THE EFFECT OF RANDOMIZED, CONTROLLED YOGA TRAINING INTERVENTION TRIALS ON CHRONIC PAIN: A SYSTEMATIC REVIEW AND META-ANALYSIS AND THE EFFECT OF A SINGLE SESSION OF YOGA POSTURES, WITH AND WITHOUT SLOW BREATHING, ON ACUTE PAIN SENSITIVITY, ENDOGENOUS PAIN MODULATION AND STATE ANXIETY

by

LASHAWNNA N. RAY

(Under the Direction of Patrick J. O'Connor)

ABSTRACT

This dissertation involved two investigations. First, a systematic review and meta-analysis estimated the population effect size of yoga interventions for reducing pain in randomized controlled trials with samples of people in chronic pain. Forty-five effects were derived from 12 experiments; 1680 patients (mean ±SD sample size: 70±30) categorized as having chronic low back pain, chronic neck pain, migraines, cancer-related pain, arthritis, fibromyalgia, neck pain, or neuropathic pain. Thirty-seven of 45 (82%) effects were greater than zero. Unweighted Hedge's d effect sizes ranged from -0.93 to 6.46. Compared to non-yoga control conditions, yoga training significantly reduced pain symptoms among those in chronic pain by a large mean effect (Δ) of 1.31 (95%CI: 0.79 to 1.83, Z = 4.92, $p < 0.001$) and improved physical disability by a moderate mean effect (Δ) of .56 (95%CI: 0.11 to 1.02, Z = 2.41, $p = 0.016$).

The aim of the second experiment was to test, using a post-test only between-subjects design, main and interactive effects of yoga and slow breathing on both sensitivity to heat pain and endogenous pain modulation in healthy young women.

Fifty-four women were randomized into one of four 40-minute conditions: yoga with slow breathing instructions (Vinyasa), yoga with no breathing instructions, seated rest with slow breathing instructions and seated rest with no breathing instructions. Two factor ANOVA showed that yoga postures and slow breathing, and their interaction were statistically insignificant for both sensitivity to heat pain and endogenous pain modulation. These findings were unchanged in ANCOVAs that controlled for four potential confounding variables: post-condition reduction in systolic blood pressure or state anxiety, pain induced by the conditions and expectations. Compared to the non-yoga conditions, the yoga conditions resulted in a significant reduction in state anxiety scores.

It is concluded that 40-minutes of low-to-moderate intensity yoga with, or without slow breathing, reduces state anxiety but has no effect on heat pain sensitivity or endogenous pain modulation. The findings support the idea that higher intensity yoga which produces moderate intensity pain may be necessary to alter heat pain sensitivity and endogenous pain modulation.

INDEX WORDS: Pain, Vinyasa yoga, condition pain modulation, anxiety, blood pressure, slow breathing, women, meta-analysis

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by

LASHAWNNA N. RAY

BS, University of Texas at San Antonio, 2008

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THE EFFECT OF RANDOMIZED, CONTROLLED YOGA TRAINING INTERVENTION TRIALS ON CHRONIC PAIN: A SYSTEMATIC REVIEW AND META-ANALYSIS AND THE EFFECT OF A SINGLE SESSION OF YOGA ON ACUTE PAIN SENSITIVITY, ENDOGENOUS PAIN MODULATION AND STATE ANXIETY

by

LASHAWNNA N. RAY

Major Professor: Patrick J. O'Connor
Committee: Rebecca Marshall
Kevin McCully

Electronic Version Approved:

Ron Walcott
Interim Dean of the Graduate School
The University of Georgia
August 2020

DEDICATION

"I think that that's the wisest thing –

to prevent illness before we try to cure something" – Maya Angelou.

I believe in prevention versus reaction. Mindfulness and yoga have taught me that and I dedicate this dissertation to my practice.

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CHAPTER 1

INTRODUCTION

Yoga is increasingly popular, especially among women [1]. One cross-sectional study of 34,525 adults in the United States found that yoga practitioners thought that yoga was effective for multiple reasons including enhancing general wellness and disease prevention (78%), improving the mood of energy (66%), supporting immune function (50%) and treating back pain (20%) [2]. Evidence supports that yoga has healthful effects. For example, acute and chronic yoga can reduce anxiety [3], systolic blood pressure [4-6], and pain [7].

Chronic pain is defined as pain that persists or recurs for more than 3 months [8]. Chronic pain conditions afflict at least 116 million adults in the United States and cost about $600 billion in annual direct medical costs and lost productivity [9]. A range of barriers prevent adequate treatment for chronic pain, including some healthcare providers that minimize the important of treating pain, the lack of universal health care or insurance, and a shortage of care providers in rural areas [9]. Many treatments lack effectiveness or have dangerous side effects or high potential for abuse [10]. Nonpharmacological treatments for chronic pain, such as yoga, reduce the risk of long-term adverse outcomes but more research is needed to understand the magnitude of the efficacy of these treatments as well as who does, and does not, benefit [11].

Several reviews and meta-analyses of yoga training show clinically meaningful pain relief. For example, one meta-analysis found that yoga interventions both improved pain (Standardized mean difference [SMD] = -.74) and reduced pain-related disability (SMD = -.79)

[12]. A subsequent review and meta-analysis by Ward, Stebbings [13] of 17 studies and more than 1,600 participants found that yoga improved self-reported and objective measures of physical function. Practicing yoga also improve symptoms that are commonly comorbid with pain and potentially contribute to poor control of chronic pain, including anxiety, depression and fatigue. Additionally, one review about the efficacy of yoga for low back pain found patients who engaged in yoga showed significant reductions in pain medication usage at post-treatment and three-month follow-up [14].

Historically, research into chronic pain has proceeded by focusing on a single type of pain defined by its location such as back or neck pain. In recent years, it has increasingly been recognized that there are common mechanisms that underlie chronic pain regardless of the location. Thus, there is a need to examine nonpharmacological treatments, such as yoga, in light of the broad category of chronic pain rather than only by focusing separately on each specific pain condition in relation to its body location.

Chapter 2 of this dissertation provides a succinct review of yoga and pain. Included are sections relevant to the novel research questions addressed in this dissertation. For example, how yoga differs from other types of exercise and potential mechanisms by which yoga could reduce pain are considered. Because one of the experiments summarized in this dissertation involves acute exercise and tests whether slow breathing plays a role in pain modulation, information about yoga and ventilation is reviewed as is the concept of conditioned pain modulation.

Chapter 3 of this dissertation presents a meta-analysis of randomized controlled trials of yoga training effects on chronic pain. The primary purpose of the meta-analysis was to estimate the population effect size of yoga interventions for reducing pain in samples suffering from chronic pain. The secondary purpose was to determine if variables of practical importance, such as yoga style or training duration, account for variation in the population effect. A tertiary purpose is to assess whether yoga programs have favorable effects on related outcomes such as quality of life and physical function.

Chapter 4 of this dissertation describes an experiment that examined, using a post-test only, between-subjects design, the effect of a single session of yoga postures and slow breathing on conditioned pain modulation in young women.

Chapter 5 provides a brief overview of what was learned from the meta-analysis presented in Chapter 3 and the experiment summarized in Chapter 4 and the implications for future research and practice.

CHAPTER 2

LITERATURE REVIEW

Yoga is a philosophy and practice that was developed in India over thousands of years ago [15]. It is a mind-body practice that involves eight components that consists of moral (Yamas) and lifestyle (Niyamas) concerns, physical postures (Asana), breathing exercises (Pranayama), self-reflection (Pratyahara). and centering (Dharana) practices, meditation (Dhyana), and harmony with the divine (Samadhi) [16]. These distinct elements offer training that builds overall wellness. There are a wide variety of yoga styles that are based on the eight features. One recent review of randomized controlled trials (RCTs) found over 53 different styles within the 306 RCTs included in the review [17]. Table 2.1 outlines the common styles practiced. Yoga is increasingly popular, especially among women [1]. Yoga has health promoting effects; for example, acute and chronic yoga can reduce pain [7], anxiety [3] and systolic blood pressure [4-6]. One cross-sectional study of 34,525 adults in the United States found that yoga was practiced most commonly to enhance general wellness and disease prevention (78%), improve the mood of energy (66%), support immune function (50%) and treat back pain (20%) [2].

Yoga is arguably more complex than some commonly studied physical activities modes, such as walking, cycling or hand grip exercise. About 50% of the time yoga is performed in a group setting and led by an instructor [18] and the mere presence of others can reduce pain [19]. However, experiments to date have not attempted to eliminate the potential social effects from the effects of yoga *per se*. Yoga typically involves a series of primarily isometric body postures held in various positions (i.e., prone, standing, supine, seated) combined with a conscious attempt to think about and/or interpret information in a specified way (e.g., mindful meditation type procedures) while using a recommended breathing technique (e.g., alternating nostrils and/or a slower than normal breathing rate). Each of these yoga elements (social setting, position, posture, mindfulness and breathing) may play a role in pain relief or psychological changes that accompany yoga.

Whether, and why, mood states, such as anxiety and energy, are altered after a single bout of yoga is poorly understood. The majority of acute yoga studies have focused on cognitive outcomes. A meta-analysis found that moderate-sized improvements in cognitive function were realized after a single bout of yoga and the largest effects were for processing speed and attention [20]. In contrast, affective outcomes of acute yoga have been investigated less frequently and with less methodological rigor. For instance, improved affect after a single 90-minute bout of yoga performed by habitual Bikram yoga practitioners was reported in one study but the results were inconclusive because of the absence of a no-treatment control [21]. One well-designed randomized experiment involving a sample of people with multiple sclerosis found that feelings of energy, compared to a resting control condition, were improved after 20-minutes of walking but unchanged after yoga of the same duration [22]. Patients with multiple sclerosis, however, who are characterized by a central nervous system pathology that contributes to pain and mood dysregulation [23], may have atypical mood responses to yoga. Compared to non-exercise control conditions, after a single bout of non-yoga exercise healthy college students repeatedly have reported increases in feelings of energy and reductions in anxiety symptoms [24, 25]. Thus, there is a gap in the literature and the current evidence is unclear whether a single session of yoga produces mood improvements in healthy young adults, and if it does what elements of the yoga experience are necessary for mood benefits.

Randomized trials of yoga training show clinically meaningful pain relief among patients with chronic low back pain [12, 26, 27]. Although chronic back pain is common there are numerous other chronic pain conditions, including neck pain, headaches, arthritis, fibromyalgia, neuropathic pain, residual pain from surgery or injury and visceral pain. The relationship between physical activity and these other types of chronic pain have been examined less frequently than low back pain. There is a need to update our understanding of the influence of exercise on chronic pain viewed from a broader perspective because recent studies point to some common mechanisms which underlie chronic pain regardless of its body location, some of which appear to be related to chronic pain comorbidities such as elevated psychological symptoms [28].

Exercise plausibly could improve chronic pain through repeated acute effects resulting from each exercise session. The effects of a single yoga session on pain sensitivity to objective noxious stimuli rarely has been investigated and is poorly understood. One uncontrolled study of 90 Hatha yoga participants found no change in pain intensity ratings from a standardized pressure stimulus applied to the second toe, middle finger or ear lobes before and after 90 minutes of Hatha yoga even though 67% of the sample expected the yoga session to reduce pain [29]. While expectations for change can influence responses to acute exercise [30], a key limitation of this study beyond the lack of a control condition was that it did not report the perceived painfulness or intensity of the yoga. Low intensity yoga may be performed without pain or may be an insufficient exercise stimulus to produce post-exercise hypoalgesia. In contrast, more challenging and intense yoga styles, such as Vinyasa, often cause transient pain in practitioners and, consequently, may provide greater pain relief post-exercise and may create greater expectations for change [18]. Alternatively, yoga-induced changes in systolic blood pressure may reduce pain sensitivity after yoga given the literature linking systolic blood pressure to pain sensitivity [31-34]. There is a need to better document the painfulness of single bouts of moderate-to-high intensity styles of yoga and the extent to which variables such as changes in systolic blood pressure, pain during yoga and/or expectations for change influence post-exercise hypoalgesia.

Some types of moderate-to-high intensity exercise, such as leg cycling, cause transient pain in the activated muscles [35]. This type of exercise-induced pain is a potential contributor to post-exercise hypoalgesia. Post-exercise hypoalgesia has been documented by reduced sensitivity to noxious stimuli presented after exercise [36]. One well-conducted experiment found that when pain was present during acute cycling exercise, compared to identical exercise in which pain was absent, the magnitude of the post-exercise reduction in pain sensitivity was greater after painful exercise [37]. Whether the presence or absence of pain during an acute yoga session moderates post-yoga pain sensitivity has never been investigated. Studies of hypoalgesia following a single bout of exercise typically have reported a moderate-sized reduction in pain in response to a noxious stimulus applied following moderate-to-high intensity exercise of various types including dynamic cycling, dynamic knee extensions and isometric hand grip [38]. There is a need to learn whether other popular exercise modes, including yoga, induce a post-exercise hypoalgesia. Careful attention to research design is needed because, for example, commonly used pre-test post-test designs could confound the potential effects of yoga *per se* on post-yoga pain sensitivity because of the potential effect of pre-test exposure to a noxious stimulus [39].

Potential mechanisms contributing to post-yoga reductions in pain sensitivity rarely have been tested [40]. One plausible way in which acute yoga could reduce pain sensitivity is by inhibiting the central nociceptive system [41]. Animal and human studies indicate that exercise-induced reductions in central nociceptive system activation occur [42], but whether this is true after a single session of yoga has never been investigated. A recognized method of assessing the central nociceptive system in humans is through conditioned pain modulation (aka, endogenous pain modulation) testing [43]. Conditioned pain modulation involves the presentation of a pain stimulus (i.e., the test stimulus) to the same body location under two conditions. In one condition the test stimulus is presented alone and in the other condition it is presented during the simultaneous presentation of a second noxious stimulus to a different body location [44]. Attenuated pain ratings of the test stimulus when the second noxious stimulus is added is thought to result from central nervous system processes that modulate perceptions of pain. Whether a single session of yoga influences these central nervous system pain modulatory processes has never been examined.

Slow breathing can reduce pain responses to standardized noxious stimuli [45-47]. Historically, explanations for the antinociceptive effects of slow breathing have focused on cognitive variables such as attention and expectations or mood changes such as reductions in anxiety. More recently, plausible neurophysiological contributors to pain relief resulting from yogic breathing, such as increased parasympathetic activity or increased pulmonary afferent input to brain areas involved in voluntary control of breathing (e.g., central amygdala, locus coeruleus), have been investigated [45, 48-50]. A better understanding of the role of the components involved in yoga, such as the effect of slow breathing, might provide information that is ultimately useful for optimizing pain relief and the mood lifting consequences of yoga.

In summary, to address gaps in the research literature this dissertation involves, first, a meta-analytic review (presented in Chapter 3). The review focuses on randomized controlled trials of the influence of yoga training on chronic pain conditions. A key novel feature is combining multiple types of chronic pain into a single analysis which contrasts prior reports that typically have focused on a single pain condition based on body location such as low back pain. Chapter 4 summarizes an experiment that tested the influence of a single bout of yoga on a mechanism by which yoga could relieve pain; namely, desensitization of the central nervous system as assessed from conditioned pain modulation. Moreover, the experiment tested whether slow breathing is, or is not, an important element in pain modulation changes with acute yoga.

Table

Table 2.1
Characteristics of Common Yoga Styles

Style	Description	Assumed Intensity*
Ashtanga	Six series of specific poses taught in order	Low to Vigorous
Bikram	26 poses and two breathing techniques; 90 minutes in heated room (105 °F; 40% humidity)	Vigorous
Hatha	General category that includes most yoga styles; asanas, pranayama and meditation	Low to Moderate
Integrative Yoga Therapy (IYT)	Created specifically for medical/wellness centers; Gentle postures, guided imagery is used for specific health issues	Low
Iyengar	Detail-oriented and alignment based; static in nature, holds postures for longer periods	Low to Moderate
Kundalini	Repeated movements, dynamic breathing, chanting, singing, meditation is incorporated to reduce stress and negative thinking	Moderate
Restorative	Gentle, relaxation and passive based; poses held at least five minutes up to 10	Very Low
Vinyasa	Links breath to movement; flow	Moderate to Vigorous
Yin	Roots from martial arts, slow and gentle style with poses held for five minutes; designed to increase circulation in joints and improve flexibility	Very Low

Note: *Yoga styles are not categorized in the Compendium of Physical Activities [51].

CHAPTER 3

THE EFFECT OF RANDOMIZED, CONTROLLED YOGA TRAINING INTERVENTION TRIALS ON CHRONIC PAIN: A SYSTEMATIC REVIEW AND META-ANALYSIS[1]

[1] Ray L.N. & O'Connor P.J. To be submitted to *Journal of Complementary and Alternative Medicine.*

Abstract

The objective of this meta-analysis is to estimate the population effect size of yoga interventions for reducing pain in randomized trials with samples of people in chronic pain. Electronic database searches were conducted between August and November 2019. Randomized controlled trials comparing yoga training (average duration of 11 weeks) to control conditions with patients in chronic pain were included. Forty-five effects were derived from 12 experiments, with a total of 1680 patients (mean ±SD sample size: 70±30) categorized as having chronic low back pain, chronic neck pain, migraines, cancer-related pain, arthritis, fibromyalgia, neck pain, or neuropathic pain. Thirty-seven of 45 (82%) of the effects were greater than zero. Unweighted Hedge's d effect sizes ranged from -0.93 to 6.46. Compared to non-yoga control conditions (most often usual care), yoga training significantly reduced pain symptoms among those in chronic pain by a large mean effect (Δ) of 1.31 (95%CI: 0.79 to 1.83, Z = 4.92, $p < 0.001$) and improved disability by a moderate mean effect (Δ) of .56 (95%CI: 0.11 to 1.02, Z = 2.41, $p = 0.016$). Short duration yoga training programs appear to be effective in attenuating pain intensity and improving self-reported physical function.

Keywords: Pain, yoga, meta-analysis, pain intensity, disability, quality of life

Introduction

Chronic pain, as defined by the International Association for the Study of Pain, is pain that persists or recurs for more than three months. Chronic pain is common, for instance, a recent study of 33,028 respondents to the 2016 National Health Interview Survey estimated that 20.4% of adults in the United States suffer from chronic pain [52]. Chronic pain is expensive with total annual costs estimated between $560 and 635 billion in 2010 dollars [53]. Chronic pain reduces quality of life, including contributing to worse mental health and greater physical disability [54, 55]. Chronic pain treatments have modest effects [56] and some, such as opioids, have serious risks, including the potential for death from overdose [57]. Thus, there continues to be a need to understand the efficacy of safe, enjoyable and potentially efficacious treatments for chronic pain, such as yoga.

The effect of yoga interventions on chronic pain has been examined most frequently for low back and neck pain. Evidence from randomized controlled trials supports that yoga can reduce neck pain (10 trials, 686 participants, mean effect size of -1.13 [95% CI −1.60, −0.66]) and low back pain (5 trials, 743 participants, mean effect size of -0.623 [95% CI −0.377 to -0.868]) [58, 59]. Smaller bodies of evidence from non-randomized studies suggests that yoga may be useful in relieving other types of chronic pain such as chronic pelvic pain [60].

Advances in understanding of the peripheral and central nervous system processes involved in chronic pain suggest some common neural mechanisms among the different types of chronic pain [61]. For example, diminished activity in neural circuitry involved in descending brain modulation of nociception increasingly is thought to contribute to the chronification of pain [62]. This type of evidence supports the rationale for examining chronic pain conditions together rather than separately; the historically common approach has been to split chronic pain patients into separate categories based on body location (e.g., headache versus back pain). Thus, there is a need for a systematic review that examines the effect of yoga interventions more broadly by combining different types of chronic pain such as arthritis, pelvic and other chronic pain conditions.

The primary purpose of this review and meta-analysis is to estimate the population effect size of randomized, controlled yoga intervention trials for reducing pain in samples suffering from chronic pain. A secondary purpose is to determine if variables of theoretical or practical importance, such as yoga style or training duration, account for variation in the population effect size. A tertiary purpose is to assess whether these yoga programs have favorable effects on measures of physical disability.

Materials and Methods

This systematic review and meta-regression analysis was conducted in a manner consistent with guidelines set forth in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [63].

Data Sources and Searches. Electronic database searches were conducted between August and November 2019. Articles were obtained from ERIC, CINHAHL, MEDLINE, PsycINFO, Web of Knowledge, Science Direct, Google Scholar and SPORTDiscus with full text data bases. We used combinations of the keywords: *yoga and pain* or "chronic pain" or "back pain" or "low back pain" or "fibromyalgia" or "neck pain" or "arthritis" or "migraine" or "surgical pain" and "random*" or "randomized controlled trial*" or "RCT."* Supplemental searches of the retrieved articles and those supplied by colleagues were performed manually.

Study Selection. Inclusion criteria included: (1) randomized controlled trials, (2) published in a peer-reviewed journal, (3) full text article in English, (4) yoga training as a treatment for a pain condition, (5) adults (>17.99 and <66.00 years), (6) pain for three months or greater, (7) a reported outcome measure of pain, and (8) sufficient data reported to calculate an effect size.

Exclusion criteria includes: (1) no clear definition of the pain as chronic, (2) no definition of the yoga training, (3) non-randomized trials, (4) sample mean age under 18 or greater than 65 years, (5) no pain outcome, (6) studies with non-chronic pain conditions, (7) studies with residential/intensive yoga training and (8) studies that compared yoga training only to a different intervention or an intervention that contained multiple therapeutic components. A flow chart showing the process of article identification, retrieval and review is presented in Figure 3.1.

[Figure 3.1 about here.]

Data Extraction and Quality Assessments

Study Characteristics. Forty-five effects were derived from 12 studies. Characteristics of the 12 studies are provided in Table 3.1. Seventy-five percent of the studies involved patients with chronic low back pain; 16.7% of the studies involved patients with chronic neck pain; and 8.3% of the studies involved a sample that combined individuals with various chronic pain conditions (e.g. migraine, cancer-related pain, arthritis, cervical neck pain). The mean percentage of females for the intervention and control groups was 67.9% and 69.9%, respectively. The average yoga training program duration was 11 weeks. The frequency of yoga sessions averaged two per week. The mean (and standard deviation) session duration was 71 (18) minutes. The most common yoga styles were Iyengar (41.7%) and Hatha (25%) [64]. Two studies (16.7%) used a combination of yoga styles. One study (8.3%) used Restorative Exercise and Strength Training for Operational Resilience and Excellence (RESTORE). This program used guidelines from the National Institutes of Health Task Force on Research Standards for

Chronic Low Back Pain and one-on-one yoga instructors with patients [65]. One study (8.3%) did not specify the type of yoga used in the treatment condition.

[Table 3.1 about here.]

Study Quality Assessment. Study quality information was extracted on several variables including: participant characteristics, design, randomization, interventions, blinding, control conditions, methods, assessments, outcomes, analysis and results. Data on study quality was assessed by the author using an established method [66].

Effect Size Calculation

Effect sizes were based on the difference between group means, standardized using the standard deviation of the control group. The pooled variance estimate was used to standardize the difference between group means [67]. All applicable outcome statistics were extracted and transformed into standardized mean differences (SMD) and their standard errors (SE) using standard formulas [68]. A SMD < 0 indicated superiority of yoga treatment compared with control. SMDs < .5 were judged as clinically relevant, and SMDs < .8 were considered large. Effect sizes were adjusted for small sample bias [68]. When exact means and standard deviations were not provided (n = 3), those studies were excluded from the analysis [69-71].

Potential Moderators. Data reported in the analyzed studies allowed for a consideration of the following eight potential moderator variables. The primary moderator, selected *a priori*, was chronic pain condition (e.g., back pain, neck pain, etc.). This was selected because of the historical focus on categorizing chronic pain patients into separate groups based on pain location. Secondary moderators included: stimulus-related (yoga type, program duration in weeks, session duration in minutes), participant-related (prior yoga exposure), design-related (type of comparison condition) and measurement-related (pain measure, disability measure). Moderator levels are provided in Table 3.2.

[Table 3.2 about here.]

Data Synthesis and Analysis

Meta-analysis was performed using macros (SPSS MeanES, MetaReg; SPSS, Inc.) [72]. We used random effects models to calculate the mean effect size delta (Δ) and to test variation in effects according to moderator variables. Heterogeneity was indicated if Q_{Total} reached a significance level of $p<.05$ and the sampling error accounted for less than 75% of the observed variance. Heterogeneity was also assessed between studies and quantified by using the I^2 statistics. $I^2>25\%$, $I^2>50\%$, and $I^2>75\%$ were regarded to indicate moderate, large, and extensive heterogeneity, respectively [73], A *p-value* greater than or equal to 0.10 was used to indicate significant heterogeneity [73]. The number of unpublished studies of null effect that would weaken the significance of observed effects to $p>.05$ was estimated as fail-safe *N* [74]. Weight was calculated by using a standard formula of the inverse of the variance. Funnel plot asymmetry was assessed by Egger's test [75]. Multiple linear regression was conducted using maximum likelihood estimations to test the significance of the moderators. Follow-up analysis was used to test for interactions between significant primary moderators.

Results

For the pain intensity outcome, 18 of 24 (75%) were greater than zero. For the disability outcome, 17 of 21 (81%) effects were greater than zero. A forest plot of the unweighted distribution of effects for the pain intensity and disability outcomes are presented in Figures 3.2 and 3.3, respectively.

Pain Intensity**.** The mean effect size Δ for pain intensity was large and equal to 1.31 (95% CI 0.79-1.83; $z = 4.92$; $p < .001$). This significant improvement in pain intensity after yoga interventions was heterogeneous (Q_{23}= 489.31; $p < .001$; I^2=95.2%), with 79.2% of the variance explained by one moderator – prior yoga exposure. The fail-safe number of effects was 2886, and examination of a funnel plot revealed an absence of publication bias (Figure 3.4).

[Figure 3.4 about here.]

Disability**.** The mean effect size Δ for disability was 0.56 (95% CI 0.11-1.02; $z = 2.41$; $p = .016$). The significant improvement in disability scores after yoga intervention was heterogeneous (Q_{20}= 384.74; $p < .001$; I^2=94.8%), with 52.7% of the variance explained by two moderators – prior yoga exposure and yoga session duration. The fail-safe number of effects was 541, and examination of a funnel plot revealed an absence of publication bias see Figure 3.5.

[Figure 3.5 about here.]

Moderator Analysis

The overall regression model for pain intensity was significant (R^2= .55; p <.001). Table 3.3 provides information on the standardized regression coefficients (β) and associated *p-values.* Prior Yoga Exposure (β = -.789; Z = -2.542; $p = .011$) variable accounted for significant variation in the overall effect of yoga on changes in pain intensity.

[Table 3.3 about here.]

The overall regression model for disability ratings was significant (R^2= .58; p <.001). The variables of Prior Yoga Exposure (β = -.6808; Z = -4.250; p <.001) and Yoga Session Duration (β = .418; Z = 2.387; $p = .017$) accounted for significant variation in the overall effect of yoga on disability score. Table 3.4 provides information on the standardized regression coefficients (β) and associated *p-values.*

[Table 3.4 about here.]

Discussion

The primary aim of this review was to estimate the population effect size of yoga interventions for reducing pain in randomized trials with samples of people in chronic pain. This meta-analysis found evidence that short-duration yoga training, mean of 11 weeks and a range of 4 to 24 weeks, reduces pain intensity to a large degree. In comparison to the non-yoga conditions employed, most frequently usual care, the evidence supports that yoga training reduces pain intensity by a large, clinically meaningful standardized effect size ranging between .79 and 1.83. This effect of yoga training on reducing chronic pain intensity overlaps with the range of magnitudes of pain relief reported in other recent meta analyses of yoga training with fewer trials than analyzed here and performed by patients suffering from back [58], neck [59], headache [76], pelvic [60], menstrual [77] and osteoarthritic [78] pain.

Given that the present analysis included multiple types of chronic pain conditions, it is perhaps not surprising that there was substantial heterogeneity. Indeed, a secondary purpose of this review was to determine if variables of theoretical or practical importance accounted for variation in the population effect size. Variation in the degree of prior yoga experience accounted for a significant portion of the heterogeneity of effect sizes related to the pain intensity outcome. For several, reasons it is plausible for yoga experience to moderate the effects of yoga training. A very large mean effect size for pain reduction (3.96) was found based on the 16.7% of effects from samples who reported participating in yoga during the past 6 months. The smallest mean effect size for pain reduction (0.46) was found based on the 20.8% of effects from samples reporting no prior participation in yoga. Mean effects between these extremes were found for those samples who had performed yoga more than six months prior to the intervention and samples from those studies that did not report prior yoga experience. While prior yoga experience is related to willingness to participate in future yoga classes [79], prior yoga experience appears to have been typically used as either an inclusion or exclusion criteria in prior yoga research studies. Most prior studies of yoga and pain have failed to consider or analyze prior yoga experience as a potential moderator of the effect of the intervention on pain. One investigation of group yoga training among pediatric patients with chronic pain reported that pain relief and other benefits of yoga are realized regardless of prior yoga experience. However, the results are uncertain because the study was neither controlled nor randomized [80]. One implication of the present finding is that the effect of yoga training on pain relief may be underestimated by the currently available research that appears to have often excluded participants if they had prior yoga experience. Although the potential mechanisms by which yoga experience could influence chronic pain are uncertain, it plausibly could relate to adherence to training, which was inadequately reported in the studies analyzed here, or to other aspects of the exercise exposure. For example, experienced yoga participants may be more able to hold poses longer, increasing the actual exercise duration within each session, or may be able to hold poses in a way that contributes to a higher exercise intensity and/or pain during the poses. Repeated exposure to acute pain could contribute to neural adaptations in the brain circuits involved in descending pain modulation. This, and other potential mechanisms related to yoga experience, such as novelty, are both poorly understood and understudied [81, 82].

Adherence could have been higher among those who participated in yoga during the prior 6 months and that could have led to greater pain relief given the evidence that past year yoga experience is associated with better adherence to yoga training among cancer survivors [83]. Pain and beliefs about pain are known to be associated with poor adherence to exercise programs, including yoga [84-86]. Evidence from a nationally representative survey of 34,525 US adults found that individuals who performed yoga in the past 12 months were more likely to be young, female, non-Hispanic white, college educated, higher income, living in the Western U.S. and had better health status [2]. The present analysis was unable to include these variables as moderators because they were inadequately reported. The present findings highlight the need for these potential moderators and adherence to be reported fully and better considered in future yoga studies.

A tertiary purpose of this review was to assess whether these yoga programs have favorable effects on measures of physical disability. This meta-analysis found evidence that short-duration yoga training improves improved disability/physical function to a clinically meaningful moderate degree. In comparison to the non-yoga conditions employed, most frequently usual care, the evidence supported that yoga training improves disability/physical function by a standardized effect size ranging between .11 and 1.02. This effect of yoga training on improving physical function overlaps with the range of magnitudes reported in other recent meta analyses of yoga training with fewer trials than analyzed here and performed by older adults [87], who are often experiencing pain, and those suffering from neck [58, 59, 76], menstrual [60, 77] and osteoarthritic [78] pain.

Prior yoga exposure and yoga session duration were significant moderators of the effect of yoga on physical disability. A large mean effect size for improvement in disability (1.864) was found based on the 19% of effects from samples who reported participating in yoga during the 6 months immediately prior to the intervention. Most of the other effects (57%) stemmed from samples who reported participating in yoga more than 6 months prior to the intervention and the mean effect size for these was small (.157). As stated above regarding the pain intensity findings, there are several plausible explanations for the larger effect size among those samples with recent yoga experience including the greater adherence or skill with which yoga poses were held. Yoga session durations 60 minutes or greater were associated with a larger effect on improvements in disability scores compared to session durations less than 60 minutes (ES of .307 versus .234). The dosage of yoga has been suggested as a critical variable that could influence health outcomes [88], but to date there appear to be no experiments that have tested the impact of different yoga doses on chronic pain relief.

It is well documented that chronic pain is multifaceted and difficult to manage. A strength of this meta-analysis is that is incorporates varying pain conditions. This allowed us to build on the existent literature of the effectiveness of yoga training in pain responses and disability [12]. This bolsters the generalizability interpreting the findings, that would not be possible in studies examining one type of pain condition.

Limitations

One limitation to this review is the small number of peer reviewed RCTs that were eligible to be included in the meta-analysis. Consequently, publication bias could occur. Heterogeneity observed is likely due to the varying pain conditions. While some aspects of the differing chronic pain are similar, pain is complex and therefore each condition also likely has unique aspects. Not explored here, but additional heterogeneity may occur from an array of methodological differences, such as demographic characteristics of the study participants, the presence and absence of comorbid conditions, and variation in the methodological rigor with which the RCT was conducted. Additionally, due to the limits in how the studies were reported, our analysis did not assess methodological attributes such as blinding, intent-to-treat, quality of study as potential moderators to determine their effects of yoga. Often, studies do not provide adequately detailed descriptions of these aspects, resulting in appearance of low quality studies [89] and making it difficult to make a thorough evaluation of the research.

Based on the statistically significant moderate-to-large effect sizes found in the present analysis, studies with larger sample sizes are warranted as are those with rigorous methodology and reporting. For example, additional details about of intervention including the environment (lighting, sounds, flooring, others present, time of day) and all the yoga components including measures of intensity indexed from heart rate or perceived exertion ratings. Consideration is needed in the future to achieve allocation concealment and blinding of at least the outcome assessors [90]. Moreover, comparisons of yoga to satisfactorily matched therapies is needed as is comparisons of different yoga styles.

Conclusions

This review found short-term yoga training among randomized controlled trial participants suffering from chronic pain results in a large reduction in pain and a moderate improvement in disability scores. The effect of yoga training on pain reductions was larger among those who had practiced yoga in the prior six months and smaller among those without yoga experience. Yoga experience similarly moderated disability scores and greater improvements in disability were associated with yoga sessions that were longer than 60 minutes.

Acknowledgements

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Author Disclosure Statement

No competing financial interests exist.

Tables

Table 3.1
Characteristics of included studies

Study	N	Pain Condition	Intervention, weeks duration	Control	Prior Yoga Exposure	Outcome Measures
Saper et al. (2009)[91]	30	CLBP	Hatha 12 weeks	Wait List	Greater than 6 months	NRS RMDQ*
Groessl et al. (2017)[92]	150	CLBP	Hatha 12 weeks	Wait List	Greater than 6 months	BPI RMDQ*
Williams et al. (2009)[93]	90	CLBP	Iyengar 24 weeks	Usual Care	Within 6 months	ODI* VAS
Highland et al. (2018)[94]	68	CLBP	RESTORE 8 weeks	Usual Care	Greater than 6 months	NRS RMDQ*
Cramer et al. (2013)[95]	51	CNP	Iyengar 9 weeks	S/S & JME	Within 6 months	VAS NDI*
Demirel et al. (2019)[96]	80	CLBP	Yoga† 6 weeks	Core Exercises	Not Reported	VAS ODI*
Kuvacic et al. (2018)[97]	30	CLBP	Combination of Yoga Styles 8 weeks	Education	None	ODI* NRS
Michalsen et al, (2012)[98]	77	CNP	Iyengar 9 weeks	S/S & JME	None	VAS NDI*
Monro et al. (2015)[99]	61	CLBP with sciatica	Yoga Therapy 12 weeks	Usual Care	Not Reported	RMDQ* ABPS ICS
Nambi et al. (2014)[100]	60	CLBP	Iyengar 4 weeks	S/S & JME	Not Reported	VAS
Schmid et al. (2019)[101]	83	Any Type of Chronic Pain Condition	Hatha 8 weeks	Usual Care	Greater than 6 months	BPI-S BPI-I*
Williams et al. 2005[102]	60	CLBP	Iyengar 16 weeks	Education	None	PDI* PPI VAS

Note: ABPS, Aberdeen Back Pain Scale; BPI, Brief Pain Inventory; BPI-I, Brief Pain Inventory-Inference; BPI-S, Brief Pain Inventory-Severity; CLBP, Chronic Low Back Pain; CNP, Chronic Neck Pain; NDI, Neck Disability Index; NPDQ, Neck Pain and Disability Questionnaire; NRS, Numeric Rating Scale; ODI, Oswestry Disability Index; PDI, Pain Disability Index; PPI, Present Pain Intensity; RESTORE, Restorative Exercise and Strength Training for Operational Resilience and Excellence; RMDQ, Roland and Morris Disability Questionnaire; VAS, Visual Analogue Scale; Strengthening / Stretching and Joint Mobility Exercise; S/S & JME; Intensity Category Scale (3 categories: none/mild, moderate, severe/intolerable); ICS

* Disability Measure

† Undefined Yoga Intervention Type

Table 3.2
Definitions for Moderators

Moderator	Levels
Type of Chronic Pain	**Low Back Pain** **Neck Pain** **Combination of other types** (osteoarthritis; migraines)
Yoga Session Duration	**31 to 60 minutes**: sessions lasted 31-60 minutes **≥ 61 minutes**: sessions lasted 61 minutes or more
Yoga Program Length	**4 to 6 weeks**: yoga training of 4 to 6 weeks **7 to 11 weeks**: yoga training of 7 to 11 weeks **≥12 weeks**: yoga training of greater than or equal to 12 weeks
Yoga Type	**Undefined:** no description of yoga intervention **Hatha:** gentle yoga **Iyengar:** focus on technical alignment **Other:** combination of yoga types
Prior Yoga Exposure	**None**: patients had never practiced yoga before **Greater than 6 months**: patients had practiced yoga before, but it was greater than 6 months prior to study start **Within 6 months**: patients had practiced yoga within the last six months of the study start **Not Reported:** not reported in data
Type of Comparison Condition	**Exercise** **Waitlist** **Usual Care** **Education**
Disability Measure	**Roland and Morris Disability Questionnaire (RMDQ)** **Oswestry Disability Index (ODI)** **Neck Disability Index (NDI)** **Brief Pain Inventory-Inference (BPI-I)** **Pain Disability Index (PDI)**
Pain Measure	**Numeric Rating Scale (NRS)** **Visual Analogue Scale (VAS)** **Brief Pain Inventory-Severity (BPI-S)** **Aberdeen Back Pain Scale (ABPS)** **Present Pain Intensity (PPI)**

Table 3.3
Standardized Regression Coefficients for Moderators; Pain

Hypothesized Effect Moderator	Standardized Regression Coefficients (β)	p-value
Prior Yoga Exposure	-0.789	0.011*
Pain Measure	-0.456	0.082
Yoga Type	0.493	0.164
Chronic Pain Condition	-0.762	0.233
Yoga Session Duration	0.355	0.270
Program Length	-0.146	0.754
Comparison Type	0.066	0.836

Note: * $p \leq .05$

Table 3.4

Standardized Regression Coefficients for Moderators; Disability

Hypothesized Effect Moderator	Standardized Regression Coefficients (β)	p-value
Prior Yoga Exposure	-0.681	<0.001*
Yoga Session Duration	0.418	0.017*
Yoga Type	0.239	0.255
Comparison Type	0.253	0.275
Disability Measure	0.166	0.416
Chronic Pain Condition	0.072	0.641
Program Length	0.166	0.658

Note: * $p \leq .05$

Table 3.5
Summary of Univariate Moderator Analysis: Pain

Effect Moderator	Contrast Weights	Effects, k	Δ	95% CI	Contrast *p-value*
Primary					
Chronic Pain Condition					
Low Back Pain	-1	20	1.491	.645 to 2.336	.023*
Neck Pain	1/2	3	.767	-1.265 to 2.798	
Other	1/2	1	-.145	†	
Secondary					
Yoga Session Duration					
31 to 60 minutes	-1	12	.964	.268 to 1.660	.301
>61 minutes	1	12	1.701	.338 to 3.062	
Program Length					
4 to 6 weeks	-1	3	1.414	-.865 to 3.693	
7 to 11 weeks	0	8	1.445	.787 to 2.109	.838
>12 weeks	1	13	1.242	-.118 to 2.601	
Yoga Type					
Undefined	-1/2	1	.403	†	
Hatha	1/2	6	.057	-.500 to .615	
Iyengar	1/2	11	2.000	.560 to 3.440	.880
Other	-1/2	6	1.536	.611 to 2.053	
Prior Yoga Exposure					
Within 6 months	-1/2	4	3.960	.060 to 7.860	
None	1/2	5	.465	-.017 to .947	.048*
Greater than 6 months	1/2	11	.873	.166 to 1.581	
Not Reported	-1/2	4	1.050	-.613 to 2.712	
Comparison Type					
Exercise	1/2	5	1.342	.519 to 2.164	
Waitlist	-1/2	5	.098	-.627 to .822	.405
Usual Care	-1/2	9	2.480	.759 to 4.201	
Education	1/2	5	.491	-.059 to 1.040	
Pain Measure					
Numeric Rating Scale	-1/2	8	1.453	.797 to 2.108	.001*
Visual Analogue Scale	-1/2	9	2.241	.466 to 4.016	

Brief Pain Inventory-Severity	1/2	4	-.164	-.338 to .010
Present Pain Intensity	0	2	.436	-.170 to 1.043
Aberdeen Back Pain Scale	1/2	1	-.044	†

Note: * $p \leq .05$; † Not Calculatable

Table 3.6
Summary of Univariate Moderator Analysis: Disability

Effect Moderator	Contrast Weights	Effects, k	Δ	95% CI	Contrast *p-value*
Primary					
Chronic Pain Condition					
Low Back Pain	-1	17	.275	.239 to .310	.797
Neck Pain	1/2	3	.257	.168 to .347	
Others	1/2	1	.281	†	
Secondary					
Yoga Session Duration					
31 to 60 minutes	-1	10	.234	.211 to .257	.005*
>61 minutes	1	11	.307	.263 to .352	
Program Length					
4 to 6 weeks	-1	1	.229	†	.061
7 to 11 weeks	0	9	.268	.236 to .301	
>12 weeks	1	21	.280	.226 to .333	
Yoga Type					
Undefined	-1/2	1	-.216	†	.249
Hatha	1/2	5	.022	-.588 to .631	
Iyengar	1/2	9	.913	-.032 to 1.859	
Other	-1/2	6	.583	.443 to .723	
Prior Yoga Exposure					
Within 6 months	-1/2	4	1.864	.262 to 3.465	.132
None	1/2	3	.627	-.299 to 1.553	
Greater than 6 months	1/2	12	.157	-.209 to .523	
Not Reported	-1/2	2	.196	-5.039 to 5. 431	
Comparison Type					
Exercise	1/2	4	.250	.198 to .302	.555
Waitlist	-1/2	5	.279	.129 to .428	
Usual Care	-1/2	9	.261	.242 to .280	
Education	1/2	3	.327	.238 to .416	
Disability Measure					
Roland and Morris Disability Questionnaire	-1/2	10	.265	.206 to .323	.866

Oswestry Disability Index	-1/2	5	.281	.207 to .356
Neck Disability Index	1/2	3	.257	.168 to .347
Pain Disability Index	0	2	.306	.268 to .344
Brief Pain Inventory-Inference	1/2	1	.281	†

Note: * $p \leq .05$; † Not Calculatable

Figures

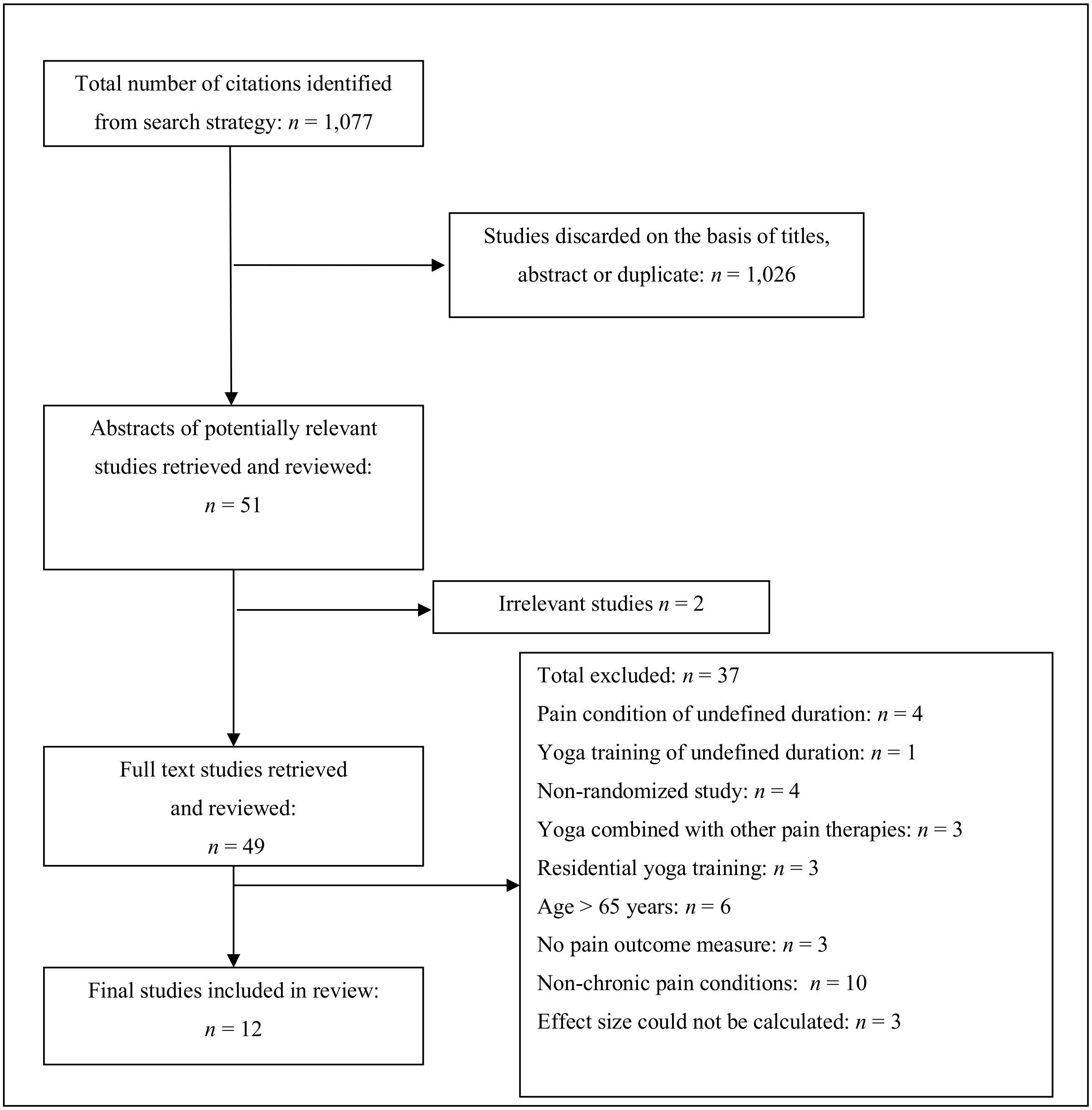

Figure 3.1. Flow chart showing the process of article identification, retrieval and review

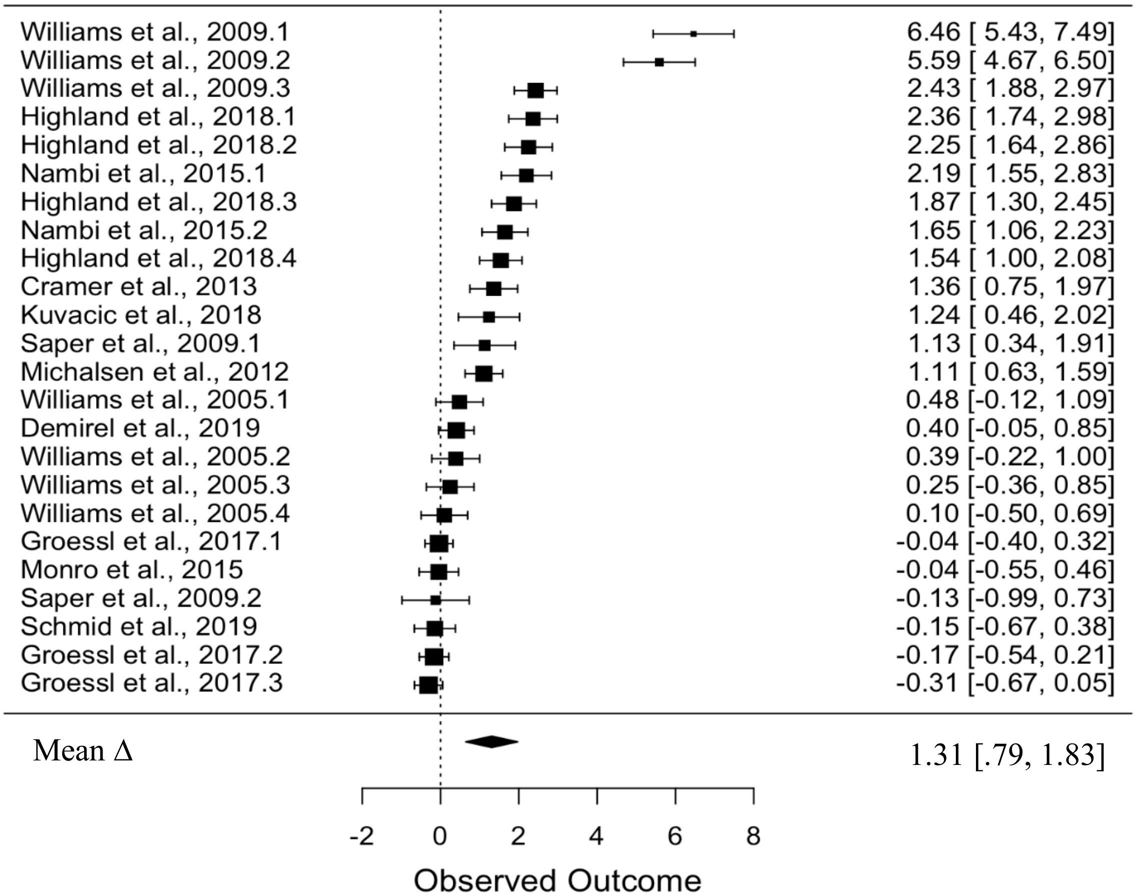

Figure 3.2. Forest plot of pain intensity effect sizes

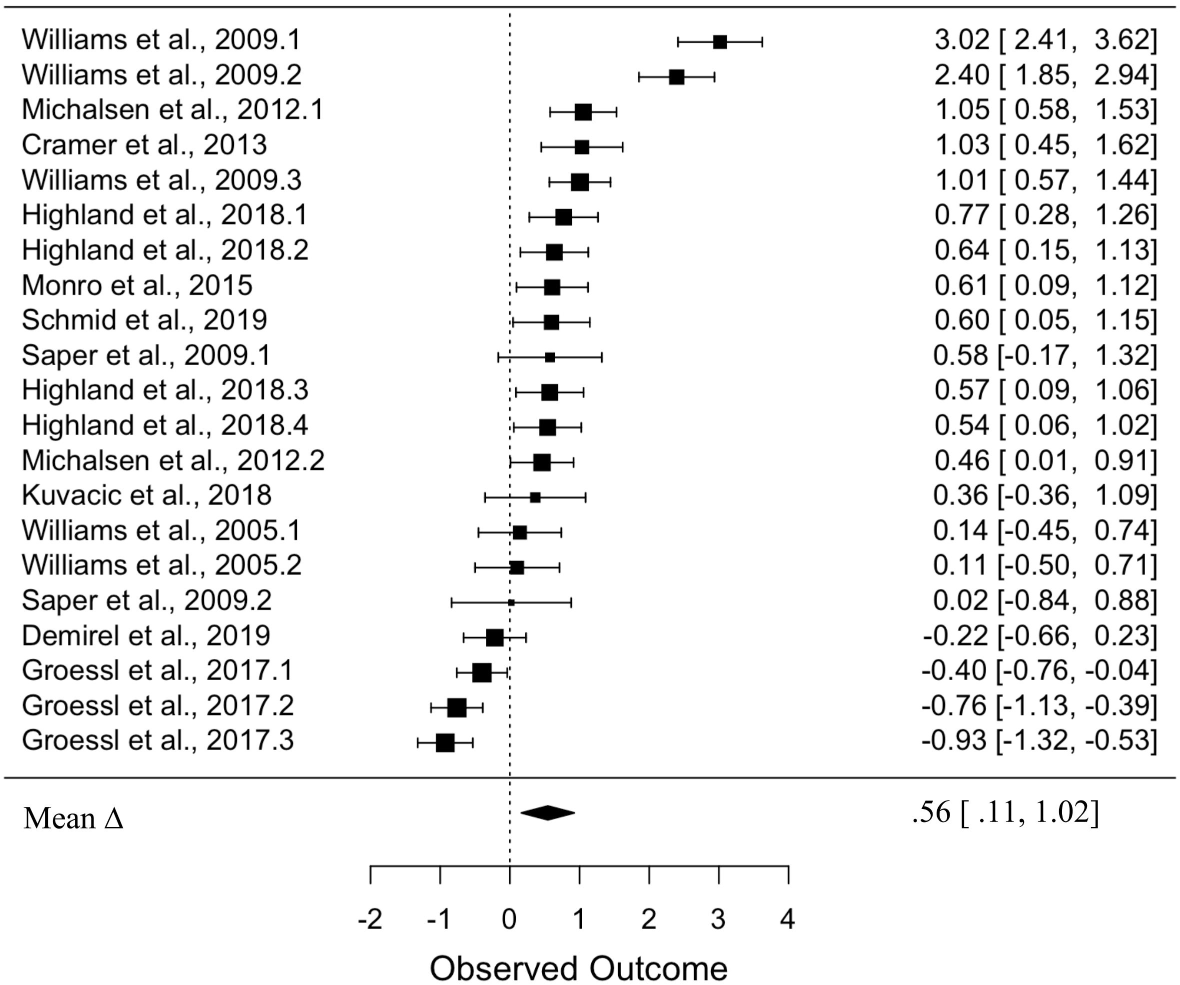

Figure 3.3. Forest plot of disability effect sizes.

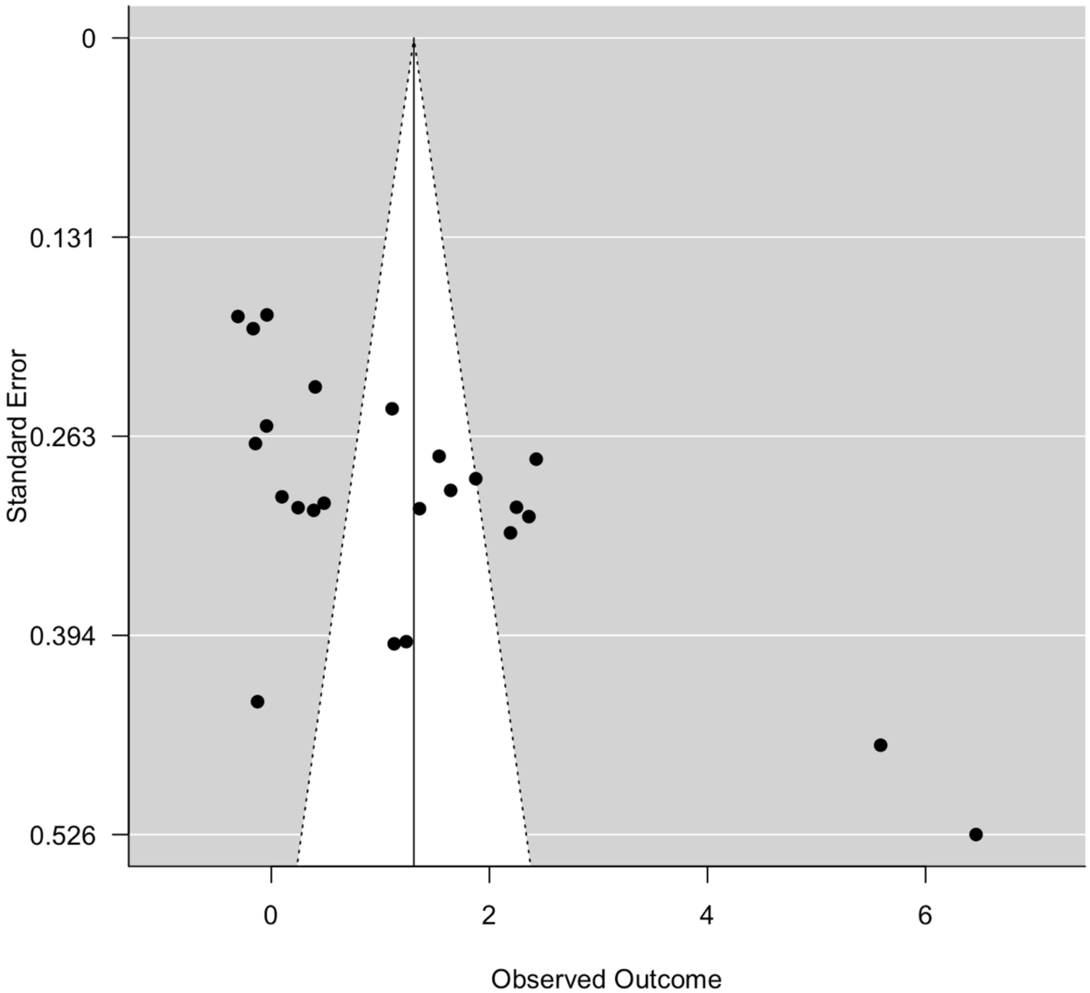

Figure 3.4. Funnel plot of pain intensity effects.

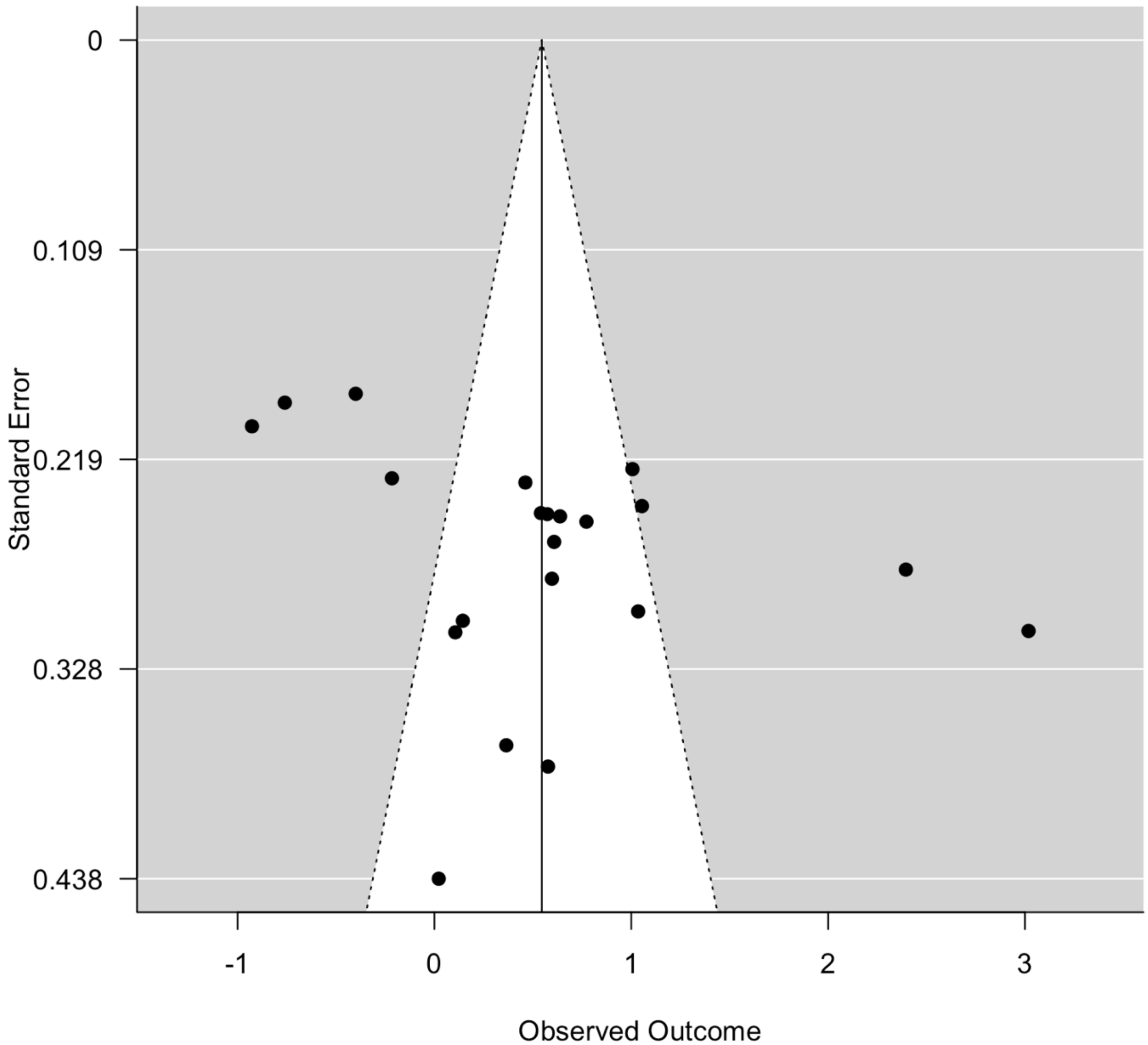

Figure 3.5. Funnel plot of disability effects.

CHAPTER 4

THE EFFECT OF A SINGLE SESSION OF YOGA POSTURES, WITH AND WITHOUT SLOW BREATHING, ON ACUTE PAIN SENSITIVITY, ENDOGENOUS PAIN MODULATION AND STATE ANXIETY[2]

[2] Ray L.N. & O'Connor P.J. To be submitted to *Complementary Therapies in Medicine.*

Abstract

Yoga is an increasingly popular mode of exercise, especially among women, that boasts health promoting effects. Regular yoga improves pain among patients with low back pain but the effect of a single session of yoga on pain and endogenous pain modulation is poorly understood. The aim of this study was to test, using a post-test only between-subjects design, main and interactive effects of yoga and slow breathing on both sensitivity to heat pain and endogenous pain modulation in healthy young women.

Fifty-four women were randomized into one of four 40-minute conditions: yoga with slow breathing instructions (Vinyasa), yoga with no breathing instructions, seated rest with slow breathing instructions and seated rest with no breathing instructions. The conditions were completed alone is a small room in which participants followed video-based instructions and models. The yoga was perceived as low-to-moderate intensity. Two factor ANOVA showed that yoga postures and slow breathing, and their interaction were statistically insignificant for both sensitivity to heat pain and endogenous pain modulation. These findings were unchanged in ANCOVAs that controlled for four potential confounding variables: post-condition reduction in systolic blood pressure or state anxiety, pain induced by the conditions and expectations. Compared to the non-yoga conditions, the yoga conditions resulted in a significant reduction in state anxiety scores.

It is concluded that 40-minutes of low-to-moderate intensity yoga with, or without slow breathing, reduces state anxiety but has no effect on heat pain sensitivity or endogenous pain modulation. The findings support the idea that higher intensity yoga which produces moderate intensity pain may be necessary to alter heat pain sensitivity and endogenous pain modulation.

Keywords: Endogenous pain, yoga, anxiety, slow breathing, conditioned pain modulation (CPM)

Introduction

One cross-sectional study of 34,525 adults in the United States found that yoga was practiced most commonly to enhance general wellness and disease prevention (78%), improve the mood of energy (66%), support immune function (50%) and treat back pain (20%) [2]. Evidence supports that yoga training typically reduces ratings of pain among samples suffering from a variety of chronic pain conditions [7, 103].

Much less research has examined the extent to which a single session of yoga influences pain ratings or processes, or which features of yoga might be critical to producing pain relief. Some people who perform yoga have high expectations for it to produce pain relief [29] and expectations *per se* can have powerful effects on pain and related behaviors [104]. Yoga is more complex than many physical activities and, generically, it is a type of exercise that involves a series of postures performed with a mindset of focusing on the current moment (mindfulness) while breathing deeply and slowly. Pain relief can be realized solely from mindfulness [105], slow breathing [106] or other types of exercise that exclude mindfulness and slow breathing such as treadmill running and cycling [38]. Moreover, the psychophysiological consequences of a single session of yoga may have contrasting effects on pain. Anxiety can exacerbate [107], while elevated systolic blood pressure can reduce [108], sensitivity to pain. A single session of yoga could increase pain sensitivity by lowering systolic blood pressure [4-6] or reducing pain sensitivity by reducing anxiety symptoms [24, 109, 110].

Whether the presence or absence of pain during an acute yoga session moderates post-yoga pain sensitivity has never been investigated. Studies of hypoalgesia following a single bout of exercise typically have reported a moderate-sized reduction in pain in response to a noxious stimulus applied following moderate-to-high intensity exercise of various types including dynamic cycling, treadmill running, dynamic knee extensions and isometric hand grip [38]. There is a need to learn whether other popular exercise modes, including yoga, induce a post-exercise hypoalgesia.

This experiment summarized here focused on examining the influence of two yoga elements: postures and breathing frequency. One plausible way the yoga postures could reduce pain sensitivity is by inhibiting the central nociceptive system [41]. Animal and human studies indicate that exercise-induced reductions in central nociceptive system activation in the post-exercise recovery period occur [42], but whether this is true after a single session of yoga has never been investigated. A recognized method of assessing the central nociceptive system in humans is through conditioned (aka, endogenous) pain modulation testing [43].

Slow breathing also can reduce pain responses to standardized noxious stimuli [45-47]. Historically, explanations for the antinociceptive effects of slow breathing have focused on cognitive variables such as attention to breathing and expectations about slow breathing or mood changes such as reductions in anxiety in response to slow breathing [106, 111]. More recently, plausible neurophysiological contributors to pain relief resulting from yogic breathing, such as increased parasympathetic activity or increased pulmonary afferent input to brain areas involved in voluntary control of breathing (e.g., central amygdala, locus coeruleus), have been investigated [45, 48, 50, 112]. A better understanding of how the overall experience of yoga reduces pain will require research that dissects the role of various yoga components, such as the effect of slow breathing.

The purpose of the experiment summarized here was to examine, using a post-test only between subjects design, the effect of a single session of yoga postures, in one group without slow breathing and in a different group with slow breathing (aka, standard Vinyasa yoga which combines postures + slow breathing), on heat pain sensitivity and endogenous pain modulation in a sample of young women. A post-test only design was used to avoid the potential artifact resulting from pre-test exposure to noxious stimuli as has been demonstrated [39]. It was hypothesized, compared to a control condition involving both seated rest and normal breathing, and statistically controlling for four potential confounding variables (i.e., expectations, systolic blood pressure, state anxiety and pain induced by the conditions), that:

(H1) exposure to 40 minutes of yoga postures, regardless of the breathing condition, would result in reductions in heat pain sensitivity and greater endogenous pain modulation (i.e., there would be a main effect of yoga postures)

(H2) exposure to 40 minutes of slow breathing, regardless of whether yoga postures were completed, would result in reductions in heat pain sensitivity and greater endogenous pain modulation (i.e., there would be a main effect of slow breathing)

(H3) there would be an interaction between yoga posture performance and the slow breathing conditions such that the largest reduction in pain sensitivity and endogenous pain modulation would result for those who breath slowly while performing yoga postures (i.e., those who perform Vinyasa style yoga).

Research Design and Methods

Experimental Design. The experimental design was a randomized, post-test only between subjects experiment with the two factors of slow breathing and yoga postures. Compared to a single 40-minute session of seated rest with normal breathing (Group A), the main and interactive effects were tested based comparisons with participants assigned to seated rest and slow breathing (Group B), yoga postures and normal breathing (Group C) and yoga postures with slow breathing (i.e., Vinyasa yoga) (Group D). The two primary outcomes were heat pain sensitivity (pain ratings to a heat stimulus to one limb) and endogenous pain modulation (change in pain rating to the heat when a cold stimulus was simultaneously applied to a different limb). Systolic blood pressure, state anxiety, pain caused by the conditions and expectations for change in pain, all potential confounding variables, were included as covariates in the analysis. State anxiety and pain ratings in response to noxious stimuli were assessed after each condition. The treatment order was blocked randomized in a plan to have a total of 64 participants assigned to each of the four groups (16 per group).

Sample Size and Statistical Power. Statistical power was calculated based on prior reliability data for conditioned pain modulation using women tested on the same equipment in the same laboratory room that was used in this experiment [113]. Power was calculated for the expected interaction effect of yoga postures and slow breathing on changes in pain intensity during conditioned pain modulation testing. A power analysis showed that a total sample of 64 participants (16 per group) would provide statistical power of 0.80 to detect a moderate sized interaction effect (f=.25) assuming a two-tailed α value of 0.05 [114]. While 64 participants were recruited and scheduled to participate, 10 were unable to be tested because of the COVID-19 pandemic. Thus, 54 women completed the study.

Participants. Inclusion criteria were women aged 18-35. Exclusion criteria included: (i) contraindications to exercise; (ii) BMI < 18 or BMI >35; (iii) any regular use of prescription medication except oral contraceptives; (iv) current known pregnancy; (v) elevated blood pressure (systolic greater than 120 and diastolic greater than 80); (vi) any cardiac or pulmonary conditions; (vii) circulatory problems (such as Reynaud's Syndrome, blood clots, or peripheral artery disease); (viii) muscular, vascular, or nerve disease; (ix) chronic use of nonprescription pain medications, cold medications or decongestants; (x) a history of hives brought on by exposure to cold; (xi) a history of hives brought on by exposure to heat or (xii) a history of vasculitis. Participants received up to $20 compensation for their completion of the laboratory testing. Payment was in the form of gift cards in which study volunteers received two five-dollar gift cards for each day of participation. A summary of the participant recruitment is provided in Figure 4.1.

Deception. Incomplete disclosure was made about both the study design and the primary outcome. The participants were not told that the study was designed to examine the effects of slow breathing during yoga. The participants also were not told explicitly that the primary outcome concerned whether acute yoga influences changes in pain intensity rating in response to standardized noxious stimuli. Participants' full knowledge of the study design could have influenced the fidelity of the independent variable or confounded the accuracy of the primary outcome measure. For example, if a participant read that the study title was the effects of breathing rate during yoga on pain intensity then she might have tried to control her breathing during yoga in the condition that did not involve slow/controlled breathing. Or she might have tried to "help" by rating a noxious stimulus as less painful after yoga in which slow breathing was emphasized.

On the final day of the study, a Post-Participation Questionnaire asked what participants thought was the purpose of the experiment. After they completed the questionnaire, the researcher explained the true purpose and ask if the participant has any further questions. Then, the participant had the opportunity to request that her data not be used in light of having learned the true purpose of the study. None of the participants elected to not have her data used.

Recruitment. Individuals self-select for possible participation based on information about the study presented in flyers, in person via word of mouth, brief in-class announcements with instructor permission, and emails to selected listservs that targeted university students. Those interested completed an online Qualtrics questionnaire and the inclusion and exclusion criteria was applied to the responses.

Procedures

Online Screening. Potential participants were accessed via Qualtrics online from any device of their choosing. The screening questions requested the name and email address for contact to schedule lab visits based on meeting eligibility criteria. The screening questions asked about age, gender, height, weight, prescription medication use, usual sleep duration and pain history. Additional questions were from the Physical Activity Readiness Questionnaire (PAR-Q).

Baseline: Day 1. Participants reported to the Exercise Psychology Laboratory for testing. While seated, the study procedures were outlined, and the participant read the informed consent which explained the experimental procedures, potential risks and benefits of participating and confidentiality of the data obtained. Participants were asked to explain orally what they would be doing and then questions or concerns regarding the study were clarified and discussed. Volunteers then signed the informed consent.

Next the participants were given a set of questionnaires to assess leisure time physical activity and selected health and other information relevant to the research including recent chronic pain, mood, and expectations about how pain intensity would be influenced by their participation. Blood pressure was assessed using oscillometry, then the participant affixed a Zephyr™ BioHarness™ (Zephyr Technology, Auckland, New Zealand) around their lower chest in a private room in order to provide exposure to the equipment and obtain baseline data. Participants were told that the BioHarness™ measured heart rate activity during the session but no mention was made of its primary purpose which was to assess breathing frequency. The BioHarness™ measures breathing frequency from a capacitance sensor embedded in the chest strap. Several investigations have concluded that the BioHarness™ yields reliable and valid estimates of breathing frequency [115-117]. A practice session for both yoga groups (groups C and D) was conducted in a laboratory room designed to resemble a yoga studio. The session included viewing a 5-minute yoga video that demonstrated models performing basic postures during which no comments were made about breathing. After the video the investigator answered questions about the video or the yoga sequence that would subsequently be performed. The practice session for the rest + slow breathing group (Group B) consisted of reviewing a video about a specific type of breathing (ujjayi) and answering questions about those instructions. All groups then received a familiarization session providing exposure to the conditioned pain modulation protocol which involved rating the intensity of pain in response to heat applied to the right forearm while the left hand was in ice cold water.

Heat Pain Familiarization. The purpose of this exposure was to ensure that the participants fully understood the heat pain stimulus to be used. The stimulus used was 46°C presented to the right ventral forearm. This stimulus has been used previously in our lab and has been presented to over 1,000 study participants in labs across the world [118, 119]. The results show that a 46°C stimulus is rated on average as mild-to-moderately painful [120]. A TSA-II NeuroSensory Analyzer (Medoc) was used to present the heat stimulus using a 30 X 30 mm thermode that was computer controlled by a Peltier heat pump system. The temperature started at 32°C and increased at a ramp rate of 4°C/sec until reaching 46°C; then maintained at that temperature for 30 seconds. Participants rated the intensity of the pain every 10 seconds. After 30 seconds the computer automatically reduced the heat stimulus at a rate of 8°C/sec back to 32°C. The first finger of the right hand was always resting on a computer mouse, that if depressed would automatically reduce the heat stimulus at a rate of 8°C/sec back to 32°C. Participants were told they could turn off the heat by depressing the button on the computer mouse at any time.

Cold Pain Familiarization. Participants inserted their left hand in a circulating ice water bath up to their wrist for 60 seconds. The temperature of water bath was 10°C ± 1 degree. Participants rated the pain intensity every 10 seconds and were told they could remove their hand at any time if pain was intolerable.

Conditioned Pain Modulation Test. Conditioned pain modulation (CPM) is a procedure that examines the paradigm that ‘pain inhibits pain’ [43]. Two separate and distinct painful stimuli are applied to the body in different areas. The test stimulus (noxious heat on the right forearm) is applied first by itself. Then after a recovery period, the same heat stimulus is applied concomitantly with the conditioned pain stimulus (placing the left hand in circulating noxious cold ice water) to examine changes in pain perception in the right forearm. This CPM method has been used previously in our lab with no adverse events [121]. More specifically with regard to timing, the CPM response in this experiment involved first being exposed to a test stimulus (46°C heat on the right forearm for 30 seconds) and reporting the pain intensity every 10 seconds followed by a 5-minute rest period. The same heat stimulus was presented a second time; however, it was applied during the final 30 seconds of a 60-second cold stimulus being presented to the other limb. The conditioned pain stimulus was provided to the left hand (i.e., the hand was submerged into circulating ice water up to the wrist). During the final 30-seconds, left hand and right forearm pain intensity were reported every 10 seconds. The outcome of primary interest is the change in pain experienced in the right forearm in response to the heat stimulus during the application of the second painful stimulus (cold to the other limb) compared to when no second noxious stimulus was applied (heat alone). After the familiarization tests were completed, the next visit was scheduled. Yoga participants were asked to come in appropriate clothing for the session.

Experimental Condition: Day – 2. Participants were asked to report to the laboratory on the experimental day. Pre-test questionnaires about compliance with study requirement (e.g. sleep duration within 2 hours of usual sleep duration, caffeine intake consistent with usual intake), mood, and several expectation questionnaires were completed. Next, blood pressure and heart rate were assessed while the participant is seated. The cuff was placed on the left arm at the level of the heart while the arm was supported by a table. The participant was instructed to sit quietly with both feet flat on the floor and to breath normally [122]. Following blood pressure assessment, the participants affixed the BioHarness™ to their chest and the experimental condition was conducted. That is, the participants entered a room alone and watched a video showing models who either performed yoga or sat while completing slow breathing. This experiment summarized here minimized potential social modulation of pain effects [123] by having participants complete yoga alone. The participants followed along with the models based on standard instructions given on the video. All the videos were 40 minutes. The seated rest condition used the same procedure, but there was no video and the participants were instructed to take a comfortable seat and rest using minimal movements and without falling asleep for 40 minutes. The videos can be viewed at: UGA ExPsych Lab YouTube (links to videos are provided in Appendix O). Participants completed the condition alone to eliminate potential confounds from social interactions and permit better focus on performing the requested postures and breathing.

Upon completion of the experimental condition, all participants sat at a desk in the same room the yoga was performed and provided overall ratings of average perceived exertion, overall ratings of average bodily pain intensity experienced during the condition using a 0 to 10 numerical scale, after which blood pressure and heart rate were assessed (approximately 2-3 minutes after completion of the video). All participants were offered a bottle of water and then walked about 30 feet to a separate testing room and sat in a padded, comfortable chair (model #4500, Rehab Seatings Systems, Inc., Brookline, MA) where they completed a mood assessment and performed a conditioned pain modulation test. Afterwards, the participant completed the final post-testing questionnaire assessments. Table 4.1 outlines the timing of the study procedures.

Measures. Several assessments were collected, and the non-copyrighted questionnaires are illustrated in Appendices A-N. To assess breathing frequency, the BioHarness™ wearable technology was used. The BioHarness™ included a module and strap that was affixed on the midaxillary line. Validity and reliability of the BioHarness™ has been established [124, 125]. State anxiety was measured via the anxiety subscale of the Profile of Mood States-II (POMS-II) [126].

The conditioned pain modulation protocol was used to measure both heat pain sensitivity and endogenous pain modulation. The protocol began with the participant being exposed to 30 seconds of their test stimulus (46-degree Centigrade heat on the right forearm). Pain intensity was rated every 10 seconds on 0 to 10 numerical scale. The average of the pain intensity ratings at 20- and 30-seconds was the criterion outcome measure used to test whether there was a difference between the groups in heat pain sensitivity. A five-minute seated rest period then occurred.

Participants were then exposed to 60 seconds of the conditioning stimulus (i.e., submerging left hand to the distal palmar wrist crease into a circulating cold-water bath). During the last 30 seconds of the conditioning stimulus, exposure to the test stimulus (46-degree Centigrade heat on the right forearm) was simultaneously presented. Pain intensity was rated every 10 seconds. The primary outcome was calculated by using the average heat pain rating made from 50-60 seconds after the start of the conditioned pain modulation test (i.e., the last 10 seconds of the cold exposure) minus the mean of the heat pain rating made between 20-30 seconds after the start of the conditioned pain modulation test (just prior to putting the left hand in cold water). If at any point in the testing participants wanted to stop the testing, they were able to do so by clicking the mouse, resting under the right-hand forefinger. This method of testing has shown to have excellent reliability [127]. Additionally, an Omron BP760N Blood Pressure Monitor was used to assess blood pressure at three time points (Day-1: Baseline, Day 2: Pre- and Post- treatment condition). The Omron BP760N is an automatic oscillometric devise with accuracy within the range of ± 3 mmHg [128].

Data Analysis. In order to test the hypotheses, the analysis was separated into two segments. First, manipulated independent variables each with two levels: physical activity (seated rest and yoga) and breathing (normal and slow) were assessed by two 2 x 2 ANOVAs. One key outcome was pain ratings (sensitivity) to the initial heat stimulus. The primary outcome was the change in pain intensity ratings in response to a subsequent presentation of the heat stimulus when a painful cold stimulus was added concomitantly (i.e., conditioned pain modulation).

The second analysis segment was to examine the main and interaction effects for both the heat pain sensitivity outcome and the primary outcome (change in the heat pain rating during cold exposure) using an ANCOVA in order to statistically adjust for the potential confounding effects of four variables: expectations for change, post-condition systolic blood pressure, state anxiety and pain experienced during the treatments. Covariates were interpreted as accounting for a significant percentage of a change if the *F* statistic changed from being significant to non-significant (or non-significant to significant) in an ANCOVA model compared to the ANOVA model. When ANOVA/ANCOVAs were significant then Bonferroni-adjusted post hoc tests were performed. All data were entered in IBM SPSS (version 26.0.0.0) to perform the data analysis.

Results

Participants. Fifty-four participants completed all testing procedures. Participant characteristics by group are presented in Table 4.2. Most of the women in this study were white (61.1%), with a mean BMI of 22.5 (±3.25), between the ages of 20 – 22 years old (63%), and previously practiced yoga in some capacity (72%). Mean typical sleep duration was 7.34 (±.82) hours per night, with over 90% of the entire sample reporting that during a typical week they engage in at least 15 minutes of leisure time physical activity. Group B (slow breathing seated non-yoga condition) reported less leisure time physical activity than the other groups (effect size $d > .80$).

Breathing Frequency Manipulation. The experiment successfully manipulated breathing frequency. An ANOVA found a significant main effect of breathing condition on breathing frequency $F(1, 48) = 17.618, p < .0001$. Non-yoga participants took significantly fewer ($p = .002$) breaths per minute in the seated slow breathing rest condition (Group B) compared to the seated normal breathing condition (Group A). The mean difference was ~3.5 breaths per minute. The Vinyasa yoga participants (Group D, who were instructed to breath slowly and deeply) took significantly (p = .003) fewer breaths compared to when no breathing instructions were given during yoga posture performance (Group C). The mean difference was ~3 breaths per minute. Group D breathing frequency did not differ from the seated normal breathing condition (Group A) but was significantly less (p = .002) than the seated slow breathing rest condition (Group B). The breathing frequency results are illustrated in Figure 4.2. Means and standard deviations for breathing frequency during the conditions and during the conditioned pain modulation protocol are presented in Table 4.3.

Intensity of the Conditions. Mean ratings of perceived exertion were significantly higher in the yoga compared to the non-yoga conditions, $F(1, 42) = 23.516, p = .001$. The perceived intensity was low-to-moderate and means ranged between values of 11 (associated with a verbal anchor of fairly light) and 13 (somewhat hard) in Group C and Group D, respectively. With regard to perceived exertion ratings, the main effect for breathing and the interaction were statistically insignificant. Descriptive statistics are provided in Table 4.3 for each group.

Mean heart rates were significantly higher in the yoga conditions compared to the non-yoga conditions, $F(1, 48) = 8.550, p = .005$. The mean heart rate during yoga ranged between 84 and 95 beats per minute for Groups C and D, respectively. With regard to heart rates during the conditions, the main effect for breathing (p=.072) and the interaction (p=.088) were statistically insignificant. Descriptive statistics for each group are provided in Table 4.5. Additional descriptive statistics for baseline, pre- and post-condition heart rates are provided in Table 4.4.

Next, the results are provided for the four covariates: state anxiety, systolic blood pressure, expectations for change and pain induced by the conditions.

Pain Induced by the Conditions. Peak pain (0 to 10) induced by conditions A, B, C and D were 1.55 (±.1.51), 1.30 (±1.83), 1.71 (±1.77) and 2.38 (±1.80), respectively. While overall pain experienced in conditions A, B, C and D were: 1.38 (±1.30), 1.00 (±1.41), .833 (±1.19) and .833 (±.72), respectively. There were no statically significant differences between conditions for either peak or overall pain as shown in Figure 4.3.

State Anxiety. Means and standard deviations for pre- and post-condition state anxiety scores are presented in Table 4.6 and the post- minus pre-test change scores for state anxiety are presented in Table 4.7. The main effect of yoga was significant, $F(1,50) = 16.82, p < .001$. The main effect of breathing, $F(1,50) = .118, p = .73$ and the interaction of yoga and breathing on the change in anxiety were not significant, $F(1,50) = .449, p = .51$. State anxiety was unchanged in the non-yoga groups and reduced by ~ 2 raw score units in the yoga groups, and the yoga groups were non-significantly higher at the pre-test by an average of 1 to 2 raw score units compared to the non-yoga groups.

Systolic Blood Pressure. Neither the main effects of yoga or breathing on systolic blood pressure, $F(1,49) = .260, p = .612$; $F(1,49) = 1.627, p = .208$, nor their interaction were statistically significant, $F(1,49) = .058, p = .81$. Means and standard deviations for systolic blood pressure before and after the conditions are presented in Figure 4.4 and the changes in systolic blood pressure are presented in Figure 4.5.

Expectations. Table 4.8 shows the data concerning expectations. In contrast to the non-yoga groups, both the yoga group with normal breathing (Group C) and the yoga group with slow breathing (Group D) had significantly greater than chance expectations for post-condition decreases in pain (Group C = 60%; $\chi^2 = (2, N = 15) = 6.400, p = .041$) and (Group D = 78.6%; and $\chi^2 = (2, N = 14) = 13.000, p = .002$). In contrast to Groups B and C, the yoga group with slow breathing (Group D) had significantly greater than chance expectations for post-condition improvement in mood ($\chi^2 = (2, N = 14) = 7.143, p = .008$) while the non-yoga group that sat and breathed normally (Group A) had significantly greater than chance expectations for there to be no change in mood post-condition ($\chi^2 = (2, N = 14) = 7.000, p = .03$).

Heat Pain Sensitivity. Mean heat pain ratings were slightly lower in both slow breathing conditions compared to the normal breathing conditions. Mean heat pain ratings were slightly lower in both yoga conditions compared to the non-yoga conditions. However, the main effects of yoga and breathing and their interaction were statistically nonsignificant: $F(1, 50) = .051, p = .82$; $F(1, 50) = .569, p = .45$; and $F(1, 50) = .115, p = .74$, respectively. The heat pain sensitivity data are presented in Table 4.9 and Figure 4.6.

Conditioned Pain Modulation. There was not a significant main effect of yoga or breathing, $F(1, 50) = .291, p = .59$ and $F(1, 50) = 2.673, p = .11$, respectively, on the change in heat pain ratings during the conditioned pain modulation test. Nor, was there a statistically significant interaction of yoga and breathing on the change in heat pain intensity ratings, $F(1, 50) = .049, p = .83$. Means and standard deviations for the change in pain intensity are presented in Table 4.10.

Analyses with Covariates. Additional factorial ANCOVAs were conducted to control for four possible confounding factors: the influence of expectations, change in systolic blood pressure, change in anxiety and pain cause by the conditions. None of the *F* statistics in the ANCOVA models changed the main or interaction effects for either heat pain sensitivity or conditioned pain modulation from being non-significant to significant. Hence, it was interpreted that the potential confounding effects of expectations, change in systolic blood pressure, change in anxiety and pain cause by the conditions were trivial.

Discussion

This study was designed to test the effect of a single session of Vinyasa yoga postures, with and without slow breathing, on sensitivity to heat pain and endogenous pain modulation in women.

The hypotheses regarding the influence of yoga (H1), slow breathing (H2) and their interaction (H3) on heat pain sensitivity were not supported statistically. These observations are generally consistent with the only prior experiment is this literature and which found that a single session of yoga did not significantly influence pain provoked by pressure stimuli [129]. Nevertheless, the main effects for both slow breathing and for yoga in the present experiment was in the hypothesized direction, though small in magnitude. The breathing main effect also may have been significant if testing did not have to be stopped because of the COVID-19 pandemic; data were analyzed from only 11 participants who completed the slow breathing while seated condition (Group B).

These results were unchanged after statistically adjusting for four variables that plausibly could have influenced this outcome: pain experienced during the conditions, condition-induced changes in state anxiety and blood pressure and expectations that the condition would influence pain. It is worth noting that a greater percentage of the participants who were in the yoga, but not the non-yoga, conditions expected decreased pain in response to their condition. This observation is consistent with the only prior experiment in this literature [130].

The effects of a single yoga session on pain sensitivity to objective noxious stimuli rarely has been investigated and is poorly understood. One uncontrolled study of 90 Hatha yoga participants found no change in pain intensity ratings from a standardized pressure stimulus applied to the second toe, middle finger or ear lobes before and after 90 minutes of Hatha yoga even though 67% of the sample expected the yoga session to reduce pain [29]. While expectations for change can influence responses to acute exercise [30], a key limitation of this study beyond the lack of a control condition was that it did not report the perceived painfulness or intensity of the yoga. Low intensity yoga may be performed without pain and it may be an insufficient exercise stimulus to produce post-exercise hypoalgesia. In contrast, more challenging and intense yoga styles, such as Vinyasa, often cause transient pain in practitioners and, consequently, may provide greater pain relief post-exercise and may create greater expectations for change [18].

Exercise intensity may have accounted for the null findings for pain sensitivity. A meta-analysis of the hypoalgesic effect of acute exercise did not include exercise intensity as a formal moderating variable but nonetheless surmised that larger effect sizes were found with exercise of higher intensity [38]. Thus, a larger main effect of yoga on heat pain sensitivity may have been observed in the present experiment if yoga had been performed at a higher intensity. Also, of the studies included in the meta-analysis, 11 provided details on timing of assessments taken after training. The time frame ranged from 2 to 30 minutes post exercise. These shifts in pain perception after exercise lasted up to 15 minutes post exercise, with nominal to small effects at 30 minutes post exercise. As expected, the intensity of the yoga conditions in the present investigation, as documented by heart rate and perceived exertion ratings, was greater than the non-yoga conditions. The yoga conditions were low-to-moderate in perceived intensity on average rather than moderate-to-high as can occur for a some Vinyasa yoga sessions [131]. Moreover, one recent review [132] examines personal factors that influence CPM in healthy people. In six studies that examined the effects of age, all found that younger adults have better CPM than older adults. Additionally, a review and meta-analysis by Lewis et al., 2012, found that CPM is compromised in patients with chronic pain [133]. These are two factors not addressed in the present study, that may have moderated the conditioned pain modulation response.

With regards to the conditioned pain modulation results, right forearm heat pain ratings on average were lower when the left hand was is cold water for all four groups. Thus, on average the participants were responsive to the conditioned pain modulation test. The hypotheses regarding the influence of yoga (H1), slow breathing (H2) and their interaction (H3) on greater endogenous pain modulation; however, were not supported. These results could not be explained by systematic differences between the groups in pain experienced during the conditions, condition-induced changes in state anxiety and blood pressure or expectations for change in heat pain from putting the left hand in cold water. It is unlikely that smaller than planned sample size resulted from the COVID-19 pandemic influenced this outcome because the main effect for yoga was extremely small and the main effect for slow breathing was in the opposite direction of that hypothesized; that is, the reduction in pain when the left had was put into cold water was less to a small degree with slow breathing compared to normal breathing for both the yoga and non-yoga conditions.

The present results for conditioned pain modulation cannot be compared to other reports because to our knowledge no other studies have addressed the acute effect of yoga postures or slow, controlled, deep or yogic breathing on conditioned pain modulation. Acute exercise of other types in rodents and humans can produce a conditioned pain modulation effect [134, 135]; however, the effect appears to depend on the exercise inducing a moderate intensity muscle pain [37]. Our data support the hypothesis that an acute bout of yoga of a higher intensity, such as that producing a moderate intensity muscle pain, may be needed to reliably produce a conditioned pain modulation effect. Alternatively, our hypotheses may have been supported if the experiment focused on patients suffering from chronic pain for whom low-intensity exercise would likely be more painful. Also, the present research design was highly controlled, including having each participant complete their condition alone is a small laboratory room. While such control is considered a research design strength, this approach failed to take advantage of potential psychosocial influences, some of which have been shown to effect exercise-induced hypoalgesia [136]. Several studies have investigated the effects of social modulation and pain. One study comparing pain responses in the presence of others in youth and adults found that youths displayed significantly greater pain tolerance when others were present [137]. Moreover, one review of 26 studies, found that organized experimental exchanges may lead to reductions in pain measures when they indicate safety of the noxious stimulus or the environment in which it occurs, or they are designed to direct attention away from the noxious stimulus [138]. These effects are particularly apparent when the interpersonal interaction itself is prominent. In other words, low-to-moderate intensity yoga may have produced a significant conditioned pain modulation effect in a typical yoga class performed in the presence of other individuals. The present study was purposely designed so that the potential cofounding effects of socialization that occurs in yoga settings would be avoided.

The experiment successfully manipulated breathing frequency and resulted in no adverse effects. This experiment appears to be the first to confirm that instructions to breath slowly during the completion of yoga postures actually can result in reduced breathing frequency. The success of the breathing manipulation was not a foregone conclusion, in part because the sample included individuals who were not highly experienced with yoga. Also, anecdotal evidence suggests that yoga experience may be needed to learn how to breathe slowly while holding yoga poses. The significant difference between the conditions in breathing frequency also provides further evidence for the validity of the BioHarness™ as a tool for assessing breathing frequency. Our results trended towards finding an effect of breathing. One potential reason for this absence of statistically significant effect is that the brief practice session offered may not have been enough training to produce a greater decrease in breath frequency. As demonstrated in recent study, eight minutes of biofeedback gameplay was successful at reducing breath frequency and resulted in better attentional-cognitive performance than the non-biofeedback control [139]. Future studies should include consider length and type of breathing training to ensure the desired breathing technique is understood and can be adhered to.

The conditions produced low intensity pain, both overall and peak, in each condition. It may seem surprising that the mean peak and overall pain data was highest in the sitting and breathing normally condition (Group A) but this likely resulted from the only individual enrolled in the experiment with chronic pain being assigned to this group. Additionally, it is plausible that the higher reported overall pain could be due to the discomfort or novelty of sitting in a certain position for an extended amount of time. Although participants were given instruction on changing position for comfort, if that advice was ignored pain could have resulted. Also, poor posture during meditation is not uncommon [140]. The low pain and low-to-moderate perceived exertion values during yoga in this experiment provide evidence for the emphasis placed on safety in the conduct of this investigation. The low mean pain intensity and perceived exertion values were lower than moderate pain and perceived exertion values reported in a prior study of Bikram yoga [141].

Compared to the non-yoga conditions, the yoga conditions resulted in a significant reduction in state anxiety scores. This finding is consistent with other studies showing that a single session of yoga results a reduction of anxiety symptoms [142-144]. Although each of the non-yoga and yoga groups were characterized by low pre-test anxiety scores, the scores were lowest for the non-yoga groups and close to the lowest score possible. Accordingly, a floor effect for the non-yoga groups may have contributed to the effect of yoga on state anxiety. Seated rest, with or without yoga breathing, can be anxiolytic [129, 145]. A unique result in the present investigation was the greater expectation for mood improvement associated with Vinyasa yoga (Group D). These expectations about mood, state anxiety is one type of mood state, may have contributed to the greater state anxiety reductions found after yoga compared to the non-yoga conditions.

Slower frequency breathing had no effect on state anxiety. However, patients with breathing disorders suffer from a high prevalence of anxiety and anxiety disorders [146]. Slow, deep or yoga style breathing are widely regarded as useful for reducing anxiety among people suffering from anxiety disorders, stress and medical conditions that cause distress [147]. The absence of slow breathing caused reduction in state anxiety observed here may have happened for several reasons, including the low pre-condition anxiety scores or that a larger reduction in breathing frequency may have been required to produce the outcome. Not all experiments involving yoga-style breathing show a reduction in state anxiety [129] and studies that have documented reductions in state anxiety after a single session of yoga rarely have documented an objective change in breathing as was done in the present study [148].

Average systolic blood pressure was slightly lower after each of the conditions and there was no significant difference between the groups. Nevertheless, the mean reduction in systolic blood pressure after both yoga conditions combined of 3.67 mmHg is within the 95% confidence interval (mean of -4.80 mmHg) reported in a meta-analysis of 65 acute exercise studies [149]. In that analysis, larger reductions in systolic blood pressure were reported for males, who performed running and who were not taking hypertensive medications. None of the participants in the present study were taking hypertensive medication but because this study focused on females, performing a generally less dynamic physical activity than running and the likely lower intensity compared to running all could have contributed to a smaller effect on post-exercise hypotension. A floor effect also may have contributed to the present systolic blood pressure findings because all the groups were characterized by low mean pre-test systolic blood pressures, which ranged from 100 to 106 mmHg.

Yoga is comprised of varying combinations of physical postures (asanas), breathing techniques (pranayama) and meditation (dhyana) [150]. A common yoga style used is research involves Hatha yoga interventions [151]. This style of yoga is typically more restorative in nature (i.e., fewer poses held for a longer duration). While 72.2% of our sample had prior yoga experience, only 31.5% had Vinyasa experience. Characteristically, Vinyasa yoga is more vigorous and meets the criteria of moderate-intensity physical activity [152]. Because we did not exclude based on prior yoga experience, we developed an advanced beginner routine to ensure safety and full participation. While no participant dropped out during a yoga session because of difficulty with the poses or their intensity, our choice of an advance beginner routine likely influenced our outcome. Future studies should consider and compare how different yoga styles and intensities affects pain sensitivity.

One aspect of yoga not addressed by the present research design was meditation. Seventy-six percent of our sample had some prior exposure to mediation. There are many forms of mediation. Meditation can be defined as a form of mental training that enhances one's ability to be present; with and keen and non-judgmental awareness of one's thoughts and emotions. The literature supports that meditation can improve overall well-being, to include improvements in anxiety [153], stress and pain [154]; however, most prior research has focused on the regular practice of meditation. A few case studies have found a single session of meditation to be associated hypoalgesia and activation of brain areas known to be involved in pain processing [155]. The degree to which participants engaged in a mindful or meditative state was not determined in the present study in order to focus on the effects of posture and breathing. Future studies should assess this component of yoga, to further expound its complexity.

The COVID-19 pandemic contributed to the present study being underpowered to detect the hypothesized interaction effect of yoga postures and slow breathing on changes in pain intensity during conditioned pain modulation testing. Although the overwhelming majority of participants reported that they fully followed human models and instructions presented in the videos (59.3% completely agreed and 38.9% mostly agreed), the conditions were completed in privacy and no video documented the sessions. Thus, it is plausible that full expression of asana and pranayama may not have been obtained. One study found significant differences between novice and experienced practitioners on the level of expression achieved and a large percentage of the participants in the present study seldom engaged in yoga [156]. Thus, inadequate behavioral engagement in the conditions may have contributed to the absence of a significant interaction effects.

The present investigation is the first, to our knowledge, to explore whether a single session of yoga influences central nervous system pain modulatory processes. Strengths of the investigation included the use a post-test only design to avoid bias that can result from multiple heat exposures [37] and the use of a resting control condition in the design for comparison; in prior related studies with a control condition [157, 158] larger effect sizes were observed (.83-1.18).

Limitations

There are some important limitations in this study. The sample includes a small selection of healthy women; therefore, these results may not generalize to older adults, men, or unhealthy samples. Women ,in general, are more likely to participate in yoga, report dysphoric mood states and are at greater risk for developing chronic pain [14, 37]. Also, given that sex-related differences in pain are common, we sought to avoid this potential confound by testing only one sex. The lack of control for the phase of menstrual cycle in the participants is a potential limitation. Although, we used a video to standardize the instructions given to each participant, the lack of instructor feedback, a common element of yoga, may have introduced novelty-related bias for those participants who had no prior experience performing yoga alone while following video-based instructions.

In conclusion the findings support that a single session of video-based yoga is safe and produces marginally lower (<.50 raw score units) heat pain intensity ratings. Additionally, low-to-moderate intensity video-based yoga performed alone results in a significant reduction in state anxiety scores, even among a sample of women with below normal anxiety symptoms prior to starting the yoga session. These findings are interesting and potentially important for generating a body of research that can form an empirical basis for creating non-pharmacological and safe alternatives to acutely address pain management.

Table 4.1.
Timeline of Study Procedures / Phases of Testing

Time (hours:min)	Task	Test Phase
Screening	Participant complete questions online (5 mins)	Screening
	Day 1	
0:00-0:02	Greet participant	Pre-participation
0:02-0:07	Participant completes informed consent process	Informed consent
0:07-0:09	Participant completes physical activity history	Descriptive data
0:09-0:11	Participant completes demographic questionnaire	Descriptive data
0:11-0:13	Participant completes baseline pain and expectation questionnaires	Moderator data
0:13-0:18	Participant completes mood questionnaire	Moderator data
0:18-0:19	Collect baseline blood pressure	Descriptive data
0:10-0:20	Collect height and weight	Descriptive data
0:20-0:25	Explain equipment and demo procedures	Methods Practice
0:25-0:30	Fitted for heart and breathing equipment	Methods Practice
0:30-0:35	Brief exposure to one of the treatments	Habituation
0:35-0:40	Brief exposure to conditioned pain modulation protocol	Habituation
0:40-0:45	Answer any questions and schedule next visit	Schedule visit 2
	Day 2	
0:00-0:02	Greet participant	Preparation
0:02-0:05	Confirm compliance to pre-test procedures	Compliance check

0:05-0:07	Fitted to equipment	Equipment check
0:07-0:09	Expectation questionnaire	Moderator data
0:09-0:12	Mood questionnaire	Outcome Measure
0:12-0:15	Collect pre-condition blood pressure	Moderator data
0:15-0:55	Completion of Experimental Condition	Treatment
0:55-0:58	Mood questionnaire	Outcome data
0:58-1:00	Collect post-condition blood pressure	Moderator measure
1:00-1:07	Conditioned pain modulation test	Outcome assessment
1:07-1:10	Post-Experiment Purpose questionnaire	Moderator measure
1:10-1:15	End of protocol	Completion

Table 4.2
Selected Characteristics of the Samples, Mean (Standard Deviation)

	Non-Yoga Groups		Yoga Groups	
	Group A	Group B	Group C	Group D
N	14	11	15	14
Age (years)	21.29 (2.49)	20.55 (1.51)	20.33 (2.02)	20.36 (1.22)
BMI	21.90 (2.52)	22.93 (3.49)	23.07 (4.09)	22.02 (2.83)
Chronic Pain (%)	7.1	0	0	0
Average Sleep	7.30 (.59)	7.18 (1.15)	7.48 (.88)	7.36 (.72)
Race (%)				
White/Caucasian	42.9	54.5	66.7	78.6
Hispanic or Latino	7.1	0	6.7	0
Black or African American	7.1	9.1	13.3	7.1
Asian/Pacific Islander	21.4	18.2	6.7	14.3
Other	21.4	18.2	6.7	0
Resting Heart Rate and Blood Pressure				
Baseline HR (bpm)	69 (20.36)	71.55 (10.13)	68.20 (12.89)	68.57 (7.53)
Baseline SBP (mmHg)	103.57 (8.80)	99.81 (6.29)	101.80 (10.23)	102.86 (7.96)
Baseline DBP (mmHg)	71.43 (8.13)	70.73 (6.21)	70.20 (7.60)	68.00 (7.15)
Godin Leisure Time Physical Activity Scores				
Total	64.43 (42.75)	36.73 (19.58)	56.93 (42.93)	56.93 (29.09)
Mild	4.07 (3.63)	2.27 (1.79)	3.93 (2.63)	4.21 (2.55)
Moderate	3.50 (2.77)	3.36 (1.97)	3.87 (3.18)	3.71 (2.56)
Strenuous	3.87 (3.60)	1.45 (1.57)	2.87 (3.48)	2.86 (1.99)
Yoga and Related Practices Information (%)				
Yoga Experience (%)	78.6	54.5	80	71.4
Daily	9.1	0	0	0
Weekly	9.1	33.3	50	0
Monthly	36.4	16.7	8.3	20
Seldom	45.5	50	41.7	80
Location				
Home	9.1	0	25	30
Studio	27.3	83.3	25	30
Both	63.6	16.7	50	40
Vinyasa Yoga Experience (%)	28.6	27.3	40	28.6
Meditation and Related Practices Information (%)				

Experience (%) with Meditation Including Guided Breathing	71.4	90.9	73.3	71.4
Daily	10	10	0	0
Weekly	0	10	27.3	20
Monthly	10	30	18.2	10
Seldom	80	50	54.5	70
Type of Meditation (%)				
Own	20	10	36.4	0
Teacher/App	70	80	45.5	60
Both	10	10	18.2	40

Abbreviations: y, years; bpm, beats per minute; HR; Heart Rate;
SBP, Systolic Blood Pressure; DBP, Diastolic Blood Pressure

Notes: Values above represent means (± standard deviations) unless otherwise noted.

Table 4.3
Descriptive Statistics for Breathing Rates during the Conditions and the Conditioned Pain Modulation (CPM) Protocol

	N	Min	Max	Mean	SE	SD
			Breathing Frequency During the Conditions			
Group A	13	13	19	16.07	0.618	2.226
Group B	11	10	15	12.53	0.726	2.408
Group C	14	16	23	18.97	0.601	2.249
Group D	14	11	18	15.90	0.520	1.946
			Breathing Frequency During the CPM Protocol			
Group A	12	14	19	16.77	0.529	1.833
Group B	11	14	21	16.95	0.740	2.453
Group C	14	14	23	17.71	0.635	2.377
Group D	14	13	25	16.96	0.740	2.770

Note: The BioHarness™ malfunctioned during some sessions, which resulted in a loss of data

Groups: A = sitting + normal breathing, B = sitting + slow breathing, C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]

Table 4.4
Descriptive Statistics for Heart Rate at Baseline (BL) and Before (Pre) and After (Post) the Conditions and Immediate Post-Condition Overall Average Ratings of Perceived Exertion

		N	Min	Max	Mean	SE	SD
				Heart Rate			
Group A	BL	14	8	88	69.00	5.442	20.362
	Pre	14	60	90	76.57	2.378	8.899
	Post	14	50	86	69.50	2.493	9.329
Group B	BL	11	53	87	71.55	3.055	10.133
	Pre	11	57	101	78.09	4.080	13.531
	Post	11	61	82	72.45	2.184	7.244
Group C	BL	15	48	90	68.20	3.328	12.891
	Pre	15	50	90	70.53	3.263	12.637
	Post	15	46	86	66.73	3.220	12.470
Group D	BL	14	61	83	68.57	2.013	7.532
	Pre	14	61	95	75.00	2.961	11.080
	Post	13	43	84	70.77	3.288	11.854
				Ratings of Perceived Exertion			
	Group A	8	6	11	8.00	0.655	1.852
	Group B	9	6	13	9.11	0.754	2.261
	Group C	15	7	16	11.60	0.576	2.230
	Group D	14	8	18	12.57	0.754	2.821

Note: Four participants did not provide ratings of perceived exertion and three RPE ratings were excluded because the participants misunderstood the instructions (e.g., gave a maximal effort rating during the seated rest with normal breathing condition).

Groups: A = sitting + normal breathing, B = sitting + slow breathing, C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]

Table 4.5
Descriptive Statistics for Breathing Rates during the Conditions and Conditioned Pain Modulation Protocol

	N	Min	Max	Mean	SE	SD
			Heart Rate During Condition			
Group A	13	59	101	79.74	2.787	10.050
Group B	11	62	101	80.05	3.915	12.986
Group C	14	55	112	83.55	4.037	15.106
Group D	14	79	102	95.07	1.723	6.447
			Mean Heart Rate During CPM Protocol			
Group A	12	59	86	74.82	2.148	7.440
Group B	11	28	89	70.41	5.199	17.243
Group C	14	12	85	68.08	5.047	18.882
Group D	14	64	88	79.60	2.087	7.809

Note: The BioHarness™ malfunctioned during the session, which resulted in a loss of data

Groups: A = sitting + normal breathing, B = sitting + slow breathing, C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]

Table 4.6
Mean (and SD) State Anxiety Scores and Systolic Blood Pressure Values Pre- and Post-Condition

		State Anxiety Scores		Systolic Blood Pressure (mmHg)	
Group	*n*	*Pre*	*Post*	*Pre*	*Pre*
A	14	1.07 (1.69)	.57 (.94)	106.14 (12.08)	100.93 (9.79)
B	11	1.00 (1.61)	.64 (1.21)	100.18 (6.66)	98.09 (97.11)
C	15	2.13 (1.25)	.20 (.41)	100.13 (13.11)	96.47 (10.60)
D	14	3.21 (3.04)	.86 (1.66)	103.43 (7.07)	101.46 (8.40) †

† Post-Condition blood pressure was not collected for one participant in Group D (*n*=13)

Groups: A = sitting + normal breathing, B = sitting + slow breathing, C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]

Table 4.7
Means and Standard Deviations: State Anxiety Change Scores

Group	Yoga	Breathing	*M*	*SD*	N
A	No	No	-.50	.941	14
B	No	Yes	-.36	1.629	11
C	Yes	No	-1.93	1.438	15
D	Yes	Yes	-2.36	1.946	14

Groups: A = sitting + normal breathing, B = sitting + slow breathing,
C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]

Table 4.8

Group percentages expecting decreases, increases or no change in pain and mood.

	Non-Yoga Groups		Yoga Groups	
	Group A	Group B	Group C	Group D
Expected change in heat pain from putting left hand in cold water				
Decrease Pain	42.9	27.3	53.3	50
No Change	35.7	36.4	26.7	28.6
Increase Pain	21.4	36.4	20	21.4
Chi-Square	0.61	0.91	0.25	0.4
Expected change in mood from participating in the condition				
Worse Mood	7.1	0	0	0
No Change	64.3	54.5	46.7	14.3
Improve Mood	28.6	45.5	53.3	85.7
Chi-Square	0.03*	0.76	0.8	.008*
Expected pain change in response to the conditions				
Decrease Pain	35.7	45.5	60	78.6
No Change	57.1	54.5	33.3	14.3
Increase Pain	7.1	0	6.7	7.1
Chi-Square	0.07	0.76	.04*	.002*

Groups: A = sitting + normal breathing, B = sitting + slow breathing,
C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]
Non-chi-square values represent percentage of the samples.
* $p<.05$

Table 4.9
Means and Standard Deviations for Test and Conditioning Stimuli

Group	Rating	Min	Max	Mean	SE	SD
A	HP 1	1.00	7.00	3.36	0.53	1.98
N=14	HP 2	0.50	6.00	2.75	0.49	1.84
	HP 3	0.50	6.00	2.29	0.39	1.45
	CP1	0.50	5.00	2.64	0.35	1.29
	CP2	1.00	6.00	3.46	0.46	1.71
	CP3	2.00	9.00	4.29	0.52	1.95
	HP 1	0.50	6.00	1.93	0.42	1.58
	HP 2	0.00	5.00	1.43	0.40	1.49
	HP 3	0.00	5.00	1.21	0.39	1.46
B	HP 1	0.00	7.00	3.41	0.72	2.40
N=11	HP 2	0.00	6.00	2.18	0.55	1.82
	HP 3	0.00	6.00	1.82	0.54	1.78
	CP1	0.50	7.00	3.41	0.60	1.99
	CP2	0.50	9.00	3.95	0.76	2.50
	CP3	1.00	10.00	4.55	0.76	2.51
	HP 1	0.00	5.00	2.41	0.51	1.70
	HP 2	0.00	4.00	1.73	0.44	1.47
	HP 3	0.00	3.00	1.09	0.31	1.02
C	HP 1	0.50	8.00	3.17	0.52	2.02
N=15	HP 2	0.50	7.00	2.57	0.44	1.72
	HP 3	0.00	6.00	1.93	0.44	1.71
	CP1	0.00	5.00	2.17	0.43	1.68
	CP2	0.00	6.00	2.80	0.48	1.85
	CP3	0.50	8.00	3.47	0.63	2.45
	HP 1	0.00	4.00	1.40	0.31	1.20
	HP 2	0.00	3.00	1.17	0.27	1.03
	HP 3	0.00	2.00	0.73	0.20	0.78
D	HP 1	0.50	7.00	2.82	0.49	1.84
N=14	HP 2	0.00	6.50	2.25	0.49	1.84
	HP 3	0.00	6.50	1.86	0.54	2.00
	CP1	0.00	7.00	2.36	0.49	1.82
	CP2	0.00	8.00	3.43	0.49	1.85

CP3	0.00	8.00	3.57	0.54	2.02
HP 1	0.00	7.00	1.79	0.51	1.92
HP 2	0.00	5.00	1.25	0.38	1.42
HP 3	0.00	7.00	1.18	0.52	1.95

Groups: A = sitting + normal breathing, B = sitting + slow breathing,
C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]

Table 4.10

Means and Standard Deviations of Change in Heat Pain Intensity Rating

Group	Yoga	Breathing	*M*	*SD*	N
A	No	No	-1.196	1.161	14
B	No	Yes	-.591	.882	11
C	Yes	No	-1.300	1.293	15
D	Yes	Yes	-.839	1.303	14

Groups: A = sitting + normal breathing, B = sitting + slow breathing,
C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]

FIGURES

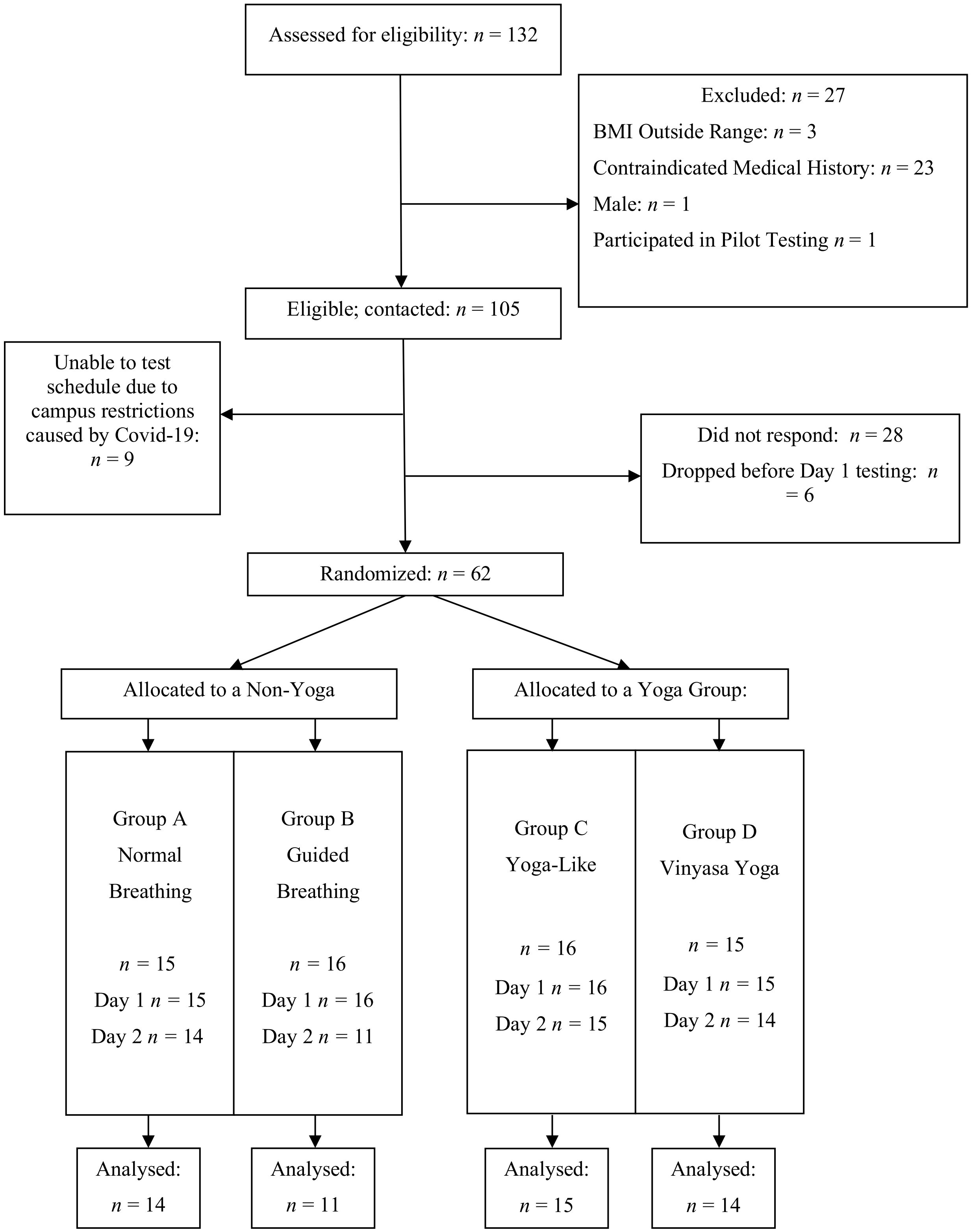

Figure 4.1 Participant flow diagram. Total included in analysis: N=54.

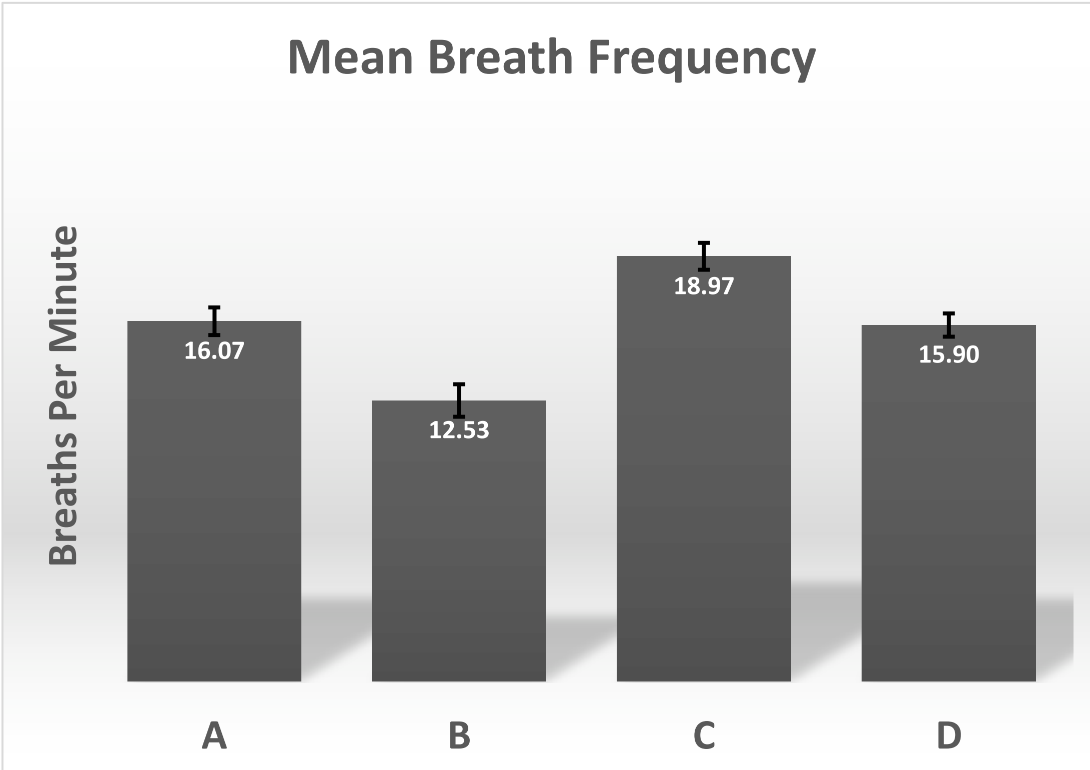

Figure 4.2. Mean (± SE) breathing frequency for the four treatment groups.

Groups: A = sitting + normal breathing, B = sitting + slow breathing, C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]

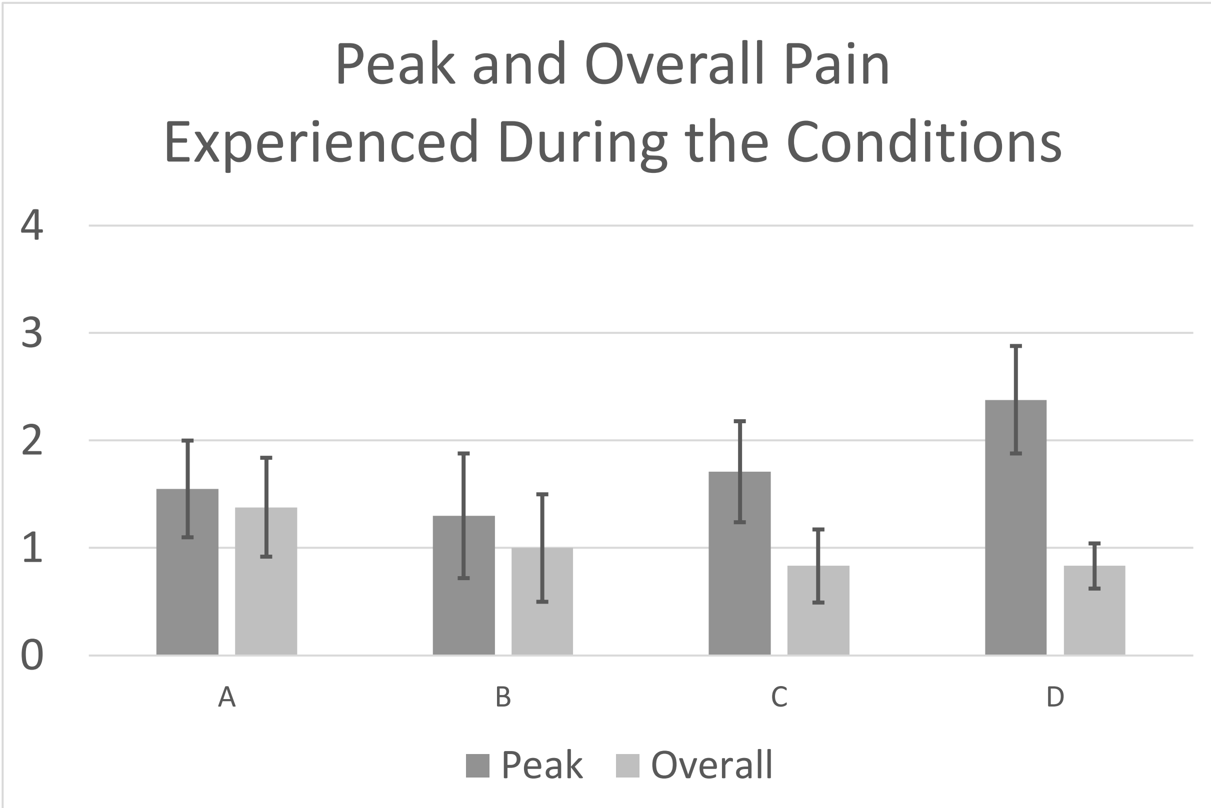

Figure 4.3. Mean (± SD) peak and overall pain during the conditions. Values less than three represent low intensity pain.

Groups: A = sitting + normal breathing, B = sitting + slow breathing, C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]

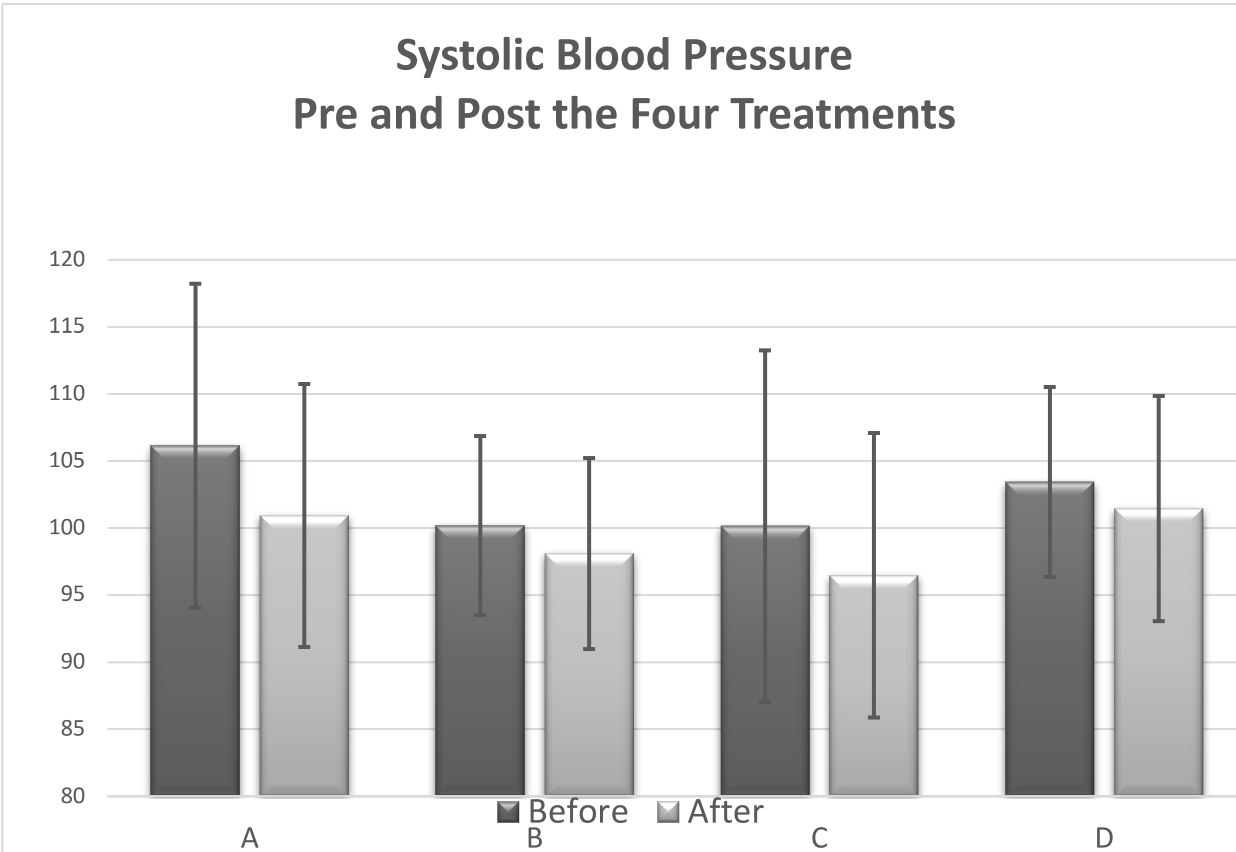

Figure 4.4. Mean (± SD) systolic blood pressure (mmHg) before and after the conditions.

Groups: A = sitting + normal breathing, B = sitting + slow breathing,
C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]
.

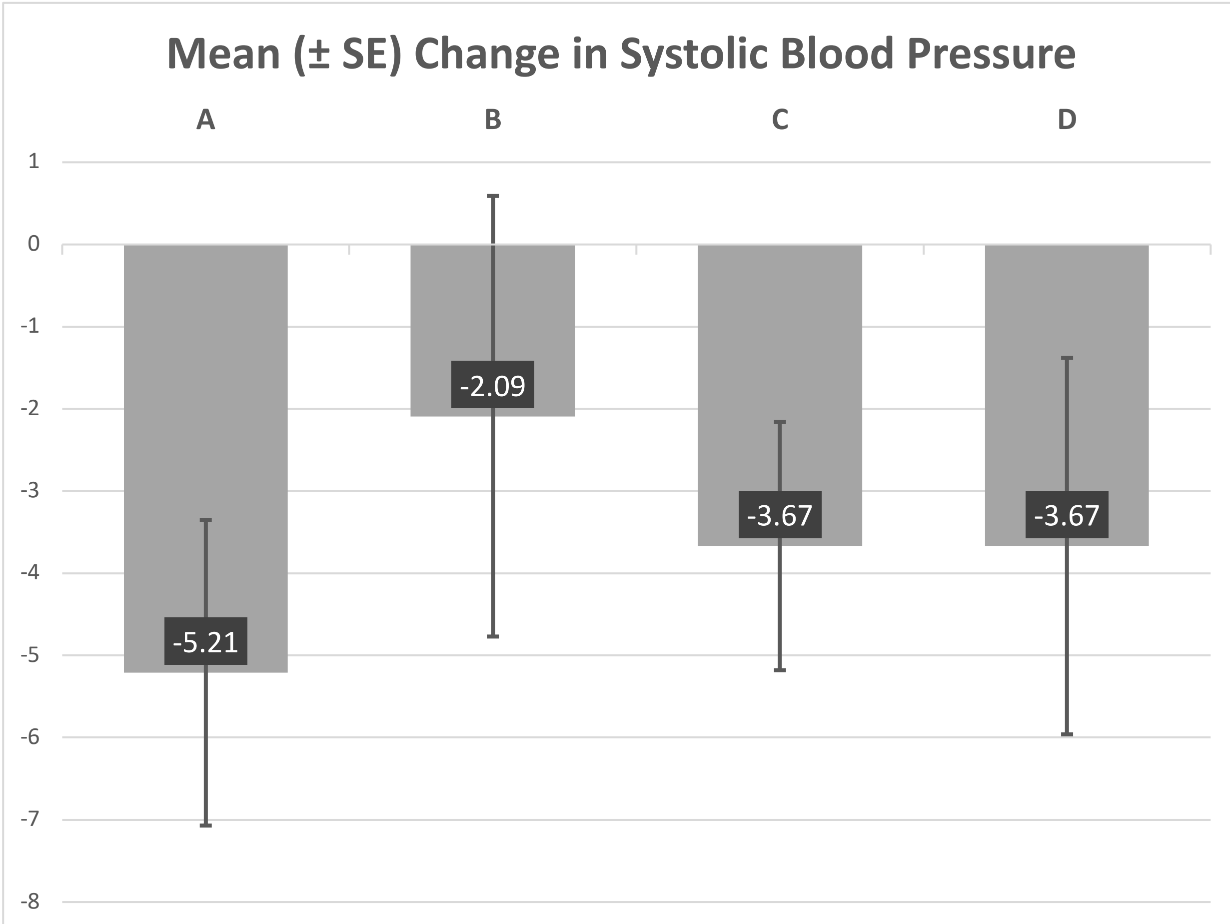

Figure 4.5. Mean (± SE) change systolic blood pressure (mmHg) before and after the conditions.

Groups: A = sitting + normal breathing, B = sitting + slow breathing,
C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]

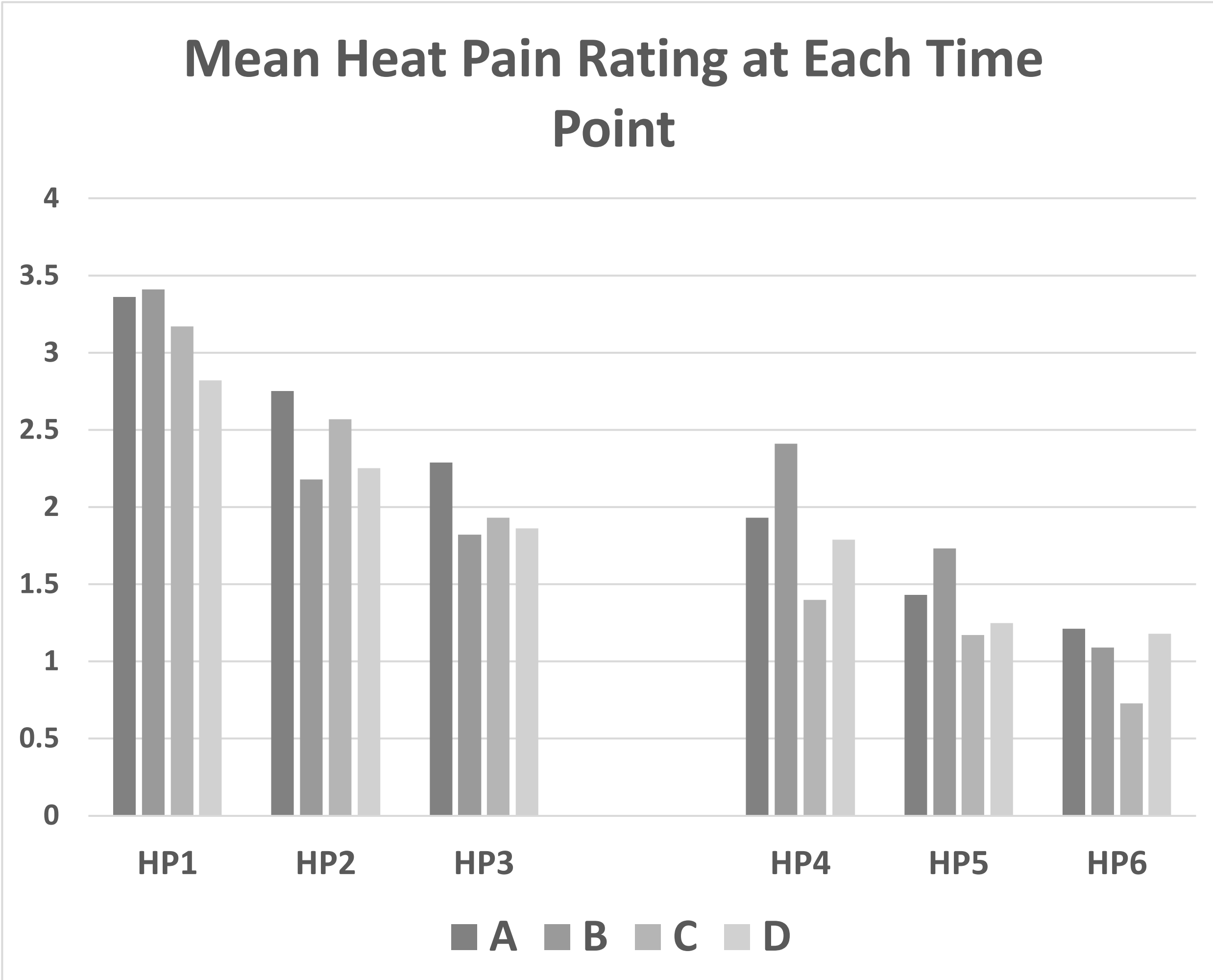

Figure 4.6. Mean (± SE) heat pain sensitivity. HP1-3 refers to ratings given during the heat pain test stimulus; while HP4-6 refers to ratings during the CPM protocol (cold +hot) and occurred during the last 30 seconds of test. Heat pain was set at 46°C heat on the right forearm for 30 seconds.

Groups: A = sitting + normal breathing, B = sitting + slow breathing,
C = yoga postures + normal breathing, D = yoga postures + slow breathing [Vinyasa]

CHAPTER 5

CONCLUSION

The purposes of this dissertation were to examine if performing yoga would reduce pain. This was investigated two-fold, by exploring chronic and acute pain. First, a review and meta-analysis estimated the population effect size of yoga interventions for reducing pain in randomized trials with samples of people in chronic pain. Second, to investigate, using a post-test only between-subjects design, the effect of a single session of yoga postures, in one group without slow breathing and in a different group with slow breathing, on endogenous pain modulation and mood in young women.

A large cross-sectional study, found that yoga practitioners thought that yoga was effective for several reasons including enhancing general wellness and disease prevention (78%), improving the mood of energy (66%), supporting immune function (50%) and restoring back pain (20%) [2]. Evidence supports that acute and regular yoga has multiple healthful effects. For example, acute and chronic yoga can reduce anxiety [3], systolic blood pressure [4-6], and pain [7].

The meta-analysis in this dissertation included randomized controlled trials comparing yoga to control conditions with patients in chronic pain were included. Forty-five effects were derived from 12 experiments, with a total of 1680 patients (mean ±SD sample size: 70±30) categorized as having chronic low back pain, chronic neck pain, migraines, cancer-related pain, arthritis, fibromyalgia, neck pain, or neuropathic pain. Thirty-seven of 45 (82%) of the effects were greater than zero. Unweighted Hedge's d effect sizes ranged from -0.93 to 6.46.

Compared to non-yoga control conditions (most often usual care), yoga training significantly reduced pain symptoms among those in chronic pain by a large mean effect (Δ) of 1.31 (95%CI: 0.79 to 1.83, $Z = 4.92$, $p < 0.001$) and improved disability by a moderate mean effect (Δ) of .56 (95%CI: 0.11 to 1.02, $Z = 2.41$, $p = 0.016$).

The second study of this dissertation aimed to examine, the effect of a single session of yoga postures, in one group without slow breathing and in a different group with slow breathing, on endogenous pain modulation and mood in young women. It was hypothesized that compared to a control condition involving both seated rest and normal breathing, and controlling for the potential confounding effect of expectations, systolic blood pressure, state anxiety and pain induced by the conditions. More specifically: (H1) exposure to 40 minutes of yoga postures, regardless of the breathing condition, will result in reductions in heat pain sensitivity and greater endogenous pain modulation (i.e., there will be a main effect of yoga postures); (H2) exposure to 40 minutes of slow breathing, regardless of whether yoga postures were completed, will result in reductions in heat pain sensitivity and greater endogenous pain modulation (i.e., there will be a main effect of slow breathing); and (H3) there will be an interaction between yoga posture performance and slow breathing conditions such that the largest reduction in pain sensitivity and endogenous pain modulation will result for those who breath slowly while performing yoga postures (i.e., those who perform Vinyasa style yoga).

This study was the first, to our knowledge, to explore whether a single session of yoga influences central nervous system pain modulatory processes. Results from this study found heat pain intensity ratings were on average slightly lower (<.50 raw score units) but the main effects of yoga and breathing and their interaction were statistically nonsignificant. When compared to the non-yoga conditions, the yoga conditions resulted in a significant reduction in state anxiety scores. Slower frequency breathing had no effect on state anxiety. The absence of a reduction in state anxiety observed here may have happened for several reasons, including the low pre-condition anxiety scores or that a larger reduction in breathing frequency may have been required to produce the outcome.

Results did not support hypotheses regarding the influence of yoga (H1), slow breathing (H2) and their interaction (H3) on heat pain sensitivity. These observations are generally consistent with the only prior experiment is this literature and which found that a single session of yoga did not significantly influence pain provoked by pressure stimuli [129]. Nevertheless, the main effect for yoga in the present experiment was in the hypothesized direction, still small in magnitude. Specifically, heat pain sensitivity was reduced after yoga to a small magnitude (~ ¼ standard deviation) compared to the seated with normal breathing condition (Group A). That these effect sizes on pain were not larger after the yoga conditions, especially given the significantly greater expectations for reduced pain with yoga, is also consistent with the only prior experiment in this literature [130]. A larger main effect for yoga may have been observed with yoga of a higher intensity. Although the hypotheses were not supported, this study provides a steppingstone to determine at what is the minimal dosage of yoga to start seeing positive benefits to improved pain and overall well-being. With the improvements found in anxiety, this can also be seen as enhanced stress management. Physically, heat pain ratings were lower, although not statically significant, but reductions with those experiencing chronic pain, those decreases may be clinically meaningful. With repeated sessions, those small reductions would contribute to greater reduction of pain and improved disability. This trend would lean towards less use of pain medication.

A possible explanation for the findings regarding the breathing main effect is testing was stopped due to COVID-19 pandemic; data were analyzed from only 11 participants who completed the slow breathing while seated condition (Group B). Though, this seems unlikely because the slow breathing effects were in the opposite direction of that hypothesized; that is, the pain change with CPM was less to a small degree with slow breathing compared to normal breathing in both the yoga and non-yoga condition. To our knowledge no other studies have addressed the acute effect of slow, controlled, deep or yogic breathing on conditioned pain modulation.

Pioneered by Beck and Ellis, cognitive behavioral therapy is a form of psychological treatment that has been shown to be successful treating various challenges such as: depression, anxiety disorders, alcohol and drug use problems, marital problems, eating disorders and severe mental illness [159, 160]. Conversely, mindfulness is commonly defined as the ability to be present; with and keen and non-judgmental awareness of one's thoughts and emotions. The are several types of mindfulness interventions. The first to treat chronic pain was mindfulness-based stress reduction [161]. Mindfulness-based stress reduction is a formal 8-week intensive intervention that consists of 2.5 to 3 hours weekly sessions that includes exercises of body scans, gentle yoga, and meditations. A pilot study comparing the effects of mindfulness-based and cognitive-behavioral stress reduction in 50 participants found mindfulness-based stress reduction subjects improved on all eight outcomes, with all of the differences being significant while cognitive-behavioral stress reduction subjects improved on six of eight outcomes, with significant improvements on well-being, perceived stress, and depression [162]. These results imply that mindfulness-based stress reduction and cognitive-behavioral stress reduction may both be effective in reducing perceived stress and depression, mindfulness-based stress reduction may be more effective in increasing mindfulness and energy and reducing pain. Furthermore, a study conducted by Brunner et al., 2017, investigated the impact of a brief yoga program on working memory maintenance, manipulation and attentive mindfulness [163]. They found that a 6-session yoga program was coupled with improvement on manipulation and maintenance measures as well as enhanced mindfulness scores.

Future research should investigate the underlying mechanism(s) that affect pain sensitivity in the chronic pain populations. These studies should be more well-designed, large-scale and have appropriate control conditions. Implications of these finding provide interesting and potentially important for generating a body of research that can form an empirical basis for creating non-pharmacological and safe alternatives to acutely address pain management.

A recent meta-analysis examines the effects of yoga training on chronic pain [103], found that prior yoga exposure significantly moderated pain intensity and disability scores. Potential limitations to this variable are that studies often do not report prior yoga experience and it typically used and an exclusion citation in research. Substantial information is needed on how prior yoga exposure/experience is measured. There is no uniform measure for this variable. This self-report measure should include details such as type of yoga practiced, number of classes attended or approximate hours, the time of day classes were attended, if they were instructor led or not, and the number of months with regular practice. New studies should be conducted to examine yoga experience as a moderator to fully understand is influence in pain populations. Moreover, research should continue to explore the components of yoga in order to further understand the aspects of asana and pranayama, their distinctive psychophysiological effects as well as collectively.

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APPENDICES
A. Demographics and Health Questionnaire

Date________________ ID _________

What is your age? _________

Ethnicity origin (or Race): Please specify your ethnicity

- ☐White/Caucasian
- ☐Hispanic or Latino
- ☐Black or African American
- ☐Native American or American Indian
- ☐Asian/Pacific Islander
- ☐Other ____________

What is your height? ___________

What is your weight? ____________

During the past two years have you had chronic pain, defined as pain on most days per week lasting for 6 or more months? No Yes

If you had chronic pain, what was the usual intensity of your chronic pain? Mild Moderate Severe

If you had chronic pain, was your chronic pain present in one body location or more than one? One More

What was (were) the body location(s) of your pain?

How much sleep do you get on average per night? ____ hours

(e.g., 7.5 hours = 7 hours and 30 minutes8.25 hours = 8 hours and 15 minutes)

B. Medical Questionnaire		
Please read the statements carefully and answer each one honestly: check YES or NO.		
Yes	**No**	
		1. Are you currently pregnant?
		2. Do you currently have, or have you ever had high blood pressure?
		3. Are you currently taking any prescription medicine (other than oral contraceptives)?
		4. Are you currently taking nonprescription pain medications, cold medication or decongestants?
		5. Do you currently have, or have you ever had a pulmonary/lung condition?
		6. Do you currently have, or have you ever had circulatory problems (such as diabetes, Reynaud's Syndrome, blood clots or PAD)?
		7. Do you currently have, or have you ever had any type of muscular, vascular or nerve disease?
		8. Do you have a history of hives brought on by exposure to cold?
		9. Do you have a history of hives brought on by exposure to heat?
		10. Do you currently have, or have you ever had a history of vasculitis?

C. Physical Activity Readiness Questionnaire (PAR-Q)		
Date:		**Participant ID:**
Please read the statements carefully and answer each one honestly: check YES or NO.		
Yes	**No**	
		1. I have a heart condition and my healthcare professional recommends only medically supervised physical activity.
		2. During or right after I exercises, I often have pains or pressure in my neck, left shoulder, or arm.
		3. I have developed chest pain within the last month.
		4. I tend to lose consciousness or fall over due to dizziness.
		5. I feel extremely breathless after mild exertion.
		6. My healthcare provider recommended that I take medicine for high blood pressure or a heart condition.
		7. I have a bone or joint problem that limits my ability to do moderate-intensity physical activity.
		8. I have a medical condition or other physical reason not mentioned here that might need special attention in an exercise program.

D. Leisure time physical activity questionnaire

Godin Leisure-Time Exercise Questionnaire

1. During a typical **7-Day period** (a week), how many times on the average do you do the following kinds of exercise for **more than 15 minutes** during your free time (write on each line the appropriate number).

	Times Per Week
a) **STRENUOUS EXERCISE** **(HEART BEATS RAPIDLY)** (e.g., running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)	__________
b) **MODERATE EXERCISE** **(NOT EXHAUSTING)** (e.g., fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, popular and folk dancing)	__________
c) **MILD EXERCISE** **(MINIMAL EFFORT)** (e.g., yoga, archery, fishing from river bank, bowling, horseshoes, golf, snow-mobiling, easy walking)	__________

2. During a typical **7-Day period** (a week), in your leisure time, how often do you engage in any regular activity **long enough to work up a sweat** (heart beats rapidly)?

OFTEN	SOMETIMES	NEVER/RARELY
1. ☐	2. ☐	3. ☐

Date________________ ID _________

E. Pre-Test Survey

Are you dressed appropriately for experimental condition? No Yes

If no then reschedule.

What time did you fall asleep last night? ________________

What time did you wake up this morning? ______________

How many minutes of being awake after falling asleep did you have last night? ____________

Have you consumed any caffeine today? If so, how much did you take (i.e. coffee, tea, soda, supplements) and at what time? No Yes

____

Are you in any current pain today? No Yes
If so, have you taken any pain medications today? No Yes

Have you taken any cold medications or decongestants today? No Yes

Have you taken any mood-altering medications today? No Yes

Is there anything really unusual that has happened in your life today? No Yes

F. Expectation Measures

Expectation for Change in Heat Pain

Date________________ ID _________

What do you expect will happen to feelings of heat pain in your right arm when you put your left hand into ice water?

a) it will decrease the pain

b) it will not change the pain

c) it will increase the pain

If you answered a or c indicate the percentage change you expect from 0 to 100%, otherwise indicate N/A

Percentage change expected_______________________

Expectation for Change in Mood

Date________________ ID _________

What do you expect will happen to your mood in response to the session?

a) it will worsen my mood

b) it will not change my mood

c) it will improve my mood

If you answered a or c indicate the percentage change you expect from 0 to 100%, otherwise indicate N/A

Percentage change expected_______________________

Expectation for Change in Pain Sensitivity

What do you expect will happen to your sensitivity to pain in response to the yoga session?

a) a given stimulus will feel less painful than usual

b) it will not change

c) a given stimulus will feel more painful than usual

If you answered a or c indicate the percentage change you expect from 0 to 100%, otherwise indicate N/A

Percentage change expected_______________________

G. Yoga Exposure Survey

Have you ever practiced yoga before?   No   Yes

If yes, how often do you usually practice yoga?
Every day
Every week
Every month
At least a few times per year

When I previously practiced yoga, usually it was:

a) home-based
b) studio-based
c) about half home-based and half studio-based

If you have previously practiced yoga, what type of yoga did you most frequently practice?

Have you ever practiced Vinyasa yoga?

a) No
b) Yes
c) Not sure

H. Pain Intensity Scale

Instructions. You are about to undergo a conditioned pain modulation test. The scale before you contain the numbers 0-10. You will use this scale to assess perceptions of pain experienced in your _______ (right forearm or left hand and right forearm). In this context, pain is defined as the intensity of hurt that you feel. Don't underestimate or overestimate the degree of hurt you feel, just try to estimate it as honestly and objectively as possible.

The numbers on the scale represent a range of pain intensity from "very faint pain" (number 1/2) to "extremely intense pain-almost unbearable" (number 10). When you feel no pain, you should respond with the number 0. If you experience extremely intense pain that is almost unbearable, you should respond with the number 10. If the pain is greater than 10, respond with the number that represents the pain intensity you feel in relation to 10. For example, if the pain is twice as intense as 10 give the number 20.

Repeatedly during the test, you will be asked to rate the feelings of pain from your _______ (right forearm or left hand and right forearm). When rating these pain sensations, be sure to attend only to the specific sensations in your _______ (right forearm or left hand and right forearm) and not report other pains you may be feeling.

0	**NO PAIN AT ALL**
1/2	VERY FAINT PAIN (just noticeable)
1	WEAK PAIN
2	MILD PAIN
3	MODERATE PAIN
4	SOMEWHAT STRONG PAIN
5	STRONG PAIN
6	
7	VERY STRONG PAIN
8	
9	
10	EXTREMELY INTENSE PAIN (almost unbearable)
*	UNBEARABLE PAIN

I. Pain Unpleasantness Scale

Instructions. The scale before you contain the numbers 0-10. You will use this scale to assess perceptions of UNPLEASANTNESS experienced from your PERCEIVED PAIN. In this context, unpleasantness is defined as the quality of hurt that you feel; how annoying or bothersome it feels. Don't underestimate or overestimate the degree of the sensation, just try to estimate it as honestly and objectively as possible.

The numbers on the scale represent a range of pain unpleasantness from "very faint unpleasantness" (number 1/2) to "extremely unpleasant almost unbearable" (number 10). When it is not unpleasant, you should respond with the number 0. The sensation is so strong it is extremely unpleasant that is almost unbearable, you should respond with the number 10. If it is greater than 10, respond with the number that represents the unpleasantness you feel in relation to 10. For example, if it is twice as intense as 10 give the number 20.

Repeatedly during the test, you will be asked to rate the feelings of unpleasantness from your _______ (right forearm or left hand and right forearm. When rating these sensations, be sure to attend only to the specific sensations in your _______ (right forearm or left hand and right forearm) and not report other sensations you may be feeling.

*	**UNBEARABLE**
10	EXTREMELY UNPLEASEANT (almost unbearable)
9	
8	
7	VERY UNPLEASANT
6	
5	UNPLEASANT
4	
3	MODERATELY UNPLEASANT
2	MILDLY UNPLEASANT
1	WEAKLY UNPLEASANT
1/2	VERY FAINT UNPLEASANTNESS (just noticeable)
0	NOT UNPLEASANT

J. Pain Intensity – during the testing session

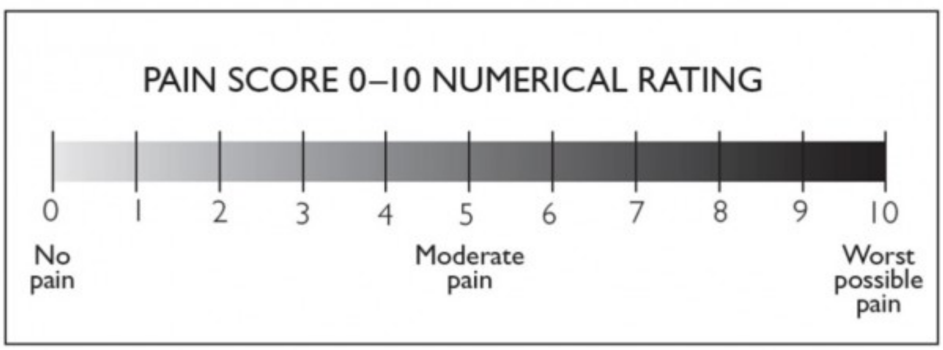
We want to know the intensity of the pain you may have felt during the session you just completed.

Instructions. Please indicate your level of pain experienced **during** the session, ranging from "0" (no pain at all) to "10" (highest pain imaginable). Be as honest and accurate as possible.

Peak pain at any point during the session: ________

Overall pain at any point during the session: ________

If you felt any pain, what was the dominant location of the pain?

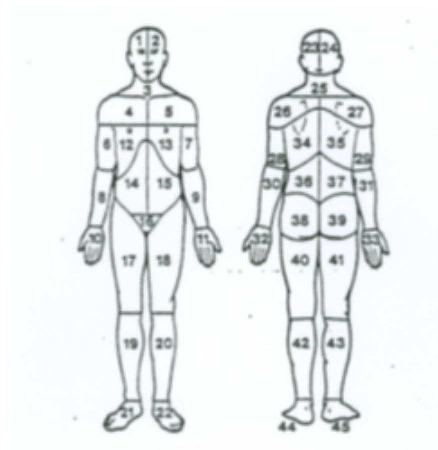


K. Current pain location and intensity

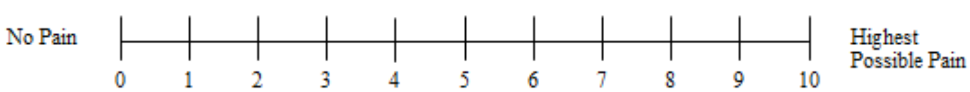
PAIN QUESTIONNAIRE

1. Are you experiencing any pain whatsoever today? ______________ (Yes or No)

2. If you answered yes then draw on the figure below to indicate the locations on your body where you feel pain.



3. How much does the pain hurt? Use the scale below to indicate the overall intensity of the pain you are feeling. A score of 0 represents "no pain." A score of 10 represents "the highest possible pain intensity" that you can imagine.



L. Rating of Perceived Exertion

Instructions. Use the numbers and the words on the scale below to rate the intensity of the effort you put yoga session you just completed. Twenty is a true maximal effort – the type you would give if your life was on the line. Six is no effort at all, such as sitting quietly. You can use whole numbers and half numbers such as 14, 12.5 or 16.5. A rating of 6.5 would be a minimal and just noticeable effort. Appraise your feelings of exertion as honestly as possible. Your own feeling of effort and exertion is important, not how it compares to other people's. Look at the scales and the expressions and then give a number that best represents the intensity of the effort you put your session.

6	No exertion at all
7	
7.5	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

M. Guided Breathing/Meditation Exposure Survey

Have you ever practiced meditation or guided breathing sessions before? No Yes
If yes, how often do you usually practice the technique?

a) Every day
b) Every week
c) Every month
d) At least a few times per year

When I previously practiced, usually it was:
a) On my own
b) Through a meditation teacher or app
c) About half the time on my own and half time with a teacher or an app

If you have previously practiced, what type did you most frequently practice (i.e. guided visualization, mindfulness, kundalini, etc)?

N. Post-Participation Questionnaire

I fully participated in the video session:

- o Completely Agree
- o Mostly Agree
- o Slightly Agree
- o Mostly Disagree
- o Completely Disagree

What do you believe was the purpose of this experiment?

O. Video Links

Sitting + normal breathing-	Group A: https://youtu.be/Z6uettyYtxw
Sitting + slow breathing-	Group B: https://youtu.be/gdwvonkVxyM
Yoga postures + normal breathing-	Group C: https://youtu.be/wRX97H6edL4
Yoga postures + slow breathing-	Group D: https://youtu.be/vPOK9NAE8dI

P. Yoga Sequence/Protocol

All Levels Head to Toe with modifications to challenge and support

Ujayii pranayama tutorial 2 minutes

Opening : Intention
Seated neck stretch
Seated cat/cow - focus neck mobility, core
Seated Twist - focus length, space
Sitting on Knees - kapalabhati breath of fire
Thread Needle R/L - focus mobilizing upper back
Childs pose 1-2 minutes - focus deepening breath
Dog pose 5 breaths - focus hands, feet, core
Forward fold or Ragdoll - 5 breaths
Mountain Pose - 3-5 breaths - focus grounding/anchoring
Sun A 3x's - develop rhythm and pace/link breath and body
1. Slow with knees/chest/chin - focus strength/core - step forward
2.Slow with chaturanga
3.One breath/One movement with Chaturanga
Child's pose - 5 b observe mind + body
Sun B 3x's -
1.Slow with knee to chest hover/Anjanayasana/low lunge &/or prayer twist 3-5 breaths
2.Slow with Warrior I hold/cactus arms
3. One breath/One movement
Child's pose - 5 breaths - return to focus/intention/breath
Yogi toe lock - bend knees as needed - sit bones up - crown of head down
Mountain Pose
Deep in the Hips + Hamstrings:
Forward Fold
Vinyasa
R foot forward to R thumb - Warrior II - Side Angle Extended - Reverse Warrior
Child - Dog - or Vinyasa
L side repeat - focus awaken, open, strengthen, integration
Child - Dog - or Vinyasa
Forward fold - Pada Hastasana - focus mobilizing middle back/thoracic spine 5 breaths
Core + Inversions:
Have a seat - Half boat/boat option to pulse
Child's Pose
Headstand variations: dolphin
Twist: create suppleness in spine and surrounding tissues

Seated opposite hand to foot twist / bent knee option
Baddah Konasana/reclined cobbler pose - fold - focus - surrender
Backbend: grounding revitalizing
Bridge options: with block, wheel
Feet wide knees together to rest -
5 breaths
Mild twist: to balance spine and offer a moment of pause for student
Reclining twist - option to stack bottom leg
Transition to Forward bend: rock forward and back 2-3x's
Seated forward bend
Shoulder stand: option for supported with block
Closing: legs up/shaking optional
Happy Baby
Savasana
Seated Breath/Peace In - Peace Out