am able to accept the thoughts and feelings that I have.	1	2	3	4
I am able to focus on the present moment.	1	2	3	4
I am able to pay close attention to one thing for a long period of time.	1	2	3	4

Mindful Attention Awareness Scale
(Brown and Ryan, 2003)

Instructions: Below is a collection of statements about your everyday experience. Using the 1-6 scale below, please indicate how frequently or infrequently you currently have each experience. Please answer according to what *really reflects* your experience rather than what you think your experience should be. Please treat each item separately from every other item.

1	2	3	4	5	6
Almost Always	Very Frequently	Somewhat Frequently	Somewhat Infrequently	Very Infrequently	Almost Never

I could be experiencing some emotion and not be conscious of it until some time later.	1	2	3	4	5	6
I break or spill things because of carelessness, not paying attention, or thinking of something else.	1	2	3	4	5	6
I find it difficult to stay focused on what's happening in the present.	1	2	3	4	5	6
I tend to walk quickly to get where I'm going without paying attention to what I experience along the way.	1	2	3	4	5	6
I tend not to notice feelings of physical tension or discomfort until they really grab my attention.	1	2	3	4	5	6
I forget a person's name almost as soon as I've been told it for the first time.	1	2	3	4	5	6
It seems I am "running on automatic," without much awareness of what I'm doing.	1	2	3	4	5	6
I rush through activities without being really attentive to them.	1	2	3	4	5	6
I get so focused on the goal I want to achieve that I lose touch with what I'm doing right now to get there.	1	2	3	4	5	6
I do jobs or tasks automatically, without being aware of what I'm doing.	1	2	3	4	5	6
I find myself listening to someone with one ear, doing something else at the same time.	1	2	3	4	5	6

I drive places on “automatic pilot” and then wonder why I went there.	1	2	3	4	5	6
I find myself preoccupied with the future or the past.	1	2	3	4	5	6
I find myself doing things without paying attention.	1	2	3	4	5	6
I snack without being aware that I’m eating.	1	2	3	4	5	6

Five Facet Mindfulness Questionnaire
(Baer et al., 2006)

Please rate each of the following statements using the scale provided. Write the number in the blank that best describes your own opinion of what is generally true for you.

1	2	3	4	5
Never or Rarely true	Rarely true	Sometimes true	often true	very often always true

_____ 1. When I'm walking, I deliberately notice the sensations of my body moving.
_____ 2. I'm good at finding words to describe my feelings.
_____ 3. I criticize myself for having irrational or inappropriate emotions.
_____ 4. I perceive my feelings and emotions without having to react to them.
_____ 5. When I do things, my mind wanders off and I'm easily distracted.
_____ 6. When I take a shower or bath, I stay alert to the sensations of water on my body.
_____ 7. I can easily put my beliefs, opinions, and expectations into words.
_____ 8. I don't pay attention to what I'm doing because I'm daydreaming, worrying, or otherwise distracted.
_____ 9. I watch my feelings without getting lost in them.
_____ 10. I tell myself I shouldn't be feeling the way I'm feeling.
_____ 11. I notice how foods and drinks affect my thoughts, bodily sensations, and emotions.
_____ 12. It's hard for me to find the words to describe what I'm thinking.
_____ 13. I am easily distracted.
_____ 14. I believe some of my thoughts are abnormal or bad and I shouldn't think that way.
_____ 15. I pay attention to sensations, such as the wind in my hair or sun on my face.
_____ 16. I have trouble thinking of the right words to express how I feel about things
_____ 17. I make judgments about whether my thoughts are good or bad.
_____ 18. I find it difficult to stay focused on what's happening in the present.
_____ 19. When I have distressing thoughts or images, I "step back" and am aware of the thought or image without getting taken over by it.
_____ 20. I pay attention to sounds, such as clocks ticking, birds chirping, or cars passing.
_____ 21. In difficult situations, I can pause without immediately reacting.
_____ 22. When I have a sensation in my body, it's difficult for me to describe it because I can't find the right words.
_____ 23. It seems I am "running on automatic" without much awareness of what I'm doing.
_____24. When I have distressing thoughts or images, I feel calm soon after.
_____ 25. I tell myself that I shouldn't be thinking the way I'm thinking.
_____ 26. I notice the smells and aromas of things.
_____ 27. Even when I'm feeling terribly upset, I can find a way to put it into words.
_____ 28. I rush through activities without being really attentive to them.
_____ 29. When I have distressing thoughts or images I am able just to notice them without reacting.
_____ 30. I think some of my emotions are bad or inappropriate and I shouldn't feel them.

_____ 31. I notice visual elements in art or nature, such as colors, shapes, textures, or patterns of light and shadow.
_____ 32. My natural tendency is to put my experiences into words.
_____ 33. When I have distressing thoughts or images, I just notice them and let them go.
_____ 34. I do jobs or tasks automatically without being aware of what I'm doing.
_____ 35. When I have distressing thoughts or images, I judge myself as good or bad, depending what the thought/image is about.
_____ 36. I pay attention to how my emotions affect my thoughts and behavior.
_____ 37. I can usually describe how I feel at the moment in considerable detail.
_____ 38. I find myself doing things without paying attention.
_____ 39. I disapprove of myself when I have irrational ideas.

Pain Catastrophizing Scale
(Sullivan, 1995)

Instructions: We are interested in the types of thoughts and feeling that you have when you are in pain. Listed below are thirteen statements describing different thoughts and feelings that may be associated with pain. Using the scale, please indicate the degree to which you have these thoughts and feelings when you are experiencing pain.

0	1	2	3	4
Not at all	To a slight degree	To a moderate degree	To a great degree	All of the time

I worry all the time about whether the pain will end.	0	1	2	3	4
I feel I can't go on.	0	1	2	3	4
It's awful and I feel that it overwhelms me.	0	1	2	3	4
It's terrible and I think it's never going to get any better.	0	1	2	3	4
I feel I can't stand it anymore.	0	1	2	3	4
I become afraid that the pain will get worse.	0	1	2	3	4
I keep thinking of other painful events.	0	1	2	3	4
I anxiously want the pain to go away.	0	1	2	3	4
I can't seem to keep it out of my mind.	0	1	2	3	4
I keep thinking about how much it hurts.	0	1	2	3	4
I keep thinking about how badly I want the pain to stop.	0	1	2	3	4
There's nothing I can do to reduce the intensity of the pain.	0	1	2	3	4
I wonder whether something serious may happen.	0	1	2	3	4

Fear of Pain Questionnaire – 9

(McNeil et al., 2018)

Instructions**:** The items listed below describe painful experiences. Please look at each item and think about how fearful you are of experiencing the pain associated with each item. If you have never experienced the pain of a particular item, please answer on the basis of how fearful you expect you would be if you had such an experience. Circle one number for each item below to rate your fear of pain in relation to each event.

I fear the pain associated with:

		Not at all	**A little**	**A fair amount**	**Very much**	**Extreme**
1.	Breaking your arm	1	2	3	4	5
2.	Having a foot doctor remove a wart from your foot with a sharp instrument	1	2	3	4	5
3.	Getting a papercut on your finger	1	2	3	4	5
4.	Receiving an injection in your mouth	1	2	3	4	5
5.	Getting strong soap in both your eyes while bathing or showering	1	2	3	4	5
6.	Having someone slam a heavy car door on your hand	1	2	3	4	5
7.	Gulping a hot drink before it has cooled	1	2	3	4	5
8.	Receiving an injection in your hip/buttocks	1	2	3	4	5
9.	Falling down a flight of concrete stairs	1	2	3	4	5

Pain Sensitivity Questionnaire
(Ruscheweyh et al., 2009)

Instructions: This questionnaire contains a series of questions in which you should imagine yourself in certain situations. You should then decide if these situations would be painful for you and if yes, how painful they would be. Let 0 stand for no pain; 1 is an only just noticeable pain and 10 the most severe pain that you can imagine or consider possible. Please mark the scale with a cross on the number that is most true for you. Keep in mind that there are no ‘‘right” or ‘‘wrong” answers; only your personal assessment of the situation counts. Please try as much as possible not to allow your fear or aversion of the imagined situations affect your assessment of painfulness.

1. Imagine you bump your shin badly on a hard edge, for example, on the edge of a glass coffee table.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

2. Imagine you burn your tongue on a very hot drink.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

3. Imagine your muscles are slightly sore as the result of physical activity.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

4. Imagine you trap your finger in a drawer.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

5. Imagine you take a shower with lukewarm water.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

6. Imagine you have mild sunburn on your shoulders.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

7. Imagine you grazed your knee falling off your bicycle.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

8. Imagine you accidentally bite your tongue or cheek badly while eating.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

9. Imagine walking across a cool tiled floor with bare feet.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

10. Imagine you have a minor cut on your finger and inadvertently get lemon juice in the wound.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

11. Imagine you prick your fingertip on the thorn of a rose.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

12. Imagine you stick your bare hands in the snow for a couple of minutes or bring your hands in contact with snow for some time, for example, while making snowballs.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

13. Imagine you shake hands with someone who has a normal grip.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

14. Imagine you shake hands with someone who has a very strong grip.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

15. Imagine you pick up a hot pot by inadvertently grabbing its equally hot handles.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

16. Imagine you are wearing sandals and someone with heavy boots steps on your foot.

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

17. Imagine you bump your elbow on the edge of a table (‘‘funny bone”).

How painful would that be for you?
0 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7 --- 8 --- 9 --- 10
0 = not at all painful 10 = most severe pain imaginable

Positive and Negative Affect Schedule
(Watson et al., 1988)

Indicate the extent you have felt this way over the past week		**Very slightly or not at all**	**A little**	**Moderately**	**Quite a bit**	**Extremely**
1.	Interested	1	2	3	4	5
2.	Distressed	1	2	3	4	5
3.	Excited	1	2	3	4	5
4.	Upset	1	2	3	4	5
5.	Strong	1	2	3	4	5
6.	Guilty	1	2	3	4	5
7.	Scared	1	2	3	4	5
8.	Hostile	1	2	3	4	5
9.	Enthusiastic	1	2	3	4	5
10.	Proud	1	2	3	4	5
11.	Irritable	1	2	3	4	5

12.	Alert	1	2	3	4	5
13.	Ashamed	1	2	3	4	5
14.	Inspired	1	2	3	4	5
15.	Nervous	1	2	3	4	5
16.	Determined	1	2	3	4	5
17.	Attentive	1	2	3	4	5
18.	Jitter	1	2	3	4	5
19.	Active	1	2	3	4	5
20.	Afraid	1	2	3	4	5

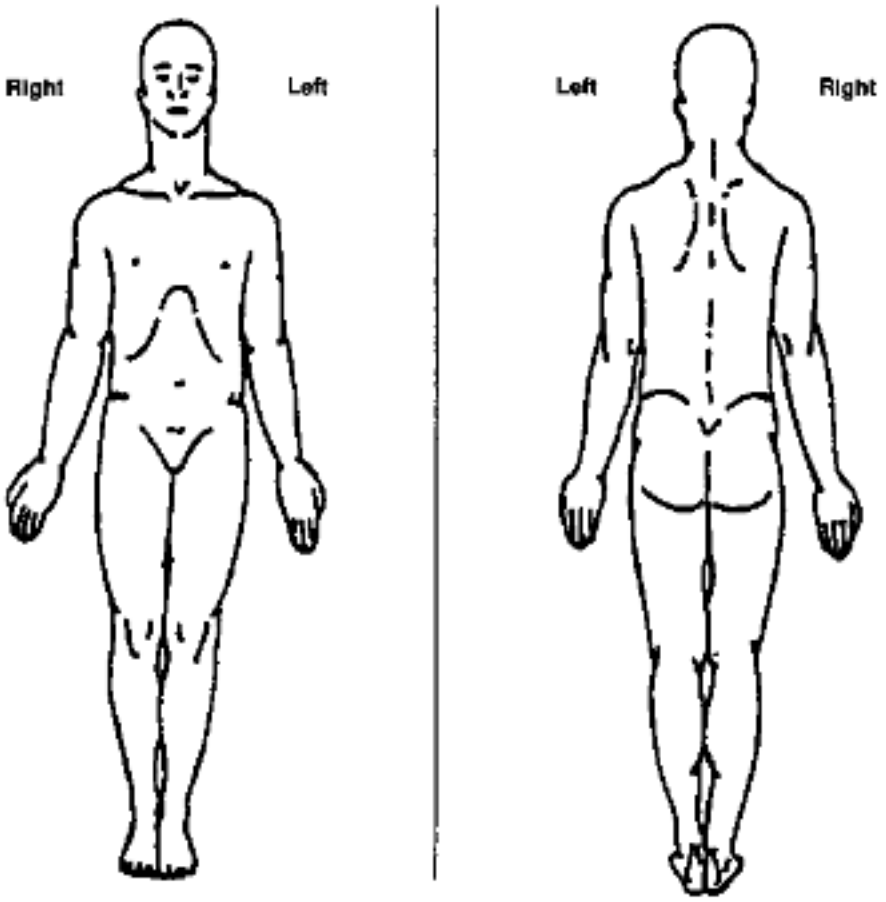
Brief Pain Inventory – Short Form

(Cleeland, 1999)

1. Throughout our lives, most of us have had pain from time to time (such as minor headaches, sprains, and toothaches). Have you had pain other than these every-day kinds of pain today?

   1. Yes 2. No

2. On the diagram, shade in the areas where you feel pain. Put an X on the area that hurts the most.



3. Please rate your pain by circling the one number that best describes your pain at its **worst** in the last 24 hours. 0 = No Pain, 10 = pain as bad as you can imagine.

   0 1 2 3 4 5 6 7 8 9 10

4. Please rate your pain by circling the one number that best describes your pain at its **least** in the last 24 hours. 0 = No Pain, 10 = pain as bad as you can imagine.

   0 1 2 3 4 5 6 7 8 9 10

5. Please rate your pain by circling the one number that best describes your pain **on average**. 0 = No Pain, 10 = pain as bad as you can imagine.

0 1 2 3 4 5 6 7 8 9 10

6. Please rate your pain by circling the one number that tells us how much pain you have **right now**. 0 = No Pain, 10 = pain as bad as you can imagine.

0 1 2 3 4 5 6 7 8 9 10

7. What treatments or medications are you receiving for your pain?

8. In the last 24 hours, how much relief have pain treatments or medications provided? Please circle the one percentage that most shows how much **relief** you have received. 0 = No relief, 100% = Complete relief.

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

9. Circle the one number that describes how, during the past 24 hours, pain has interfered with your:

   A. General activity

   0 1 2 3 4 5 6 7 8 9 10
   0 = Does not interfere, 10 = Completely interferes

   B. Mood

   0 1 2 3 4 5 6 7 8 9 10
   0 = Does not interfere, 10 = Completely interferes

   C. Walking ability

   0 1 2 3 4 5 6 7 8 9 10
   0 = Does not interfere, 10 = Completely interferes

   D. Normal work (includes both work outside the home and housework)

   0 1 2 3 4 5 6 7 8 9 10
   0 = Does not interfere, 10 = Completely interferes

   E. Relations with other people

   0 1 2 3 4 5 6 7 8 9 10
   0 = Does not interfere, 10 = Completely interferes

F. Sleep

0 1 2 3 4 5 6 7 8 9 10

0 = Does not interfere, 10 = Completely interferes

G. Enjoyment of life

0 1 2 3 4 5 6 7 8 9 10

0 = Does not interfere, 10 = Completely interferes

Demographics Questions

Gender:
- Man
- Woman
- Transgender man
- Transgender woman
- Other _____

Age: _____

Height: _____ ft _____in
Weight: _____

Are you under a doctor's care for a medical condition? (If yes, please describe below)

Are you taking any prescription medications? (If yes, please identify below)

Do you have any chronic health concerns or problems? (If yes, please describe below)

Have you experienced any illness or injury within the past 7 days? (If yes, please describe below)

Employment Status:
- Unemployed
- Full-time employed
- Part-time employed
- Self-employed
- Student
- Retired
- On disability
- Other (with option to fill in)

If employed, what is your profession? _____

If student, what is your year?
- Freshman
- Sophomore
- Junior
- Senior
- Other: _____

Sexual orientation:

Straight/Heterosexual
Lesbian/Homosexual Female
Gay/Homosexual Male
Bi-sexual
Other _____

Political orientation:

Very conservative
Conservative
Moderate
Liberal
Very liberal

What political party best represents your beliefs?
___Democrat ___ Republican ___Libertarian ___Independent ___Other

Marital Status:

_____Single
_____Married
_____Separated
_____Divorced
_____Widowed

Ethnicity:

_____White/Caucasian
_____Hispanic/Latino(a)
_____African-American/Black
_____Asian
_____Native American
_____Other – Please list:_____

What is your religious affiliation?

_____ Christian _____ Muslim
_____ Jewish
_____ Hindu _____ Atheist
_____ Buddhist _____ Agnostic
_____ Not religious _____ Other – Please list: _____

What is your family income?

_____Less than $10,000
_____$10,000 to $19,999
_____$20,000 to $29,999
_____$30,000 to $39,999
_____$40,000 to $49,999
_____$50,000 to $59,999
_____$60,000 to $69,999
_____$70,000 to $79,999
_____$80,000 to $89,999
_____$90,000 to $99,999
_____$100,000 to $149,999
_____$150,000 or more

How would you characterize your hometown?

_____ rural (unincorporated)
_____ small town (village or town)
_____ suburban (metropolitan area of a large city)
_____ small city (population < 30,000)
_____ medium-sized city (population 30,000 – 100,000)
_____ large city (population > 100,000)

Please list all psychology courses that you have taken.

_____

_____

Have you ever:
Practiced meditation regularly Y/N
Practiced yoga regularly Y/N
Practiced Tai Chi regularly. Y/N
Practiced martial arts regularly Y/N
Used the app called “Headspace” Y/N

Daily Log

Instructions: To help keep track of your daily exercises with the app, we would like for you to complete the daily log below. Each time you complete an exercise, please record the date and time of day. Then, provide a brief reaction to the exercise. In the reaction column, please provide any information that seems relevant. This could be things that you enjoyed or didn't enjoy about the exercise, whether the exercise was easy or difficult, or how you felt before, during, or after the exercise.

Date	Start Time	End Time	Reaction

Appendix B

Table B1. Results of Sensitivity Analyses for Primary Study 1 Outcomes.

	Condition			Time			Condition x Time		
Measure	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Analyses with Covariates									
CAMS-R	1.77	0.19	0.02	1.55	0.22	0.01	1.74	0.19	0.02
MAAS	0.62	0.43	0.01	0.04	0.85	0.00	0.28	0.60	0.00
FFMQ Composite	0.91	0.34	0.01	**6.28**	**0.01**	**0.05**	1.14	0.28	0.01
Pain Catastrophizing	0.00	0.99	0.00	0.53	0.47	0.01	0.02	0.89	0.00
Fear of Pain	2.43	0.12	0.02	**6.44**	**0.01**	**0.05**	1.45	0.23	0.01
Pain Sensitivity	0.00	0.96	0.00	**14.21**	**0.00**	**0.11**	0.09	0.77	0.00
Analyses without Multivariate Outliers									
CAMS-R	0.91	0.34	0.01	1.30	0.26	0.01	0.23	0.64	0.00
MAAS	0.66	0.42	0.01	0.01	0.93	0.00	0.06	0.81	0.00
FFMQ Composite	0.91	0.34	0.01	**9.78**	**0.00**	**0.08**	0.74	0.39	0.01
Pain Catastrophizing	0.01	0.91	0.00	2.17	0.14	0.02	0.40	0.53	0.00
Fear of Pain	0.69	0.41	0.01	**4.27**	**0.04**	**0.04**	0.99	0.32	0.01
Pain Sensitivity	0.31	0.58	0.00	**15.24**	**0.00**	**0.12**	0.01	0.94	0.00
Analyses without Participants Excluded for Significant Life Events									
CAMS-R	1.13	0.29	0.01	1.50	0.22	0.01	0.73	0.39	0.01
MAAS	0.41	0.53	0.00	0.03	0.86	0.00	0.36	0.55	0.00
FFMQ Composite	0.74	0.39	0.01	**7.73**	**0.01**	**0.06**	0.43	0.51	0.00
Pain Catastrophizing	0.01	0.93	0.00	0.55	0.46	0.01	0.01	0.91	0.00
Fear of Pain	1.50	0.22	0.01	**4.93**	**0.03**	**0.04**	1.34	0.25	0.01
Pain Sensitivity	0.18	0.67	0.00	**17.08**	**0.00**	**0.13**	0.00	0.95	0.00
Analyses with Square-Root Corrected Pain Sensitivity									
Pain Sensitivity	0.10	0.76	0.00	**19.00**	**0.00**	**0.15**	0.00	0.96	0.00

CAMSR = Cognitive and Affective Mindfulness Scale- Revised; MAAS = Mindful Attention Awareness Scale; FFMQ = Five Facet Mindfulness Questionnaire.

Table B2. Results of Sensitivity Analyses for Primary Study 2 Outcomes.

Measure	Condition			Time			Condition x Time		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Analyses without Covariates									
CAMS-R	0.27	0.61	0.00	**5.06**	**0.03**	**0.06**	3.92	0.05	0.05
MAAS	0.36	0.55	0.00	0.02	0.88	0.00	1.91	0.17	0.02
FFMQ Composite	0.56	0.46	0.01	3.46	0.07	0.04	2.39	0.13	0.03
Pain Catastrophizing	0.96	0.33	0.01	3.53	0.06	0.04	0.00	0.98	0.00
Fear of Pain	0.84	0.36	0.01	0.64	0.43	0.01	0.57	0.45	0.01
Pain Sensitivity	**4.30**	**0.04**	**0.05**	**8.78**	**0.00**	**0.10**	3.11	0.08	0.04
Pain Severity	0.03	0.86	0.00	**12.14**	**0.00**	**0.13**	0.00	0.95	0.00
Analyses with Square-Root Corrected Pain Sensitivity									
Corrected Pain Sensitivity	**4.18**	**0.04**	**0.05**	**10.59**	**0.00**	**0.11**	3.37	0.07	0.04

CAMSR = Cognitive and Affective Mindfulness Scale- Revised; MAAS = Mindful Attention Awareness Scale; FFMQ = Five Facet Mindfulness Questionnaire.

Appendix C

Table C1. Descriptive Statistics for FFMQ Subscale Scores at each Study Session for Studies1 and 2.

FFMQ Subscale	Study 1						Study 2					
	Session 1			Session 2			Session 1			Session 2		
	M	*SD*	α	*M*	*SD*	α	*M*	*SD*	α	*M*	*SD*	α
Observe	26.54	5.8	0.80	26.93	6.11	0.84	27.04	4.77	0.70	26.94	4.59	0.71
Describe	26.16	6.6	0.90	25.99	6.92	0.91	26.10	6.37	0.90	26.56	6.64	0.92
Awareness	24.96	6.3	0.88	24.65	6.21	0.88	23.64	6.12	0.90	23.76	6.90	0.93
Non-judgment	25.38	7.2	0.91	26.80	6.63	0.91	22.69	6.49	0.89	24.97	6.70	0.93
Non-reactance	19.68	4.6	0.79	20.92	4.87	0.84	19.83	4.28	0.76	20.69	4.18	0.76

FFMQ = Five Facet Mindfulness Questionnaire.

Table C2. Results of Analyses of Variance Between Session 1 and Session 2 for FFMQ Subscales for Study 1.

	Condition			**Time**			**Condition x Time**		
FFMQ Subscale	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Observe	0.10	0.75	0.00	0.91	0.34	0.01	0.76	0.39	0.01
Describe	0.01	0.94	0.00	0.21	0.65	0.00	0.41	0.52	0.00
Awareness	0.08	0.78	0.00	0.76	0.39	0.01	1.47	0.23	0.01
Non-judgment	1.04	0.31	0.01	**9.65**	**0.00**	**0.08**	3.12	0.08	0.03
Non-reactance	0.83	0.36	0.01	**12.24**	**0.00**	**0.10**	0.11	0.74	0.00

FFMQ = Five Facet Mindfulness Questionnaire.

Table C3. Results of Analyses of Variance Between Session 1 and Session 2 for FFMQ Subscales for Study 2.

	Condition			**Time**			**Condition x Time**		
FFMQ Subscale	*F*	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Observe	0.01	0.92	0.00	0.65	0.42	0.01	0.37	0.55	0.01
Describe	0.36	0.55	0.01	3.51	0.07	0.05	1.51	0.22	0.02
Awareness	1.45	0.23	0.02	1.68	0.20	0.02	0.44	0.51	0.01
Non-judgment	0.06	0.81	0.00	**4.46**	**0.04**	**0.06**	**4.81**	**0.03**	**0.06**
Non-reactance	0.69	0.41	0.01	2.19	0.14	0.03	0.14	0.71	0.00

FFMQ = Five Facet Mindfulness Questionnaire.