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THE ROLE OF DIAPHRAGMATIC BREATHING IN SELF-REGULATION SKILLS TRAINING

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THE ROLE OF DIAPHRAGMATIC BREATHING
IN SELF-REGULATION SKILLS TRAINING

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Arts & Sciences at the University of Kentucky

By

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2017

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ABSTRACT OF DISSERTATION

THE ROLE OF DIAPHRAGMATIC BREATHING IN SELF-REGULATION SKILLS TRAINING

A central component of many psychological interventions is breathing training. Breathing training protocols based on a mindfulness or a cognitive behavioral therapy (CBT) have demonstrated value in the management of psychological and medical ailments. Yet, despite the wealth of literature examining each approach, little direct comparison exists. An additional concern is the proliferation of smart phone health (mHealth) applications (apps) providing breathing training with little empirical evidence to support their clinical use. A possible explanation for the interest in breathing and mHealth apps is the growing body of literature indicating breathing training provides wide ranging health benefits through improved stasis of the autonomic nervous system (ANS). As ANS dysregulation underlies many chronic health conditions such as persistent temporomandibular disorders (TMDs), there is a need for empirical research to identify the most effective modality of breathing training and validate the clinical efficacy of breathing based mHealth apps.

Study One compared the effectiveness of a mindfulness breathing meditation (MB) and a CBT based protocol teaching diaphragmatic breathing (DB) to improve biomarkers of ANS stasis. An attention control approach based on the Nolen-Hoeksema task (C) was included as a comparison group. Ninety participants were randomly assigned to either the MB, DB, or C condition. Within each condition, 30 participants were provided skills training with practice time and completed a behavioral self-regulation task. Participants in the DB condition approach had significantly lower breathing rates than those in the MB and C conditions ($p < .001$). DB condition participants experienced improvements on high-frequency heart rate variability ($p < .05$) and the standard deviation in NN intervals ($p < .001$), which served as indicators for ANS stasis. No differences were found between conditions on the behavioral self-regulation task (p 's $> .05$). Given these results, the DB training protocol was converted into a mHealth app to facilitate a clinical trial with patients suffering persistent TMDs.

Study Two examined the additive benefits of including the mHealth app with standard dental care (SDC+) versus standard dental care alone (SDC). Nineteen patients seeking care for persistent TMDs were recruited. All participants were asked to track daily ratings of pain (VAS), relaxation (RR), and complete weekly assessments on several comorbid psycho-social factors. Within the SDC+ condition participants were asked to track the proximate effects of

each breathing practice on VAS and RR ratings. Given a high drop-out rate (nine participants) and low overall sample size ($N = 10$), results are exploratory at best. Within the SDC+ condition, results indicated reliable improvements in average VAS and RR ratings from before and after SDC+ participants used the mHealth app (p 's $< .05$).

Within a one session training paradigm, results supported the use of a DB based intervention above the use of a MB or C intervention. Future research should consider the effects of having multiple training sessions. Study Two results were complicated by a limited sample size and failed to provide a clear picture of whether the conjunctive treatment in the SDC+ condition provided additional symptom relief above traditional dental care alone. Although exploratory results indicated the mHealth app provided temporary improvements in pain and feelings of relaxation, a well powered trial is needed to clarify whether the finding represents an enduring treatment effect.

KEYWORDS: Temporomandibular disorders, myalgia, chronic pain, diaphragmatic breathing, smart phone

Matthew E. B. Russell

December 14, 2017

THE ROLE OF DIAPHRAGMATIC BREATHING
IN SELF-REGULATION SKILLS TRAINING

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Chapter One: Introduction

Temporomandibular disorders (TMDs) have a prevalence rate of 10-15% and represent a debilitating chronic pain condition (Roldán-Barraza, Janko, Villanueva, Araya, & Lauer, 2014). Chronic pain occurs when pain persists past the expected tissue healing time of three months and is described as an unpleasant sensory and emotional experience without apparent biological value (Harstall & Ospina, 2003; Flor & Turk, 2015). TMDs are one of the most common chronic orofacial pain conditions and represent a heterogeneous family of musculoskeletal disorders. The average pain intensity of TMDs is comparable to back pain and TMDs often progress into chronic pain conditions (referred to as persistent TMDs from here forward) in 51% to 67% of diagnosed cases (Maixner et al., 2011b). In addition, research has suggested individuals with persistent TMDs endure compromised psychological functioning (Burriss, Evans, & Carlson, 2010; Carlson, 2007; Carlson et al., 1998; Fillingim et al., 2013; Gatchel, Peng, Peters, Fuchs, & Turk, 2007). Although the relationship between pain and psychological functioning is complex and bidirectional, studies indicate individuals with persistent TMDs experience higher base rates for mood and anxiety disorders compared to pain free individuals (Carlson, 2007; Fillingim et al., 2013; Fillingim et al., 2011; Edwards, Dworkin, Sullivan, Turk, & Wasan, 2016). Persistent TMDs are also linked with chronic activation of the sympathetic nervous system, which leads to unnecessary allostatic load on the body and subsequent increased susceptibility to other persistent pain conditions (Goldstein & McEwen, 2002; Kendall-Tackett, 2010; Maixner et al., 2011a; McEwen, 2006; Purdy, 2013; Sapolsky, 2004). Despite the complex nature of persistent TMDs, interventions can significantly improve symptoms and enable individuals to live high quality lives (Carlson, Bertrand, Ehrlich, Maxwell, & Burton, 2001; Schmidt, Joyner, Carlson, & Hooten, 2013; Roldán-Barraza et al., 2014; Turner, Mancl, & Aaron, 2006).

Traditional Dental Treatment

Currently, there are a variety of dental interventions for TMDs. Most dental providers start with the most conservative and least invasive interventions. If required, interventions shift to

more invasive and irreversible approaches such as surgery or orthodontics (De Boever, Nilner, Orthlieb, & Steenks, 2008; Okeson, 2014). The first treatment approach is often patient education including clenching awareness, habit reversal, soft diet, gentle stretches, sleep hygiene, and functioning within pain free limits. If unsuccessful, more intensive treatments are offered based on each patient's symptom presentation and include the use of more advanced self-regulation skills training, non-steroidal anti-inflammatory medications (e.g. Ibuprofen, Meloxicam), stabilization splint therapy, muscle relaxant medications (e.g. Baclofen, Tizanidine), injections (e.g. Botox), and finally irreversible dental interventions (i.e. surgery, orthodontics, or occlusal adjustments). Despite an arsenal of treatments, patients with persistent TMDs find symptom management is the normative experience rather than symptom resolution.

Symptom management for persistent TMDs consumes considerable patient and clinic resources (Carlson, 2007). Research has indicated a small subset of patients with persistent TMDs account for an estimated 85% of the total costs associated with treating all diagnosed cases of persistent TMDs (Maixner et al., 2011b). Therefore, research identifying risk factors for the development and maintenance of persistent TMDs is essential. Maixner et al. (2011b) advocated a heuristic model of causal influences for the onset and persistence of TMDs. The model identified psychological distress and pain amplification as two overarching phenotypical risk factors that include a constellation of more specific phenotypical risk factors. Given the complex interactions among the two-overarching phenotypical risk factors, efficacious treatment is best achieved through a biopsychosocial framework (Schiffman et al., 2014; Gatchel et al., 2007). The biopsychosocial model of treatment emphasizes that the transition from pain to chronic pain warrants a shift in treatment perspective from disease (pain alone) to illness (pain plus contributing psychosocial factors) (Gatchel et al., 2007). The importance of including psychosocial treatments into traditional medical approaches has received increasing interest.

Psychosocial Treatment

In 2014, a meta-analysis of available randomized clinical trials examined the effectiveness of psychosocial and dental treatments in amelioration of persistent TMD symptomology (Roldán-Barraza et al., 2014). Although interpretations of data were hampered by a limited number of studies containing standardized measures, results suggested participants experienced greater long-term relief from self-reported pain and depression symptoms following a psychosocial intervention compared to standard dental treatment alone. In 2010, Davis et al., found stress management, psychological distress, sleep problems, and psychophysiological self-regulation predicted pain symptoms better than measures of oral parafunction (i.e. problem behaviors associated with the muscles used for chewing). Taken together, adherence to the biopsychosocial model of treatment through incorporation of psychosocial interventions into traditional dental treatments is likely to produce the best patient outcomes.

For a wide range of chronic pain conditions, a 2004 meta-analysis indicated a medium to strong effect size for mindfulness based stress reduction (MBSR) on psychological and pain related outcomes (Grossman, Niemann, Schmidt, & Walach, 2004; Kabat-Zinn, 1982). Through enhanced awareness and balanced acceptance of the experiences in the present moment and mental processes, MBSR or mindfulness based interventions have built a body of literature supporting their ability to reduce negative affect, limit somatization, and improve vitality and coping. The clinical effects of mindfulness based interventions generalize well to persistent TMDs (Chiesa & Serretti, 2011; Grossman et al., 2004; Hofmann, Sawyer, Witt, & Oh, 2010; Merrill & Goodman, 2016).

Another approach is the use of Cognitive Behavioral Therapy (CBT), which is a goal oriented therapy focused on changing cognitions and behaviors related to chronic pain patients' common difficulties. A 2006 meta-analysis demonstrated strong support for CBT's ability to reduce pain interference and depressive symptoms, and to produce clinically meaningful improvements in almost twice as many participants than education/control approaches (Turner et

al., 2006). Although the approach and therapy goals differ between mindfulness and CBT, both offer a means to target the biopsychosocial challenges common to patients with chronic pain conditions through specific skills training.

Considerable literature supports the use of specific components of psychosocial interventions for chronic pain conditions such as general relaxation practices, biofeedback, or specific breathing protocols (Carlson et al., 2001; Gevirtz, 2013; Lehrer & Gevirtz, 2014; Schmidt, Joyner, Tonyan, Reid, & Hooten, 2012; Schmidt et al., 2013; Vaschillo, Vaschillo, & Lehrer, 2006; Merrill & Goodman, 2016). A meta-analysis in 2007 examined CBT, self-regulation (biofeedback, relaxation, and hypnosis), behavioral therapy, and supportive counseling for non-cancerous chronic low back pain. Results indicated clinical improvements were maximized when CBT, including instruction on self-regulation skills, was used in conjunction with multidisciplinary treatments versus medical or psychological treatments alone (Hoffman, Papas, Chatkoff, & Kerns, 2007).

Although multiple mechanisms of change were involved, two possible explanations for symptom reduction are improved self-efficacy for pain management and improved pain coping skills (Turner, Holtzmann, & Mancl, 2007; Burns, Kubilus, Bruehl, Harden, & Lofland, 2003). Several recent reviews of MBSR and similar mindfulness based interventions for chronic pain suggested improved patient pain coping and reduced somatization may be a primary mechanism of psychological symptom and stress reduction (Chiesa & Serretti, 2011). Yet, despite a wealth of material indicating the clinical utility of multidisciplinary treatment including psychosocial interventions, it remains unclear to what degree each intervention influences symptom reduction (Kress et al., 2015). Therefore, a logical next step is to examine specific components of self-regulation interventions in conjunction with traditional medical treatments for chronic pain conditions like persistent TMDs.

The use of breathing for mind-body healing has existed for many centuries and was codified in the 18th century with Zen Rinzai practices but has evolved and been incorporated into

a large array of western behavioral relaxation interventions (Lehrer, Sasaki, & Saito, 1999; Schmidt et al., 2013). One of the primary meditation exercises within mindfulness therapies is bringing present focused and non-judgmental awareness to one's breathing, while CBT interventions use a more didactic approach to teach patients specific breathing interventions. Research has indicated breathing interventions can influence heart rate variability (HRV), which is a biomarker negatively correlated with persistent TMD symptom severity and an indicator of stasis within the autonomic nervous system (Burg, Wolf, & Michalak, 2012; Krygier et al., 2013; Lehrer, Vaschillo, & Vaschillo, 2000; Maixner et al., 2011a; Schmidt et al., 2013). Previous research has indicated chronic pain conditions like persistent TMDs result in decreased HRV and reduce an individual's ability to physiologically self-regulate (Solberg Nes, Carlson, Crofford, Leeuw, & Segerstrom, 2010). Interestingly, research suggests regular activation of self-regulatory systems improves future capacity for more efficient self-regulation (Muraven, Baumeister, & Tice, 1999).

Several breathing based interventions are known to improve HRV and have demonstrated efficacy in management of persistent TMDs or similar chronic pain conditions (Brown, Gerbarg, & Muench, 2013; Carlson et al., 2001; Lehrer, 2007; Schmidt et al., 2012; Schmidt et al., 2013). The etiology of persistent TMDs is complex and often complicated by the bi-directional relationship between physiological symptoms and psycho-social factors. However, evidence supports three possible mechanisms of action for breathing that likely overlap to improve management of persistent pain conditions.

First, chronic pain conditions are consistently linked to dysregulation within the autonomic nervous system, quantified as decreased HRV (Maixner et al., 2011a). HRV reflects vagus nerve control of cardiac inter-beat intervals with increased vagus nerve influence represented by higher HRV (Fried & Grimaldi, 1993, p.118; Porges, 2007). HRV is also influenced by the baroreflex. The baroreflex modulates blood pressure through changes in heart rate and contraction of blood vessels in efforts to maintain a consistent blood pressure (Lehrer et

al., 2003; Lehrer & Gevirtz, 2014; Porges, 2007). Research indicates vagal and baroreflex control over HRV is optimally increased through breathing diaphragmatically at a rate of 5.5 to six breaths-per-minute (Lehrer et al., 2000; Lehrer & Gevirtz, 2014; Russell, Scott, Boggero, & Carlson, 2016). Within this range, the effects of breathing on HRV are amplified by compensatory fluctuations in heart rate through the baroreflex (Lehrer et al., 2003).

Breathing training also provides relief for persistent pain conditions through reductions in neuronal activity. Chronic pain conditions are associated with hyper-excitability of neurons in sensory pathways (Rogawski & Löscher, 2004) which contribute to increased pain via a positive feedback loop of aberrant nociception (Nordin, Nyström, Wallin, & Hagbarth, 1984; Ochoa & Torebjörk, 1989). Similar to anti-epileptic drugs (e.g. gabapentin) that are hypothesized to inhibit neuronal hyperactivity (Yogeeswari, Ragavendran, & Sriram, 2007), paced breathing interventions may affect neuronal firing thresholds thereby providing pain relief (Fried & Grimaldi, 1993). During inhalation, sodium (Na^+) ions flow into neurons as the transmembrane is depolarized and trigger an action potential. During exhalation, the transmembrane is polarized which blocks an influx of sodium ions and subsequently prevents an action potential. Therefore, increased respiration rates result in higher rates of sodium channel neuronal firing whereas lower respiration rates can limit the frequency of neuronal firings providing a reduced pain experience (Glynn, Lloyd, & Folkhard, 1981). Research on hyperventilation supports this mechanism of action (Fried, 1987; Fried & Grimaldi, 1993).

The final mechanism of action for breathing on persistent pain conditions is related to blood chemistry. Research suggests lower breathing rates facilitate a balanced exchange of oxygen and CO_2 during periods of physical inactivity, reduce neuronal firing, and support the bicarbonate ion buffer system (Chen, Eldridge, & Wagner, 1991; Fried & Grimaldi, 1993). The bicarbonate ion buffer system regulates blood pH between a range of 7.3 to 7.5 ideally (for a complete review of this system see Hall & Guyton, 2011). When blood becomes too acidic, the body experiences a range of symptoms easily relieved through increased respiration. However,

when the body experiences low levels of CO₂ within the blood (hypocapnia and corresponding alkalosis) it can result in increased neuronal firing, muscle fatigue, vasoconstriction, increased sympathetic tone, and increased pain (Fried & Grimaldi, 1993; Laffey & Kavanagh, 2002). Low concentrations of CO₂ within the blood are also associated with increases in pH level that can reduce the ability of oxygen to disassociate from hemoglobin to replenish cells. Taken together, proper breathing likely improves pain management through multiple mechanisms.

Breathing interventions are also linked to positive effects on neural regions associated with emotion regulation, cognitive function, attention, subjective awareness, and decision making (Brown, Gerbarg, & Muench, 2013; Carlson et al., 2001; Fried & Grimaldi, 1993 p. 87-88; Kaushik, Kaushik, Mahajan, & Rajesh, 2005; Mehling, Hamel, Acree, Byl, & Hecht, 2005; Zutra, Fasman, Davis, & Craig, 2010). Further, research has suggested proper breathing training may prevent hypoxic events and protect against aggravation of anxiety symptoms, depressive symptoms, or increased pain sensitivity (Brown, Gerbarg, & Muench, 2013; Fried & Grimaldi, 1993 p. 88-92), which are both comorbid conditions for persistent TMDs (Greenspan et al., 2011). Despite less evidence for a direct effect of breathing on psychological distress, the high comorbidity of psychological distress within patients suffering persistent TMDs warrants consideration of a behavioral intervention likely to affect both psychological and physical systems (Fillingim et al., 2013).

Current Study

Given the support for breathing interventions with patients suffering persistent TMDs, the present project first compared the efficacy of breathing interventions modeled after mindfulness breathing meditations and CBT-oriented diaphragmatic breathing training protocols. Then, the training approach found to be most effective, was converted into a smart phone health (mHealth) application (app) to improve accessibility and facilitate a clinical trial with patients suffering persistent TMDs. Both studies explored important theoretical questions. Despite previous

literature suggesting both mindfulness and CBT based approaches for breathing training are effective at increasing HRV, little research exists directly comparing the two (Kabat-Zinn, 2005).

Therefore, the first study tested the effects of different training approaches for breathing based relaxation strategies. A 3x3 between-subjects design was used to examine the effects of a mindfulness based breathing training, CBT based training on diaphragmatic breathing, and an attention control approach on HRV indices and other indicators of psychological health. For the second study, the training approach found to be most effective from the first study (e.g. CBT-based diaphragmatic breathing) was used to create an mHealth app.

With the widespread availability of smart phone devices as a platform for anytime/anywhere health interventions and their cost efficiency, mHealth apps are fast becoming a popular alternative to clinic based behavioral interventions (Luxton, Hansen, & Stanfill, 2014). Given the positive outcomes from breathing training, there is considerable effort on developing technology assisted breathing interventions (Chittaro & Sioni, 2014a, 2014b; Luxton et al., 2014; Mani, Kavanagh, Hides, & Stoyanov, 2015; National Center for Telehealth & Technologies, 2011a, 2011b). The United States Department of Defense in conjunction with the Veteran's Health Administration has committed substantial resources to develop several mHealth apps focused on diaphragmatic breathing training (National Center for Telehealth & Technologies, 2011a, 2011b). In addition, it is noteworthy that a recent review of mindfulness based mHealth apps resulted in 560 unique options with 23 considered "high quality", all of which included a breathing meditation (Mani et al., 2015). The second study evaluated the clinical effectiveness of a mHealth app within a clinical population of patients suffering from persistent TMDs. As persistent TMDs represent an array of disorders with a broad range of etiologies, the second study focused on persistent TMDs with a muscle based etiology. Participants were required to have a primary diagnosis of myalgia (i.e. local myalgia, myofascial pain, and myofascial pain with referral) based on the Research Diagnostic Criteria for TMDs (Schiffman et al., 2014). The

mHealth app was evaluated by examining standard dental care alone (SDC) versus standard dental care plus the mHealth app (SDC+).

The second study had two main objectives. The first objective was to evaluate the effectiveness of the mHealth app in teaching slow paced diaphragmatic breathing. Following treatment, we anticipated SDC+ participants would show lower resting breathing rates than SDC participants. We also anticipated SDC+ participants would show increased HRV, diaphragm muscle engagement, and end tidal CO₂ (ETCO₂) measurements as compared to SDC participants. The second objective was to assess the intervention's ability to improve clinical outcomes above standard dental interventions. We anticipated SDC+ participants would report greater reduction in self-report measures of pain than the SDC participants. It was also expected SDC+ participants would have greater improvement than the SDC participants on measures of overall perceived stress, pain severity, pain interference, psychological distress, sleep quality, and physical activity levels. Finally, we expected participants' improvement on outcome measures, within the SDC+ condition, would be moderated by intervention engagement. Intervention engagement was quantified as the interaction of frequency of practices, duration of each practice, and overall treatment duration.

Although the second study was modeled after two clinical trials that supported the use of diaphragmatic breathing skills training for persistent TMD symptom management (Carlson et al., 2001; Schmidt et al., 2013), we anticipated the potential impact of several confounding factors. Previous research indicated a critical intervention dosage of 30 minutes of breathing practice per day on average is necessary to obtain significant improvement on measures of symptom severity (Schmidt et al., 2013). We attempted to mitigate this concern through the use of monetary incentives described below. In addition, similar clinical trials restricted treatment length to two weeks (Schmidt et al., 2012; Schmidt et al., 2013) instead of allowing treatment length to vary based on the dental treatment plan. Although imposing arbitrary treatment lengths may limit generalization to standard dental treatment practices, a specific treatment length may improve

treatment adherence and limit participant attrition. Another concern was whether TMD symptom severity would follow either a persistent or recurrent pattern. If participants suffer from recurrent TMD rather than persistent TMD, a longitudinal clinical trial may be vulnerable to recidivism of symptom severity. The concern is not easily addressed but semi-standardized endpoints were used in Study Two to mitigate any potential effects from recurrent TMDs.

Chapter Two: Study One Methodology

All procedures were approved by the University of Kentucky internal review board and all participants agreed to participate via an informed consent protocol. The study investigated the effects of two breathing entrainment approaches on HRV indices, a behavioral measure of self-regulation, and questionnaires of state mindfulness. A mixed model design was used. The between-subjects factor was participant assignment to either the mindfulness breathing condition (MB), diaphragmatic breathing condition (DB), or the Nolen-Hoeksema attention activity condition (C). The within-subjects factor was measurement of HRV and additional physiological measures during the five-minute baseline recording (BL), during six-minute condition specific skills practice session (PRAC), and during a 16-minute lab based measure of behavioral self-regulation with a cued go/no-go test (CT). At baseline, participant demographics and state levels of mindfulness were recorded.

Participants and Recruitment Methods

Participants consisted of 90 University of Kentucky undergraduate students who were self-selected volunteers screened for the inclusion criteria set forth below. Given the focus on respiration, autonomic nervous system modulation through breathing training, and evaluation of participants' capacity to sustain attention and regulate their inhibitory control, participants were screened for pertinent medical conditions. All participants were screened for the presence of chronic respiratory conditions (e.g. asthma, COPD), hypertension, gastrointestinal disorders, or neurodevelopmental disorders (e.g. ADHD) through self-report questions prior to study inclusion. Volunteer participants reporting these conditions were excluded from the project. Given the use of colored cues in the lab test of behavioral self-regulation, participants were also screened for self-reports of color-blindness and excluded if color blindness was indicated.

Treatment Conditions

Participants in the MB, DB, and C conditions were provided directions with audio and visual prompts with an in-room computer. Instruction lasted between six and seven minutes and

pre-recorded scripts were used (see script samples below). Participants were asked to practice the condition specific technique for five minutes during a skills practice session.

Participants in the DB condition were instructed on how to breathe from the diaphragm muscle and follow a 4-2-4 breathing pace (inhale for 4 seconds, exhale for 2 seconds, pause for 4 seconds). MB participants were instructed on how to observe the movements and sensations of their breathing in a nonjudgmental way. No specific instructions on mechanics or pace of breathing were provided. C participants were asked to imagine and focus on a series of objects and settings, to serve as a distracting manipulation that is cognitively engaging but not focused specifically on breathing.

Mindfulness Breathing Meditation. “We are very interested in understanding your responses to the study procedures. We will guide you through focusing your attention on your breathing, such as noticing the way your breath flows in, fills your lungs, and exits your body. This mindful awareness, or mindful breathing, will be the next part of today’s study experience.”

“Please begin by making yourself comfortable in the chair. Coming away from the back of the chair so your spine can be self-supporting, so that your back, and neck, and head are in line in an erect posture, but not stiff. The shoulders can be dropped and relaxed, so that your posture embodies a sense of dignity, a sense of being awake, aware, in touch with this moment, and letting your eyes close, with smooth eyelids and smooth forehead. Your arms resting at your sides or in your lap, in whatever way feels comfortable.” (Pause for 5 seconds)

“Coming now to focus on your breathing. Focusing on wherever you feel the breath moving most distinctly, in and out of your body. This may be at the tip of the nose, the back of the throat, or the chest, or down in the belly, down in the abdomen, as it rises on the in-breath, and falls away on the out-breath. Noticing, precisely, the sensations that accompany each in-breath and each out-breath. Each breath is unique; each has different sensations. Simply tuning into each one in its own time, giving each its own attention. Just this breath coming in. Just this

breath going out. Allowing the breath to anchor you in the present moment.” (Pause for 10 seconds)

“And bringing your mind back to the present breath whenever you notice it’s wandered away. And this may happen many times. And just as often as it happens, then very gently bringing it back. Sometimes the mind wanders for a few moments, and sometimes it wanders for a long time. And it’s possible to find yourself judging and criticizing yourself for the wandering mind. But that’s what minds do. And so, the task is not to try to still or clear the mind of any thoughts, but simply to notice what it’s doing, and then gently bringing it back when you notice that it’s wandered. So, if that happens, many times, bringing it back, just as many times, beginning over and over and over again, with the next in-breath or the next out-breath. And using the stretches of silence to carry on this work by yourself (Pause for 20 seconds). And now, expanding your awareness around the breath, so that you’re aware of the sensations as your breath fills your body. Allowing yourself to be open to these sensations, so that you’re able to feel what’s here, right now. What sensations are you feeling with your breath in the moment?” (Pause for 10 seconds)

“And if your attention wanders from the breath, from these sensations, at any point, coming back to being aware of the breath and the sensations here, in this moment... and in this moment... and in this moment.” (Pause for 20 seconds) “And remembering that this sense of being present is available to you at any moment. By reconnecting with your breath, reconnecting with what’s going on right now, moment by moment.”

A similar pattern of prompts outlined above was provided during the five-minute skills practice session. Prompts occurred at 20- to 30-second intervals.

Diaphragmatic Breathing Training. “We are very interested in understanding your responses to the study procedures. We will help you change your breathing so that the stomach is moving in and out rather than breathing with your chest, as research has shown that this can help

you relax better. This is called “belly breathing,” or “diaphragmatic breathing,” and it can help you relax and maintain calmness in today’s study experience.”

“Please remember the rule: you should do nothing to increase your sense of discomfort while you are practicing the breathing. To start breathing with your stomach, or diaphragm, you should rest in a comfortable position with your head centered, supported, and in the midline of your body. Your eyes are relaxed, with smooth eyelids, and smooth forehead. Your mouth is relaxed, with lips apart, teeth apart, and tongue relaxed. There’s no throat movement. Your shoulders are sloped and even, elbows bent. Your hands will be in a curled relaxed position, not touching one another, knees are apart, and feet are pointing away from one another at a 45- to 90-degree angle. Then, place your right hand just below your rib cage on top of your stomach. Just exhale first to release air from your body. It should be a complete, relaxed release where there is no holding, controlling, or forcing of the release. It is like a balloon collapsing as you let your air go from your body. When you are ready to take your next breath of air in, let the stomach gently rise as if you are pushing your stomach up with the column of air coming in. After you take in a comfortable, normal breath, release your muscles and let the air go just as you did at first when you started the exercise. There is no controlled, gradual release, just let go all at once and have the air move naturally out of your body. Then, pause and rest for a few moments before you take air in again to start another breath cycle. The rest period between breaths is the deepest point of your relaxation when everything is quiet and you relax before taking air in again (Pause for 10 seconds). From the beginning of this training, you should breathe at a pace that makes you feel comfortable (Pause for 5 seconds). You also want to breathe naturally and not too deeply in order to avoid over-breathing or hyperventilation. If you were to feel light-headed or dizzy, chances are you are taking in too much air with each breathe. Take a little less air in on your next breath and the breaths that follow (Pause 10 seconds). Most people find that counting to 4 while air is coming into your lungs may set a natural, relaxed pace. Once the air is released, the rest period is typically the time it takes to count from 1 to 4. So, a starting pace for you can be counted as [air

in-2-3-4, release, and rest-2-3-4] (Phrase repeated twice). Repeat this breathing pattern for several minutes to establish a comfortable, relaxed rhythm to your breathing (Pause for 5 seconds). Let your stomach rise as air enters, then let the stomach fall as you release the air, and let everything rest until taking in your next breath of air (Pause for 10 seconds). Your breathing rate will likely be somewhere between five to six breaths per minute as you practice diaphragmatic breathing. Let your breathing be slow and relaxed as your stomach moves up and down.”

Participants were provided a visual aid to assist with pacing during the five-minute skills practice session. An oval was displayed on the in-room computer that expanded, contracted, and remained still at the suggested breathing pace. No verbal direction was given during the skills practice session.

Nolen-Hoeksema Task. The control group participated in the Nolen-Hoeksema attention activity. The activity asked participants to shift their attention amongst a series of imagined objects or places and has been used as an effective attention control (adapted from Nolen-Hoeksema & Morrow, 1993). The introduction began:

“For the next few minutes, try your best to focus your attention on each of the ideas. As you listen to the items, use your imagination and concentration to focus your mind on each of the ideas. Spend a few moments visualizing and concentrating on each item. Please continue until the experimenter returns. Think about and imagine a boat slowly crossing the Atlantic (~10 second pause). Think about the layout of a typical classroom (~10 second pause). Think about the shape of a large black umbrella.”

The pattern of prompts continued for the duration of the skills training session. A similar introduction with a new set of prompts was used during the five-minute skills practice session.

Dependent Measures

Demographic Information. Participants provided information on their age, year in school, race, dominant hand, and past meditation experience.

Five Facet Mindfulness Questionnaire (FFMQ). The FFMQ is a 39-item instrument used to assess components of mindfulness and forms five subscales: observing, describing, acting with awareness, non-judging of inner experience, and non-reactivity to inner experience (Baer et al., 2008). The FFMQ has demonstrated good consistency ratings, Cronbach's $\alpha = 0.87$ (Baer et al., 2008). FFMQ items are coded on a 1- to 5-point scale, with response options of: 1 = *Never or very rarely true*, 2 = *Rarely true*, 3 = *Sometimes true*, 4 = *Often true*, and 5 = *Very often or always true*.

Breathing. Breathing rate and mechanics were recorded with a BSL-SS5LB respiratory effort transducer and amplifier module with a BioPac MP100 system (Goleta, CA). The sensor was placed around the abdomen below the rib cage and above the navel to measure diaphragm engagement. Breathing rates were recorded as breaths-per-minute (BPM).

Heart Rate Variability. ECG data were collected using a MP100 Biopac System, an ECG100B amplifier, and a three-electrode modified Lead II format. ECG was collected continuously with Acqknowledge software and analyzed with Mindware software (Gahanna, OH) in accordance with established guidelines (Berntson et al., 1997; Malik, 1996). Mindware software provides frequency HRV measures in the high frequency range, which is often associated with parasympathetically mediated effects on the heart (HF-HRV, .15 to .4Hz). It also provides time domain measures of HRV such as the square root of the mean squared differences of successive NN intervals (RMSSD) and the standard deviation of the NN intervals (SDNN). RMSSD and SDNN provide an index of parasympathetic tone on cardiac functioning unaffected by a participant's respiration frequency range. We focused our investigation on the HF-HRV frequency range, RMSSD, and SDNN to assess the effects of each skills training condition on these indices of HRV (Berntson et al., 1997; Lehrer & Gevirtz, 2014; Vaschillo, Vaschillo, & Lehrer, 2006).

Cued Go/No-Go Task. The cued go/no-go task was delivered through an in-room computer using E-Prime experiment generation software (Marczinski & Fillmore, 2003). Each

cued go/no-go trial followed this order: (1) the appearance of a fixation point (+); (2) a blank white screen for 500ms; (3) a cue image, presented for one of five stimulus onset asynchronies (SOAs = 100, 200, 300, 400, and 500ms); (4) a go or no-go target, which remained on the screen until a participant response was entered or 1,000ms elapsed; and (5) a brief inter-trial interval of 700ms.

The cue image was a rectangle (7.5cm X 2.5cm) framed by a 0.8mm black outline. The cue was presented in the center of the computer screen against a completely white background. Each cue image was presented in either a vertical (7.5cm X 2.5cm) or horizontal (2.5cm X 7.5cm) orientation for one of five SOAs. The go (color green) and no-go (color blue) targets were used to fill the interior of the outlined rectangle cue. Participants were instructed to respond or press the (/) key on the computer's keyboard if the cue filled in with green. If the rectangle cue filled in with blue they were to suppress their response (not press any key). Keyboard presses were made with the participant's index finger of their dominant hand.

The cue image orientation (vertical or horizontal) signaled the probability that a go or no-go target would be displayed. Vertically oriented cues preceded the presentation of go targets (green rectangle) on 80% of the trials and no-go targets (blue rectangle) on 20% of the trials. Horizontally oriented cues preceded no-go targets 80% of the time and go targets on 20% of the trials. The frequency of cue-target image pairings allowed the vertically and horizontally oriented rectangles to function as go and no-go cues, respectively. The SOAs ensured participants remained focused on the presentation of each new cue and prevented participants from anticipating the time lapse between cue and target presentation. A complete cued go/no-go test consisted of 250 individual trials with an equal number of the vertical (125) and horizontal (125) rectangle cues. In addition, a complete cued go/no-go test included an equal number of go (125) and no-go (125) target trials, with green and blue rectangles serving as the targets respectively. For each trial, the computer recorded whether a response occurred and the reaction time in milliseconds for that response.

The cued go/no-go task was used to evaluate the participant's ability to inhibit impulses and behaviorally self-regulate. For the present study, we were interested in participants' mean accuracy rates during the go cue and no-go target pairing as a measure of self-regulation. For a detailed description and explanation of the cued go/no-go task, please see Marczinski & Fillmore, 2003.

Procedures

Participants were screened for inclusion criteria through email or a telephone call. Once screened, interested participants were scheduled for an appointment with a research assistant. Participants were randomly assigned to condition (MB, DB, or C) prior to the laboratory visit using a table of random numbers. Upon arrival at the laboratory, participants were provided informed consent, completed the demographics information, and the FFMQ.

After completing the questionnaires, participants were connected to electrocardiogram equipment, a respiratory effort transducer, and they were then asked to sit quietly without movement or conversation for a five-minute physiological baseline recording. Next, based on the pre-determined experimental condition, participants were trained with six to seven-minute-long pre-recorded audio directions on MB, DB, or the C attention activity. For the DB condition a visual prompt was also provided to assist with participants' matching the desired breathing rate. Following training, participants were given five minutes in a skills practice session that included auditory and visual prompts via an in-room computer. For example, participants trained on mindfulness breathing meditation were provided the following prompt during the five-minute practice period, "And if your attention wanders from the breath, from these sensations, at any point, coming back to being aware of the breath and the sensations here, in this moment...and in this moment...and in this moment." HRV measures and breathing rates were recorded throughout the six-minute instruction period and the five-minute skills practice session.

All participants then completed the cued go/no-go task as a measure of inhibitory control and behavioral self-regulation. Physiological measures of HRV and breathing rates were recorded

throughout the cued go/no-go task. Participants were debriefed and dismissed. All participants received course credit for study participation.

Hypotheses

The study aim was to compare the ability of three interventions (MB, DB, and C) to reduce breathing rates, increase HRV, and improve performance on a behavioral measure of self-regulation (cued go/no-go task). For the first hypothesis, we anticipated the MB and DB conditions would show greater reductions in breathing rate than the C group during both the PRAC and CT recordings. In addition, it was anticipated the DB condition would show greater reductions in breathing rate than the MB condition across the PRAC and CT recordings. The second hypothesis predicted both the MB and DB conditions would show higher measurements on HRV incidences than the C condition during the PRAC and CT recordings, but the DB condition would show the most increases in HRV indices. For the third hypothesis, it was predicted the MB and DB conditions would have higher accuracy rates on the task of behavioral self-regulation (cued go/no-go) than the C group. The DB condition was also predicted to have higher accuracy rates than the MB condition on the behavioral self-regulation task (cued go/no-go).

HRV Cleaning and Interpretation

ECG data were visually examined in 60-second tachograms without stage identifiers to avoid experimenter bias. Missing or erroneous heartbeats were cleaned according to the recommendations made by the Task Force and then expanded by the 1997 Committee Report (Berntson et al., 1997, p. 631; Task Force, 1996). Specifically, movement or aberrant heartbeats were visually examined and adjusted for by either measuring the actual R-R interval or interpolating the missing heartbeat. Movement artifacts where heartbeats were not clearly indicated were corrected with a mid-beat replacement. Double-marked R peaks and erroneous R peaks were removed. Based on recommendations from Mindware Technologies, 60-second tachograms with over 10% erroneous beats or tachograms that did not have at least 30

consecutive seconds of measurable data were not included in calculations. Following visual inspection, all participants within each of the three measurement periods had at least 60% of their 60-second tachograms included in analyses. No HRV data were excluded.

All physiological measures were recorded on a minute-by-minute basis. Overall averages were taken for each recording period. No physiological measures were excluded.

Planned Statistical Analyses

All analyses were conducted using IBM SPSS Version 24. No data were missing. All study variables were first checked for normality, homogeneity of variance, sphericity, and outliers using the criteria of three standard deviations. Outliers were identified across several physiological measures. In RMSSD two BL, two PRAC, and two CT outliers were identified. In SDNN, one BL, one PRAC, and one CT outlier were identified. No other outliers were found and all analyses were run excluding the identified outliers. Potential between condition differences in participant demographics or state mindfulness, as measured by the FFMQ, were assessed with a series of ANOVAs.

Means and standard deviations were calculated for physiological variables during BL, PRAC, and CT measurements (Table 2.1). Significant baseline differences were found between conditions for HR and RMSSD. Therefore, mixed model repeated measures multivariate analyses of co-variance (RM-ANCOVAs) were conducted to investigate within-subject differences across study stage (PRAC and CT), between-subjects differences among conditions (MB, DB, and C), and interaction effects, while controlling for baseline differences between conditions. For all other physiological measures (BPM, HF-HRV, and SDNN) mixed model repeated measures multivariate analyses of variance (RM-MANOVAs) were used to investigate within-subjects, between-subjects, and interaction effects.

For all analyses, condition was the between-subjects factor (MB, DB, and C) and study stage (BL, PRAC, and CT) was the within-subject factor or repeated measure. If sphericity was violated for either the RM-ANCOVAs or RM-MANOVAs, the Greenhouse-Geisser correction

was used. Univariate analyses and pairwise contrasts were used to investigate significant omnibus tests. To control for the number of comparisons, the Holm-Bonferroni method was used. The Holm-Bonferroni method is more precise than the overly conservative Bonferroni method, and is considered the most appropriate method to use when dependent variables are correlated with each other. For details of the Holm-Bonferroni method, see Aickin and Gensler (1996).

Several participants had missing data for the behavioral self-regulation task (cued go/no-go) from equipment malfunctions. Data were found missing for five MB, four DB, and four C participants. The data were considered missing at random. As the primary focus was on assessing the impact of the skills training on the participant's ability to self-regulate during the cued go/no-go task, our analyses focused on the go cue and no-go target pairing (Marczinski & Fillmore, 2003). An ANOVA was used to investigate potential differences on mean accuracy rates between conditions (MB, DB, and C).

Table 2.1

Means and Standard Deviations for all Physiological Measures in Study One

Variable	Baselines			Skills Practice Session			Cue Task Session		
	MB	DB	C	MB	DB	C	MB	DB	C
BPM	<i>M (SD)</i> 14.65 (3.33)	<i>M (SD)</i> 15.28 (3.40)	<i>M (SD)</i> 14.62 (3.14)	<i>M (SD)</i> 12.46 (4.23)	<i>M (SD)</i> 7.54 (3.30)	<i>M (SD)</i> 15.08 (3.20)	<i>M (SD)</i> 16.04 (3.16)	<i>M (SD)</i> 15.87 (2.82)	<i>M (SD)</i> 16.32 (2.61)
HR	78.33 (11.50)	72.65 (9.42)	80.93 (10.57)	80.35 (11.64)	72.49 (8.49)	80.22 (9.60)	77.69 (11.12)	72.24 (8.69)	80.02 (9.46)
HF-HRV	6.37 (1.00)	6.94 (1.04)	6.48 (0.73)	6.25 (1.15)	7.16 (0.94)	6.15 (1.07)	6.12 (0.92)	6.70 (0.90)	6.10 (0.97)
RMSSD	36.79 (14.70)	58.34 (22.60)	39.45 (15.45)	38.26 (20.01)	67.68 (26.85)	36.45 (18.44)	41.76 (17.26)	59.45 (26.25)	43.02 (19.98)
SDNN	54.68 (14.52)	64.63 (22.65)	54.41 (16.31)	61.71 (26.13)	97.34 (28.26)	49.73 (21.97)	58.91 (18.34)	66.37 (20.46)	58.91 (18.34)

Note: $N = 90$. MB = Mindfulness Breathing Condition; DB = Diaphragmatic Breathing Condition; C = Nolen-Hoeksema Condition; BPM = breaths-per-minute; HR = heart rate measured as the number of beats in 60 seconds; HF-HRV = High frequency heart rate variability (.15 to .4Hz); RMSSD = root mean squared of the successive differences between adjacent NN peaks measured in milliseconds; SDNN = standard deviation in NN interval measured in milliseconds.

Chapter Three: Study One Results

Participant Demographics

Participants consisted of 90 University of Kentucky undergraduate students. Participants were randomly assigned to a study condition upon arrival. Thirty participants were included in each condition. During the study, no participants discontinued or failed to finish all study measures. Demographic information for each condition including previous experience with meditation practices and state levels of mindfulness are presented in Table 3.1. No significant differences between conditions were found across all demographic variables or the measure of state mindfulness, p 's > .05.

Effect of Intervention on Outcomes

Omnibus tests for HR indicated a multivariate interaction between study stage and condition, Wilks' Lambda: $F(1,86) = 4.13, p = .02, \eta^2 = .09$. Follow-up univariate analyses showed a significant effect of condition within the PRAC session, $F(2,86) = 4.08, p = .02, \eta^2 = .09$. Pairwise contrasts indicated participants within the MB condition had significantly higher HR during the PRAC session than participants in the DB condition but were not significantly different than the C condition. Participants in the DB and C conditions did not have significantly different HR measurements. Means and standard deviations for all physiological variables are presented in Table 2.1.

Omnibus tests for RMSSD indicated a significant interaction between study stage and condition, Wilks' Lambda: $F(2,83) = 8.38, p < .001, \eta^2 = .17$. Specifically, during the PRAC session, RMSSD was significantly higher in the DB condition than the C condition but not significantly different than the MB condition (Table 3.2). No significant difference on RMSSD was found between the MB and C conditions.

Omnibus tests for BPM indicated a significant effect of study stage, Wilks' Lambda: $F(2,86) = 58.58, p < .001, \eta^2 = .58$, and an interaction between study stage and condition, Wilks' Lambda: $F(4,172) = 15.94, p < .001, \eta^2 = .27$. Follow-up univariate analyses indicated a

significant effect of condition within the PRAC session, $F(2,87) = 33.84, p < .001, \eta^2 = .44$.

During the PRAC session, pairwise contrasts indicated BPM was significantly lower in the DB condition than both the MB and C conditions. BPM was also significantly lower in the MB condition than the C condition (Table 3.2).

Omnibus tests for HF-HRV indicated a significant effect of study stage, Wilks' Lambda: $F(2,86) = 10.13, p < .001, \eta^2 = .19$. There was also a significant within-subjects effect for study stage, $F(2,174) = 7.73, p < .001, \eta^2 = .08$ and a significant within-subjects interaction between study stage and condition, $F(4,174) = 2.54, p < .05, \eta^2 = .06$. Follow-up univariate analyses indicated a significant effect of condition within the PRAC session, $F(2,87) = 33.84, p < .001, \eta^2 = .44$. During the PRAC session, pairwise contrasts showed HF-HRV was significantly higher in the DB condition than both the MB and C conditions. HF-HRV was not significantly different between the MB and C conditions (Table 3.2).

Omnibus tests for SDNN indicated a significant effect of condition, Wilks' Lambda: $F(2,85) = 21.54, p < .001, \eta^2 = .34$, and an interaction between study stage and condition, Wilks' Lambda: $F(4,170) = 19.36, p < .001, \eta^2 = .31$. Follow-up univariate analyses indicated a significant effect of condition within the PRAC session, $F(2,87) = 18.95, p < .001, \eta^2 = .30$. During the PRAC session, pairwise contrasts showed SDNN was significantly higher in the DB condition than both the MB and C conditions. No difference was found on SDNN between the MB and C conditions (Table 3.2).

ANOVA analyses on mean accuracy rates within the cued go/no-go task suggested participants' in the MB condition ($M = 94.04\%, SD = 10.69$), DB condition ($M = 93.38\%, SD = 7.24$), and C condition ($M = 95.38\%, SD = 7.73$), did not significantly differ from one another, Wilks' Lambda: $F(4,148) = 0.18, p = .95, \eta^2 = .005$.

Table 3.1

Demographic Characteristics of Participants in Study One

Demographic Variables	MB Condition		DB Condition		C Condition	
	<i>M (SD)</i>	%	<i>M (SD)</i>	%	<i>M (SD)</i>	%
Age	19.53 (1.96)		19.30 (1.90)		19.23 (3.01)	
Year in School						
Freshman		66.7		66.7		73.3
Sophomore		16.7		23.3		16.7
Junior		13.3		6.7		6.7
Senior		3.3		3.3		3.3
Race						
Caucasian or White		70.0		66.7		66.7
African American		13.3		6.7		16.7
Asian American		6.7		16.7		10.0
Hispanic or Latino		3.3		0.0		3.3
Other		6.7		10.0		3.3
Gender						
Female		76.7		86.7		80.0
Male		23.3		13.3		20.0
Meditate Weekly						
No		100		100		96.7
Previous Meditation						
None		76.7		76.7		86.7
A Little		20.0		20.0		10.0
A Medium Amount		3.3		3.3		3.3
FFMQ Scales						
Observing	26.33 (6.09)		25.57 (4.49)		24.93 (4.17)	
Describing	23.93 (2.61)		23.17 (3.49)		24.13 (2.96)	
Act w/Awareness	18.47 (3.31)		18.40 (3.10)		18.47 (2.84)	
Non-Judge	17.37 (3.99)		16.97 (2.92)		18.00 (2.92)	
Non-Reactivity	22.47 (3.62)		22.47 (3.74)		21.03 (3.55)	

Note: $N = 90$. MB = Mindfulness Breathing; DB = Diaphragmatic Breathing; C = Nolen-Hoeksema; Previous Meditation = Past Meditation Experience; FFMQ = Five Facet Mindfulness Questionnaire (Baer et al., 2008); Non-Judge = Non-Judge of Inner Experience.

Table 3.2

Pairwise Contrasts Between Conditions

Variable	Condition	Comparison	Mean	S.E.	<i>p</i>
		Condition	Difference		
BPM	C	MB	2.62	0.93	.018
	C	DB	7.54	0.93	< .001
	MB	DB	4.92	0.93	< .001
HR	C	MB	-2.39	1.11	.10
	C	DB	0.62	1.16	1.00
	MB	DB	3.00	1.13	.028
HF-HRV	C	MB	-0.11	0.27	1.00
	C	DB	-1.02	0.27	< .001
	MB	DB	-0.91	0.27	.003
RMSSD	C	MB	-1.77	3.50	1.00
	C	DB	-9.78	3.69	.029
	MB	DB	-8.01	3.80	.11
SDNN	C	MB	-14.59	7.53	.17
	C	DB	-45.38	7.53	< .001
	MB	DB	-30.79	7.53	< .001

Note: $N = 90$. Significant pairwise contrasts are bolded. C = Nolen-Hoeksema Condition; MB = Mindfulness Breathing Condition; DB = Diaphragmatic Breathing Condition; BPM = breaths-per-minute; HR = heart rate measured as the number of beats in 60 seconds; HF-HRV = High frequency heart rate variability (.15 to .4Hz); RMSSD = root mean squared of the successive differences between adjacent NN peaks measured in milliseconds; SDNN = standard deviation in NN interval measured in milliseconds; p 's significant < .017.

Chapter Four: Study One Discussion

Interpretation of Results

During the PRAC session, participants in the DB condition had significantly lower BPM than participants in the MB or C conditions. The DB condition also elicited greater improvement than the MB or C conditions in HF-HRV and SDNN but not RMSSD. Results predominantly supported hypotheses one and two, which indicated the DB condition would result in greater BPM reductions and greater increases in HRV indices than the MB or C conditions. Yet, results suggested no condition provided an effect on HRV indices and respiration rates strong enough to persist past the PRAC session. Overall, results suggested diaphragmatic breathing techniques are more effective than mindful breathing techniques at increasing physiological variables associated with PNS activation, while the stability of the effect may be limited. The limited effect for both the DB and MB conditions is understandable given the brief nature of training (five to six minutes) as well as the single practice session of five minutes, and is consistent with previous literature (Evans et al., 2014). Previous literature has shown more practice in self-regulation skills leads to a more stable change (Muraven, Baumeister, & Tice, 1999; Schmidt et al., 2013). It would be important to consider the dose level of practice necessary to produce a meaningful and lasting effect on breathing rate, HRV indices, and measures of behavioral self-regulation.

Inconsistent with hypothesis three, no differences were found between conditions on mean accuracy rates during the cued go/no-go task. The lack of between group differences may be a consequence of the breathing practice effects in all conditions failing to persist into the CT session. In addition, the cued go/no-go task appeared to suffer from ceiling effects as no condition had a mean accuracy rate below 93%. Future research should focus on populations known to have self-regulatory deficits or consider the use of additional behavioral self-regulation tasks shown to have greater discriminability between healthy individuals who are able to self-regulate normally.

In addition, the effects of multiple skills training sessions on prolonging the positive effects of the breathing interventions should be explored. As the mindfulness based breathing

meditation showed partial activation of PNS tone consistent with previous literature, additional practice may elicit greater improvement (Burg et al., 2012). Previous literature suggests one potential cause for the lack of a prolonged effect of skills training on HRV indices is initial training on self-regulatory skills may overwhelm an individual's self-regulatory resources instead of bolstering them (Evans, Eisenlohr-Moul, Button, Baer, & Segerstrom, 2014). Participants splitting resources between using the newly learned skills and the cued go/no-go task may have negatively impacted HRV indices during the CT recording period. With additional training, perhaps participants could build up their self-regulatory resources and their skill in the use of the MB or DB breathing techniques. As literature supports the use of both breathing interventions for PNS activation, future work should consider factors to identify the effective dose level including the ideal number of practices, the frequency of practice, and the duration of each practice required to generate a lasting effect on HRV indices (Burg et al., 2012; Carlson et al., 2001; Grossman et al., 2004; Krygier et al., 2013; Schmidt et al., 2013). In addition, the feasibility of participants adhering to a behavioral treatment regimen, the tolerability of the intervention, and the clinical efficacy should all be considered. However, when limited to a single session, overall results suggested a CBT based didactic approach teaching slow diaphragmatic breathing is most effective at increasing physiological indicators of PNS tone when compared to MB based intervention.

To explore further the effectiveness of the DB intervention for increasing PNS tone and producing a clinically meaningful effect with individuals suffering chronic autonomic nervous system dysregulation, an mHealth app was created with the DB training protocol outlined above. The mHealth app included audio directions and a visual pacing aid to guide a participant's breathing pace. In an effort to assess the mHealth app's efficacy to improve PNS tone within a population known to suffer from self-regulatory deficits, the app was distributed to patients seeking treatment for persistent TMDs. As an underlying risk factor for the onset and persistence of TMDs is PNS dysregulation, the present project focused on evaluating the ability of the

mHealth app to improve PNS tone. In addition, Study Two compared the combination of the mHealth app with standard dental treatment (SDC+) to standard dental treatment alone (SDC). By comparing the combination treatment to the standard practice, it was hoped the benefits of addressing the underlying PNS dysregulation so common in persistent TMDs would be made clear (Fillingim et al., 2011; Maixner et al., 2011a).

Study Two was structured as a phase one clinical trial with the goals of demonstrating at least a minimal effect on the primary outcome variables of BPM, HRV indices, and self-report measures of pain. The study examined the dose level of the mHealth app, its feasibility, and its tolerability. In order to examine the effects of dose level, the mHealth app was created with features to track the participant's frequency and duration of use. It was hoped tracking participants' frequency and duration of practice would highlight a cut score for the amount of practice necessary to achieve a maximum clinical effect. Feasibility and tolerability was assessed through considering the chosen recruitment methods, reinforcement schedule for adherence to the intervention's protocol, and participants' responses to the SDC+ versus the SDC intervention.

Chapter Five: Study Two Methodology

All procedures were approved by the University of Kentucky internal review board and all participants agreed to the study via an informed consent protocol. The study investigated whether the inclusion of a mobile phone application teaching diaphragmatic breathing with standard dental care significantly improved treatment outcomes for persistent TMDs above standard dental care alone. Although a between-subjects design was used, given the low participant number, data were viewed as exploratory. Data were not used to make causal inferences but rather to guide future research.

Participants and Recruitment Methods

All 19 participants were recruited from patients seeking dental care at the University of Kentucky's Orofacial Pain Clinic (OFPC) between August 2016 and July 2017. Licensed dentists screened participants in accordance with Research Diagnostic Criteria for a primary diagnosis of myalgia. All participants reported a primary pain duration of at least three months and a self-reported current pain level of at least 30mm on a 0 to 100mm visual analog scale for pain (VAS). Participants were also screened by a series of self-report questions and medical history review for several health conditions. Participants were excluded if they reported a history of heart disease, current use of cardiovascular medications (e.g. beta-blockers), a history of asthma or other chronic respiratory conditions (e.g. COPD), diabetes (Type 1 or 2), current pregnancy, or a history of hypertension.

Standard Dental Treatment Plus App (SDC+)

Participants were not restricted from receiving any dental interventions. Upon recruitment, participants were provided a brief orientation to the functioning of an iPod and the mHealth app. The protocol was discussed and the participant's concerns or questions were addressed. Participants were provided an iPod Touch with the mHealth app installed, a handout outlining how often and how long to practice with the mHealth app, and a packet of VAS and RR scales. Participants were asked to practice with the mHealth app at least once in the morning and

once in the evening. The length of the practices started at five minutes each and titrated upwards over the course of their participation by one minute each day until it reached a maximum length of 20 minutes. Participants were asked to complete VAS and RR ratings before and after each mHealth app practice. Thereby, a daily average for VAS and RR was recorded in addition to change scores for VAS and RR from before to after mHealth app use. Participants were scheduled for a follow-up visit by clinic staff from two to eight weeks after their initial clinic appointment. If participants failed to attend their follow-up visit, study staff contacted participants in an attempt to reschedule them for completion of visit two study procedures.

Participants were provided with directions for using an online survey system (Qualtrics). Qualtrics was used to complete weekly questionnaires on pain, sleep, physical activity levels, and psychological symptoms. Participants were asked to provide a working email address to receive survey links. If participants did not have easy access to email, they were provided with paper copies of the questionnaires.

The mHealth app was based on a computer delivered entrainment protocol previously validated through a series of studies (Russell, Hoffman, Stromberg, & Carlson, 2014; Russell et al., 2016). The mHealth app consists of audio guidance on slow paced diaphragmatic breathing and a visual pacing aid. The visual pacing aid consisted of an oval that expands for four seconds during inhalation, contracts for two seconds during exhalation, and remains still during the four-second rest phase. The mHealth app tracked participants' frequency of app use and the duration of each use to facilitate a measurement of participants' treatment adherence.

Standard Dental Treatment Alone (SDC)

Participants were not restricted from receiving any dental based intervention. Participants were informed they would receive dental treatment and be asked to track their pain and levels of relaxation over the course of their treatment using VAS and RR scales. The protocol was discussed and the participant's concerns or questions were addressed. Participants were not directly informed they were in the experiment's control condition. Participants were provided a

packet of VAS and RR scales. They were asked to complete a VAS and RR scale every morning and evening during their treatment. Participants were scheduled for a follow-up visit by clinic staff from two to eight weeks after their initial clinic appointment. If participants failed to attend their follow-up visit, study staff contacted participants in an attempt to reschedule them for completion of visit two study procedures.

Participants were provided with directions on using Qualtrics. Qualtrics was used to complete weekly questionnaires on pain, sleep, physical activity levels, and psychological symptoms. Participants were asked to provide a working email address to receive survey links. If participants did not have easy access to email, they were provided with paper copies of the questionnaires.

Dependent Measures

Demographic Form. Information regarding the participant's dental diagnoses, dental treatment plan, medications (prescription), age, ethnicity, relationship status, employment status, previous breathing training, previous meditation experience, and previous relaxation training was collected. Participants were asked to update their medications at the second OFPC visit.

Visual Analogue Scale for Pain (VAS). A VAS scale was used to assess the participant's daily ratings of pain severity (Gracely, 1983). Participants marked their responses on a 100mm line where "0" and "100" were respectively anchored with the descriptors "*no pain*" and "*the worst pain imaginable.*" Previous studies have validated the use of a VAS to assess pain intensity and the use of the descriptive anchors with TMD patients (Burckhardt & Jones, 2003; Gracely, 1983; McMillan, Nolan, & Kelly, 1997). A ruler was then used to quantify the mark, resulting in scores ranging from 0 to 100. All participants completed a baseline VAS. SDC participants completed a VAS twice per day (morning and evening) and SDC+ participants were asked to complete a VAS before and after the morning and evening practices with the iPhone application.

Relaxation Ratings Scale (RR). A one-item numerical rating scale was used to measure self-reported feelings of relaxation. Participants marked their responses on a 100mm line where “0” and “100” were respectively anchored with the descriptors “*not relaxed*” and “*very relaxed*.” The scale has not been used with patients suffering persistent TMDs previously; therefore, results related to the RR scale should be interpreted cautiously.

Perceived Stress Scale (PSS). The PSS consists of 10 items and a 0 = *never* to 4 = *very often* scale to assess the degree to which an individual perceives their stress as negative, unpredictable, uncontrollable, and overloading (Cohen, Kamarck, & Mermelstein, 1983). Individual scores on the PSS range from 0 to 40 with higher scores indicating higher perceived stress. Scores ranging from 0 to 13 would be considered low stress, 14 to 26 moderate stress, and 27 to 40 high perceived stress. It has demonstrated good internal reliability and validity, Cronbach’s $a = 0.78$.

Chronic Pain Grade Scale (CPGS). The CPGS uses seven items and a 0 = *no change* to 10 = *extreme change* scale to classify chronic pain patients into four hierarchical categories (Grade 0 to Grade 4) based on pain severity and the pain’s interference with their life (Smith et al., 1997; Von Korff, Ormel, Keefe, & Dworkin, 1992). Grade 0 is no TMD pain in prior six months, Grade 1 is low disability-low intensity, Grade 2 is low disability-high intensity, Grade 3 is high disability-moderately limiting, and Grade 4 is high disability-severely limiting. In previous studies, the CPGS’s Cronbach’s $a > 0.8$ (Smith et al., 1997).

Patient Health Questionnaire 4 (PHQ-4). The PHQ-4 is a four-item measure that evaluates participants’ symptoms of depression and anxiety (Kroenke, Spitzer, Williams, & Löwe, 2009). Scores range from 0 = *normal* to 12 = *severe symptoms of depression and anxiety*. Internal consistency scores are considered strong, Cronbach’s $a = 0.85$ (Kerper et al., 2014; Kroenke et al., 2009).

Pittsburgh Sleep Quality Index (PSQI). The PSQI is a 19-item questionnaire that examines the individual’s sleep quality (Buysse, Rynolds III, Monk, Berman, & Kupfer, 1989).

Information is gathered on the hours spent in bed, how frequently the individual is awoken, and the number of hours sleeping each night. Internal consistency was previously recorded as Cronbach's $a = 0.83$ (Buysse et al., 1989). PSQI total scores were used for analyses. Total scores incorporated information on sleep duration, disturbances, latency, day time dysfunction due to poor sleep, efficiency, overall quality, and medication use for sleep. Total PSQI scores ranged from 0 = *better sleep* to 21 = *worse sleep*.

Godin Leisure-Time Exercise Questionnaire (LSI). The LSI is a four-item questionnaire examining leisure time exercise habits. Participants reported on their exercise frequency, duration, and intensity (mild, moderate, or strenuous) over the past week (Godin & Shephard, 1997). The following formula is used to calculate scores: weekly leisure activity score = $(9 \times \text{Strenuous}) + (5 \times \text{Moderate}) + (3 \times \text{Light})$, where the words "Strenuous," "Moderate," and "Light" are replaced by the number of times an individual engages in activities classified within each category. Two-week test-retest reliability coefficients for mild, moderate, and strenuous exercise were 0.48, 0.46, and 0.94, respectively (Godin & Shephard, 1997).

Louisville Older Person Events Scale (LOPES). The LOPES is a 54-item life events scale developed with Kentucky older adults that measures significant life events occurring over the past six months in seven categories: family/relationships, home/household, legal matters/police, work/school, financial, own health, and significant others' health (Murrell et al., 1984). The questionnaire was used to assess for significant life stressors occurring during participation.

Participant Self-Report on Efficacy and Tolerability of the mHealth App.

Participants were asked a total of ten questions. The first five statements provided feedback on the perceived efficacy of the mHealth app; "*The mobile application taught me how to breathe diaphragmatically,*" "*The instructions on how to breathe were clear,*" "*The instructions on the pace of breathing were clear,*" "*The breathing pace was relaxing,*" and "*If I have/had a friend with chronic pain, I would recommend this application.*" Each statement used a Likert-type scale

of 0 to 100 with 0 = *strongly disagree* and 100 = *strongly agree*. Higher values indicate greater confidence in the efficacy of the mHealth app.

Participants were then asked to provide information about their perceived frequency of practice; “How often were you able to practice breathing with the application?” Responses options included A = *two or more times a day*, B = *once a day*, C = *3-6 times a week*, and D = *less than three times a week*.

The last four questions were used to collect qualitative data from participants to assess the mHealth app’s tolerability and to guide future changes to the protocol. Items included; “*What was the major issue keeping you from practicing more frequently,*” “*What was the major issue keeping you from practicing for longer periods of time,*” “*What was the most helpful aspect of the application,*” and “*What would you like to see changed or improved?*”

Breathing. Breathing rate and mechanics were recorded with two BSL-SS5LB respiratory effort transducers and two amplifier modules with a BioPac MP100 system (Goleta, CA). The first sensor was placed around the abdomen below the rib cage and above the navel to measure diaphragm engagement. The second sensor was placed around the chest such that the upper edge of the belt passes just underneath both armpits to measure thoracic muscle engagement. Breathing rates were recorded as breaths-per-minute. Diaphragm engagement during breathing was measured with a ratio score for movement of the diaphragm sensor versus the thoracic sensor.

Heart Rate Variability. ECG data were collected using a MP100 Biopac System, an ECG100B amplifier, and a three-electrode modified Lead II format. ECG was collected continuously with Acqknowledge software and analyzed with Mindware software (Gahanna, OH) in accordance with established guidelines (Berntson et al., 1997; Malik, 1996). Mindware software provides frequency HRV measures such as high frequency (HF-HRV, .15 to .4Hz), low frequency (LF-HRV, .04 to .15Hz), very low HRV (VLF-HRV, .003 to .04Hz), and LF/HF ratios. It also provides time domain measures of HRV such as the standard deviation of the NN intervals

(SDNN) and the square root of the mean squared differences of successive NN intervals (RMSSD). Given our stated goal of slowing patients' respiration rates into the low frequency range of 2.4 to 9 breaths-per-minute, we focused our investigation on the HRV frequency range and time domain measures that best captured respiratory sinus arrhythmia (Berntson et al., 1997; Lehrer & Gevirtz, 2014; Vaschillo, Vaschillo, & Lehrer, 2006).

End Tidal CO₂ (ETCO₂). ETCO₂ represents the partial pressure of carbon dioxide within an exhaled breath and is an indirect, but reliable, measure of alveolar CO₂. As ETCO₂ decreases, O₂ is less able to disassociate from hemoglobin and adequately oxygenate body tissues thereby increasing muscle fatigue and increasing pain perception (Fried & Grimaldi, 1993, p. 29-44, p. 255, p. 176-227). An average ETCO₂ was calculated during the participant's physiological evaluation with a Capnograph II Hand-Held Capnograph Detector (Dublin, OH) with a nasal cannula. Patients were asked to exhale only through the nose during recordings.

Procedures

All participants were new patients seeking treatment at the OFPC. As part of standard dental care at the OFPC, new patients provided a medical history and underwent a dental exam. After it was determined patients met inclusion criteria, they were approached by study personnel to discuss participation. Interested patients were provided informed consent.

The first four participants were assigned to the SDC+ condition to serve as a feasibility trial. Of the four participants, three returned for a second OFPC visit. Following the initial feasibility trial, a table of random numbers was used to pre-determine the random order of assignment to either the standard dental care plus the mHealth app (SDC+) condition or the standard dental care only (SDC) condition. SDC participants were provided information and access to the mHealth app after completion of all study procedures.

Participants were all provided dental treatment with no limitations on the type of intervention or the length of time between clinic visits. If the participant canceled their follow-up visit, typically scheduled two to eight weeks following the initial clinic visit, they were contacted

by study personnel and attempts were made to schedule a return to clinic appointment for study procedures.

During the initial clinic visit, participants were asked to complete the demographic form, VAS, RR, PSS, CPGS, PHQ-4, PSQI, and LSI. Next, participants were connected to equipment to record physiological measures of BPM, HR, HRV, and ETCO₂ during the BL, PRAC, and CT sessions.

Tracking sheets were provided for all participants to record their daily pain levels and relaxation ratings. Pain was tracked with a 100mm long VAS and relaxation ratings were measured with a 100-point numerical rating scale. SDC participants recorded pain levels and relaxation ratings in the morning and evening. SDC+ participants were asked to practice with the mHealth app teaching diaphragmatic breathing once in the morning and once in the evening. For a detailed description of the entrainment approach used in the SDC+ condition, please see cited references (Russell et al., 2014; Russell et al., 2016). To measure the immediate treatment effects, SDC+ participants were asked to record pain and relaxation ratings before and after each morning and evening practice. All participants were provided instructions on completing weekly psychosocial assessments. Every Friday, participants received an email link to an online survey to track their perceived stress, chronic pain severity, symptoms of depression and anxiety, sleep quality, and exercise engagement.

All participants were provided a \$50 gift card. Participants were made aware of a lottery system where participants could earn entries into a lottery drawing for additional \$50 gift cards through adherence to the study protocol. All participants earned a lottery entry if they completed five of the seven daily pain and relaxation ratings during a week or completed the weekly psychosocial questionnaires within 48 hours. SDC+ participants could earn an additional lottery entry if they practiced with the mHealth app on at least six days during the week.

SDC+ participants were provided additional information regarding the use of the mHealth app including: orientation to an iPod touch, a brief rationale for how the intervention

improves pain management, and a practice outline. Within the outline, participants were asked to titrate practice length upwards over the course of their participation. Practice length started at five minutes and participants were asked to add one minute each day until practice length was 20 minutes. Participants were encouraged to practice twice per day. Participants were informed the application would track the frequency of use and the duration of each practice. All SDC+ participants were provided an iPod touch with the mHealth app installed and an iPod touch charger.

At the second clinic visit, all distributed study materials were collected (tracking sheets and iPods). A second five-minute resting physiological measurement of heart rate, average breathing rate, and end tidal CO₂ levels was taken. Heart rate data was again used to calculate HRV incises. Medication changes were recorded and all participants completed the LOPES questionnaire to assess for recent significant life stressors. SDC+ participants were asked to complete the Participant Self-Report on Efficacy and Tolerability of the mHealth App questionnaire. Participants within the SDC condition were offered access to the intervention. Participants were provided financial compensation and debriefed.

Hypotheses

The study tested whether SDC+ participants experienced significant reductions in their breathing rates and improvement in measures of PNS tone above SDC participants. The first hypothesis predicted SDC+ participants would show reduced resting breathing rates compared to SDC participants. Second, we anticipated SDC+ participants would show greater improvement in indices of HRV, increased diaphragm muscle engagement, and improved ETCO₂ as compared to SDC participants. Our third hypothesis predicted SDC+ participants would show greater reductions in VAS and increases in RR than SDC participants. The fourth hypothesis predicted SDC+ participants would experience greater improvements on the PSS, CPGS, PHQ-4, PSQI, and LSI.

HRV Cleaning and Interpretation

ECG data were visually examined in 60-second tachograms without stage identifiers to avoid experimenter bias during cleaning. Missing or erroneous heartbeats were cleaned according to the recommendations made by the Task Force and then expanded by the 1997 Committee Report (Berntson et al., 1997, p. 631; Task Force, 1996). Specifically, movement or aberrant heartbeats were visually examined and adjusted for by either measuring the actual R-R interval or interpolating the missing heartbeat. Movement artifacts where the heartbeats were not clearly indicated were corrected with a mid-beat replacement. Double-marked R peaks and erroneous R peaks were removed. Based on recommendation from Mindware Technologies, epochs with over 10% erroneous beats or that did not have at least 30 consecutive seconds of measurable data were not included in calculations. After visual inspection, no participant had more than one 60-second epoch excluded and no participants' physiological recording was excluded from analyses. No HRV data were excluded.

All physiological measures were recorded on a minute-by-minute basis over the course of five-minute recordings. Overall means were calculated for each variable over both the baseline and second visit physiological recording periods. No measures were excluded.

Planned Statistical Analyses

All analyses were conducted using IBM SPSS Version 24. As no inferential statistics were used and data were examined from an exploratory perspective, missing data were not corrected. Baseline differences between conditions were not explored given the focus on within-subject changes. However, participant demographic information for the nine drop out participants, the eight SDC+ participants, and the two SDC participants are presented separately in Table 5.1. Bivariate correlations were performed to explore associations between main demographic variables and primary outcome measures at baseline. Bivariate correlations are presented for all 19 recruited participants and for the 10 participants who completed a second OFPC clinic visit (Table 5.2).

To examine Hypotheses 1 and 2 change scores were calculated within each participant for each physiological variable. Results are presented in Figures 6.1-6.5. Change scores and within participant linear regression models were used to examine Hypothesis 3. Overall change scores for VAS and RR were calculated by subtracting the participant's baseline ratings from the participant's final ratings (Figure 6.6 and Figure 6.8). Treatment changes scores for the SDC+ condition were calculated by subtracting the participant's post-practice ratings from the participant's pre-practice ratings (Figure 6.7 and Figure 6.9). Regression models tested the relationships between time (days in study or minutes practicing with App) and daily self-report measures (VAS or RR). Findings are discussed and results for each model are presented graphically (Figures 6.10-6.13). Differences between the participant's scores on questionnaires over time are also presented graphically with findings discussed (Figures 6.14-6.18).

Table 5.1

Participant Characteristics in Study Two

Variable	Dropout Participants		SDC+ Participants		SDC Participants	
	<i>M (SD)</i>	%	<i>M (SD)</i>	%	<i>M (SD)</i>	%
Age	39.67 (11.66)		34.75 (12.20)		32.00 (1.73)	
Gender						
Female		66.7		87.5		100.0
Ethnicity						
Caucasian or White		88.9		87.5		100.0
African American		-		-		-
Hispanic or Latino		-		-		-
Asian American		-		-		-
Other		11.1		12.5		-
Relationship Status						
Married		88.9		75.0		100.0
Single		-		25.0		-
Divorced		11.1		-		-
Employment Status						
Employed		88.9		100.0		100.0
Unemployed		11.1		-		-
Blood Pressure						
Systolic	125.33 (8.50)		116.80 (10.08)		112.33 (10.21)	
Diastolic	80.50 (6.12)		75.60 (5.50)		74.67 (9.02)	
Baseline VAS	59.11 (15.28)		53.13 (22.51)		53.33 (5.77)	
Days in Study	-		33.13 (16.55)		83.67 (45.61)	
Secondary Diagnoses						
Capsulitis		22.2		37.5		-
Headache attributed to TMD		11.1		25.0		-
Arthralgia		22.2		12.5		50.0
Other		22.2		12.5		-
Migraine		-		12.5		-
Degenerative Joint Disease		11.1		-		50.0
TMJ Disc Disorders		11.1		-		-

Note: Dropout Participants $n = 9$ (SDC+ = 4 and SDC = 5); SDC+ $n = 8$; SDC $n = 2$. VAS = Visual Analog Scale for Pain (Gracely, 1983); TMD = Temporomandibular disorders; TMJ = Temporomandibular joint.

Table 5.2

Bivariate Correlations among Baseline Measures

Variable	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Condition	-	.14	-.08	.09	-.12	.30	-.32	-.37	-.36	.50*	.18	-.40	-.22
2. Age	.13	-	.17	.08	-.07	.58*	-.45	-.36	-.33	-.28	-.05	-.23	-.16
3. Sex	.17	.39	-	.15	-.08	-.45	-.04	-.02	-.05	-.17	.14	.22	-.64**
4. VAS	.07	.15	-.31	-	-.18	.13	.03	-.03	-.02	-.47*	.25	-.27	-.32
5. BPM	-.37	-.27	.22	-.37	-	.08	-.14	.29	.21	-.48	-.05	-.26	.08
6. HR	.00	-.81**	-.48	.12	.51	-	-.18	-.19	-.20	-.14	-.03	-.37	.19
7. HF-HRV	.12	-.13	.14	.15	-.30	-.21	-	.80**	.79**	-.15	.07	.50*	.06
8. RMSSD	-.08	-.00	.01	.05	.33	-.20	.57	-	.90**	-.25	-.01	.24	-.08
9. SDNN	.35	.18	.43	.13	-.14	-.35	.85**	.68*	-	-.23	.01	.19	-.25
10. PSS	.34	-.12	.20	-.78**	-.09	.12	-.27	-.44	-.22	-	-.09	.10	-.21
11. CPGS	.31	.36	.21	-.12	-.05	-.68	.15	.15	.18	-.05	-	.09	.08
12. PHQ-4	-.03	-.15	.21	-.58	.01	-.34	.45	.16	.25	.33	.46	-	.12
13. PSQI	-.62	-.50	-.48	-.25	.37	.13	.14	.32	-.22	-.19	.06	.50	-

Note: Correlations below the diagonal represent the 10 participants who returned for a second OFPC visit, Correlations above the diagonal represent all 19 recruited participants. Condition was recorded as SDC+ = 1 and SDC = 0; Sex was recorded as Female = 0 and Male = 1; VAS = Visual Analog Scale of Pain (Gracely, 1983); RR = Relaxation Rating Scale; BPM = breaths-per-minute; HR = heart rate; HF-HRV = high frequency heart rate variability (.15 to .4Hz); RMSSD = square root of the mean squared differences of successive NN intervals; SDNN = Standard deviation of NN intervals; PSS = Perceived Stress Scale; CPGS = Graded Pain Grade Scale; PHQ-4 = Patient Health Questionnaire Four Items; PSQI = Pittsburg Sleep Quality Index (PSQI).

* $p < .05$, two-tailed. ** $p < .01$, two-tailed.

Chapter Six: Study Two Results

Participant Demographics

The initial study sample consisted of 19 participants. The first four participants recruited were all assigned to the SDC+ condition to serve as a feasibility trial. Of the four participants, three participants returned for their second OFPC visit and are identified as participants 101, 102, and 103. The next 15 participants were randomly assigned to either the SDC+ or SDC condition. Of the 15 participants, three SDC+ and five SDC participants dropped out of the study. Of the nine total participant dropouts, four participants reported no intentions of returning to the OFPC for dental treatment and were unwilling to return for study procedures, and three participants discontinued due to time constraints. Following multiple attempts, two participants were discontinued due to no contact.

A total of 10 participants returned to the OFPC for a second visit and were included in analyses. Of these 10 participants, eight were in the SDC+ condition (Participants 101, 102, 103, 1, 3, 7, 10, and 13) and two were in the SDC condition (Participants 2 and 8). Demographic and baseline characteristics are presented separately for the nine participants who dropped out and the 10 participants who were included in analyses (see Table 5.1). No major demographic differences were found between the eight SDC+ and the two SDC participants (Table 5.1). Of note, despite efforts to restrict the length between visits to no more than eight weeks, the SDC participants averaged almost 12 weeks between visits whereas the SDC+ participants averaged slightly under five weeks.

Dental Treatments and Baseline Characteristics

For all 10 participants, dental treatment included patient education on clenching awareness, habit reversal, soft diet, gentle stretches, sleep hygiene, and encouragement to function within pain free limits. Six participants were provided stabilization splint therapy (Participants: 101, 1, 2, 3, 7, and 13). Three participants were prescribed non-steroidal anti-inflammatory medications such as Piroxicam, Meloxicam, or clock regulated Ibuprofen

(Participants: 2, 3, and 10). Two participants were referred for a sleep study to rule-out sleep apnea (Participants 7 and 8). Participant 3 was provided melatonin for difficulties with sleep onset. Participant 10 was prescribed a muscle relaxant. No major medication changes were reported at the second OFPC visit. In addition, no significant differences between conditions were found on the number of life stressors experienced during participation.

Bivariate correlations were performed to explore baseline associations between variables for all 19 recruited participants and the 10 participants who completed study procedures (Table 5.2). Consistent with previous literature, correlations indicated the HRV measures were highly correlated with each other (Berntson et al., 1997; Malik, 1996). Participants' baseline resting heart rate was found to be negatively correlated to participants' age. Surprisingly, correlations indicated a strong negative relationship between VAS pain ratings and PSS scores. Given the low sample size, it is possible the finding is a spurious correlation.

Effect of Intervention on Physiological Variables

To examine the intervention's ability to reduce breathing rates above normal dental treatment, individual BPM change scores were calculated (Figure 6.1). Five of the eight SDC+ participants showed reductions in breathing rates from baseline to their second visit, while both SDC participants showed elevated breathing rates. From baseline to the second OFPC visit, only two of the eight SDC+ participants experienced an improvement across all three indices of HRV (See Figures 6.2-6.4). However, except for Participant 8's RMSSD change score, both SDC participants experienced increases across all HRV indices. Six of the eight SDC+ participants showed minimal to moderate increases in ratios of diaphragm engagement over thoracic engagement (Table 5.2). Results indicated participants' end tidal CO₂ (ETCO₂) were within the normal healthy range (35mmHG to 45mmHG) at baseline for both the SDC+ condition ($M = 38.90$, $SD = 3.22$) and the SDC condition ($M = 38.67$, $SD = 3.77$). We anticipated participants in the SDC+ condition would experience a greater improvement in ETCO₂ following exposure to the mHealth app than participants in the SDC condition. Yet, results indicated limited changes

from baseline to the second visit in ETCO_2 for both the SDC+ condition ($M = 38.83$, $SD = 2.87$) and the SDC condition ($M = 38.67$, $SD = 4.90$). The lack of observed change may be a result of both conditions starting within a healthy range for ETCO_2 , thereby, limiting the ability to measure a clinical effect.

Effect of Intervention on General Health Symptoms

Results indicated consist reductions in VAS from initial to final ratings as well as before and after breathing practices ratings for all SDC+ participants (Figures 6.7 and 6.8). Results also suggested improved self-reported ratings of relaxation from initial RR ratings to final RR ratings as well as before and after breathing practice RR ratings for SDC+ participants (Figures 6.9 and 6.10). When examining initial to final ratings for the SDC condition, only half of participants experienced a reduction in VAS and an increase in RR ratings. For a more detailed examination of VAS and RR changes, four linear regression models using time (days in study and minutes of practice with the mHealth app) and daily self-report measures (VAS and RR) were tested within each participant. Intercepts and slopes for each model are presented in Figures 6.10-6.13. Unfortunately, regression models failed to present a clear picture of treatment effects in VAS or RR ratings. In particular, VAS ratings across days in study showed a negative slope in only three out of six SDC+ participants (Figure 6.10). In addition, only three out of five SDC+ participants showed reductions in VAS across minutes of practice with the mHealth app (Figure 6.11). For RR ratings, four out of six SDC+ participants showed increased RR ratings across days in the study, while all but one participant showed limited changes in RR across minutes of practice with the mHealth app (Figure 6.12 and 6.13).

In order to examine changes in weekly questionnaires, total scores were calculated and are presented graphically for each week in Figures 6.14-6.18. Figure 6.14 indicated participants experienced a significant degree of fluctuation in perceived situational stress without consistent improvements over the course of treatment. Following treatment onset, outside of Participants 1 and 3, all participants experienced declines and generally low CPGS scores (Figure 6.15). Again,

outside of Participants 1 and 3, all participants indicated minimal levels of psychological distress (Figure 6.16). Figure 6.17 suggests moderate levels of sleep disturbances across conditions that did not significantly change over the course of treatment. Participants' physical activity levels were also assessed and results indicated wide within- and between-subject variations in the amount of physical activity over each week (Figure 6.18).

Treatment Adherence, Perceived Efficacy, and Tolerability

SDC+ participants' adherence to the treatment protocol was assessed through automatic tracking of frequency of use and minutes of use within the mHealth app. Given the wide range in participants' length in the study, frequency of use was examined as the number of days with at least one mHealth app practice over the total number of days in the study. SDC+ participants' frequency of use ranged from as low as 24% up to 100%. Participants' total length of practice within each week were also calculated as a measure of treatment adherence and are presented in Figure 6.19. Result indicated no participants met practice guidelines. Participant 1 was found to be the most treatment-adherent. Of note, Participant 1 experienced positive results on the majority of outcome variables including: BPM, diaphragm engagement, VAS change scores, and RR change scores.

Examination of frequency of length of mHealth practices highlighted a tendency for participants to decrease or discontinue their practice with the mHealth app a week or more before returning to the OFPC to complete the final physiological assessment. It is possible the lack of practice with the mHealth app leading up to the second OFPC visit limited the study's ability to capture the mHealth app's effects on outcome measures. On average, the eight SDC+ participants had 10.33 days between their last mHealth app practice and their second OFPC visit with a range of 0 to 29 days.

On self-report measures, SDC+ participants reported that they found the mHealth app was effective in teaching diaphragmatic breathing ($M = 86.13$), providing clear directions on mechanics of breathing ($M = 90.8$), and providing clear directions on how to pace their breathing

($M = 89.13$). SDC+ participants also reported the mHealth app was relaxing ($M = 85.13$) and noted being comfortable in recommending the app to their friends for pain management ($M = 85.25$). The majority of SDC+ participants (six) reported they were able to use the app on a daily basis. The majority of SDC+ participants also noted “finding time,” “finding alone and quiet time,” “time constraints” or “remembering to practice when busy” as the major reasons for not meeting the practice frequency or practice length guidelines. When asked to provide feedback on the most helpful aspect of the mHealth app, SDC+ participants reported the oval and bells that provided visual and auditory pacing aides for the breathing practices as the most helpful aspects. Participants indicated “less surveys at first” and “relaxing music in the background” as the two changes they would like to see in future iterations of the mHealth app.

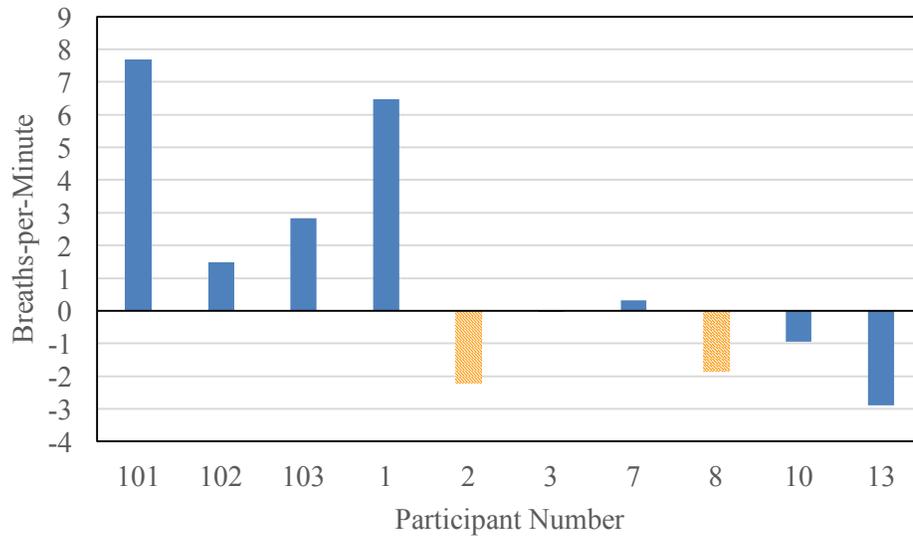


Figure 6.1. Breaths-per-minute change scores. Blue, solid bars indicate SDC+ participants; Orange, striped bars indicate SDC participants. Change scores were based on baseline measurement minus final measurement. Higher values indicate a reduction in BPM from baseline to final measurement.

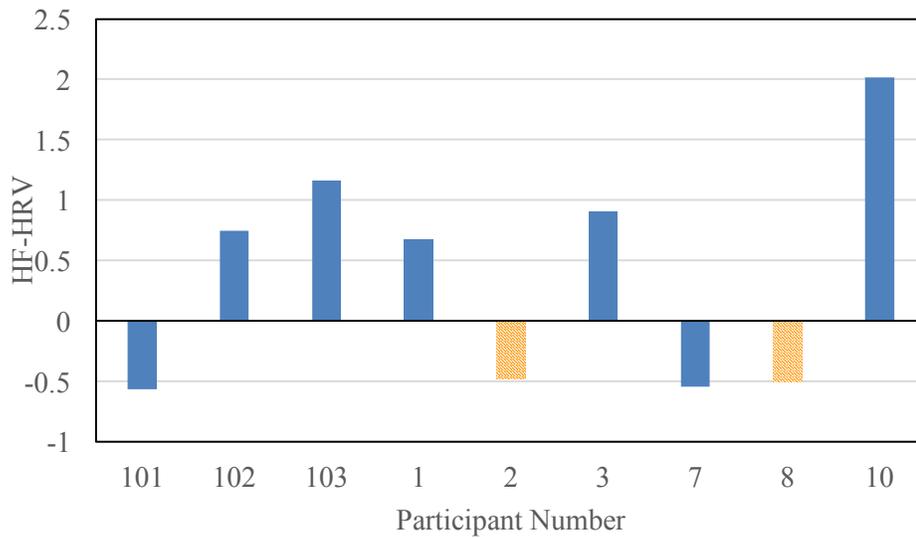


Figure 6.2. High frequency heart rate variability change scores. Blue, solid bars indicate SDC+ participants; Orange, striped bars indicate SDC participants. HF-HRV = High frequency heart rate variability (.15 to .4Hz). Change scores were based on baseline measurement minus final measurement. Higher values indicate HF-HRV decreased from baseline to final measurement.

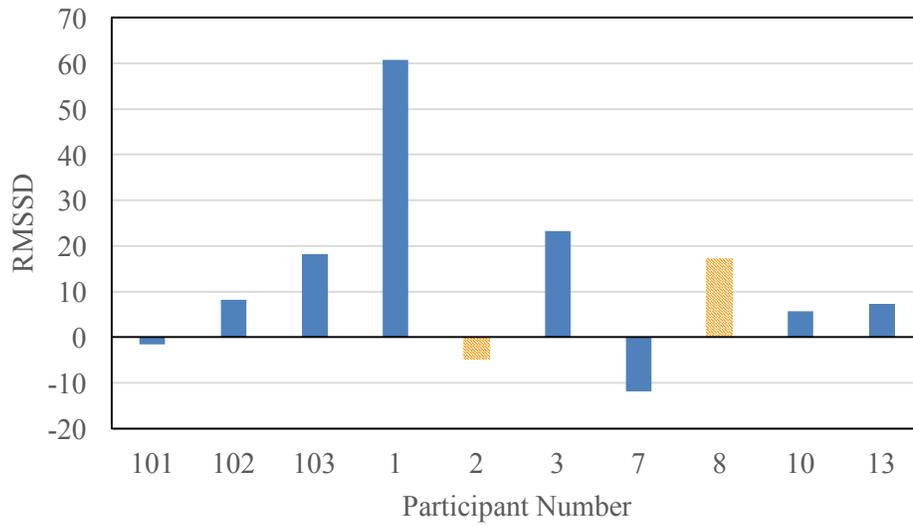


Figure 6.3. Square root of the mean squared differences change scores. Blue, solid bars indicate SDC+ participants; Orange, striped bars indicate SDC participants. RMSSD = square root of the mean squared differences of successive NN intervals. Change scores were based on baseline measurement minus final measurement. Higher values indicate RMSSD decreased from baseline to final measurement.

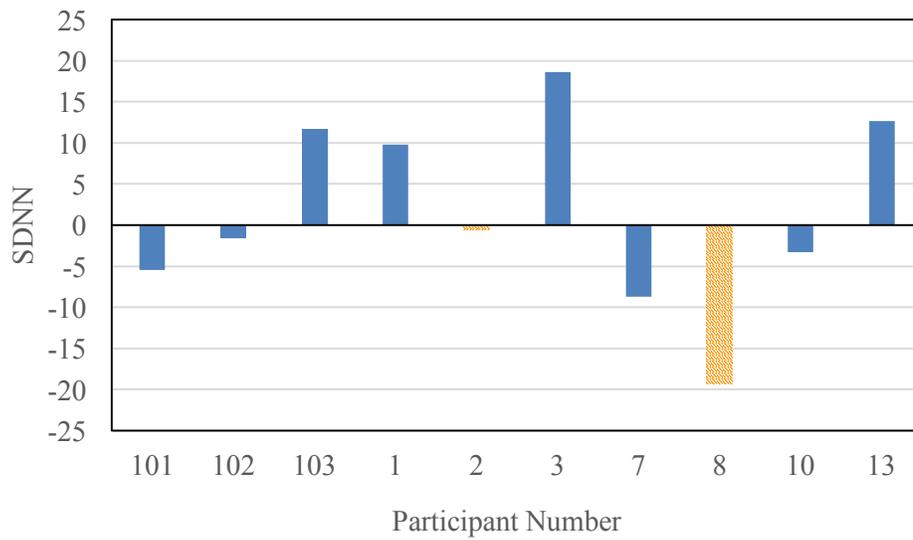


Figure 6.4. Standard deviation of NN intervals change scores. Blue, solid bars indicate SDC+ participants; Orange, striped bars indicate SDC participants. SDNN = Standard deviation of NN intervals. Change scores were based on baseline measurement minus final measurement. Higher values indicate SDNN decreased from baseline to final measurement.

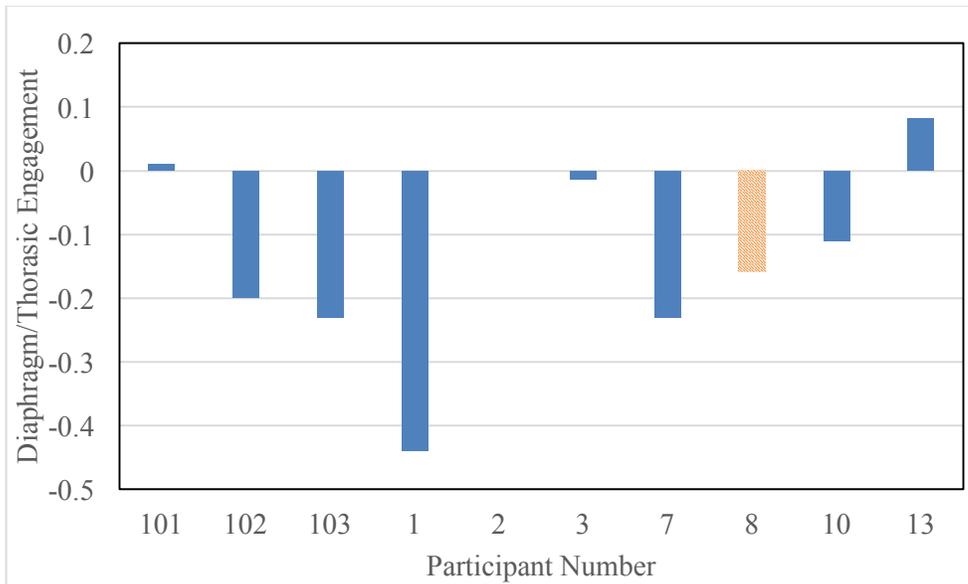


Figure 6.5. Diaphragm over thoracic engagement change scores. Blue, solid bars indicate SDC+ participants; Orange, striped bars indicate SDC participants. Change scores were based on baseline measurement minus final measurement. Higher values indicate ratio decreased from baseline to final measurement. Missing data from Participant 2.

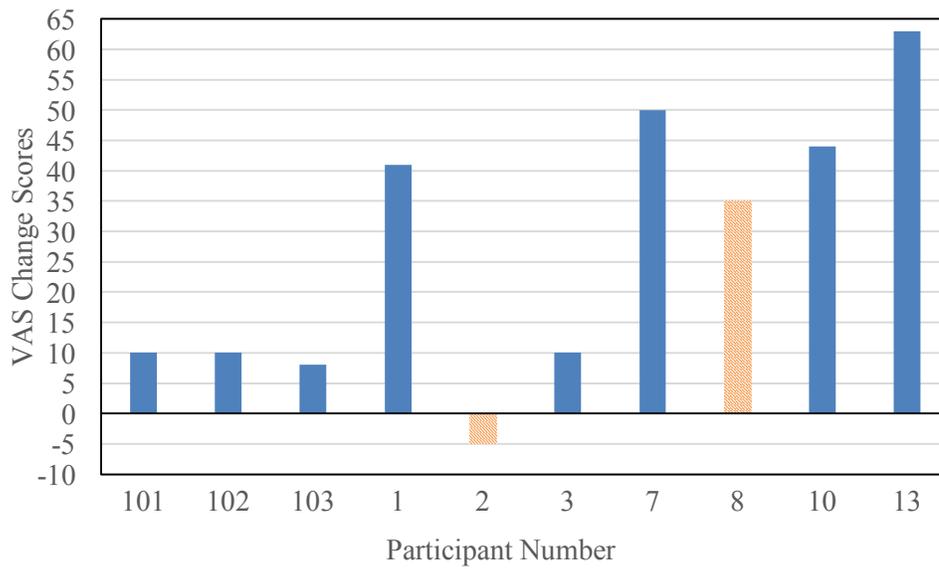


Figure 6.6. Overall change in visual analog scale for pain. Blue, solid bars indicate SDC+ participants; Orange, striped bars indicate SDC participants. VAS = Visual analog scale for pain (Gracely, 1983), scores, ranged from 0 (*no pain*) to 100 (*worse pain imaginable*). Change scores were based on baseline measurement minus final measurement. Higher values indicate VAS decreased from baseline to final measurement.

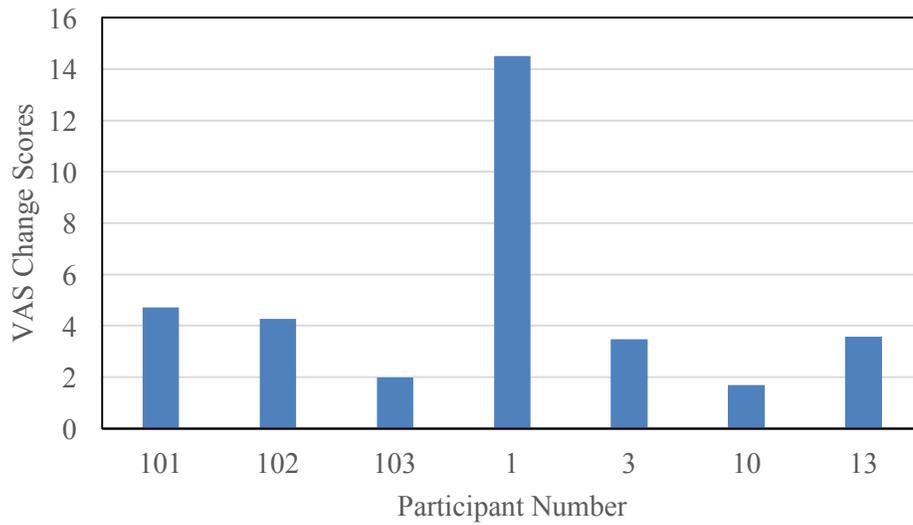


Figure 6.7. Treatment change in Visual Analog Scale for Pain for SDC+ participants. VAS = Visual Analog Scale for Pain (Gracely, 1983), scores, ranged from 0 (*no pain*) to 100 (*worse pain imaginable*). Change scores were based on pre-practice measurement minus post-practice measurement. Higher values indicate VAS decreased from before using the mHealth app to after using the mHealth app. Missing data from Participant 7.

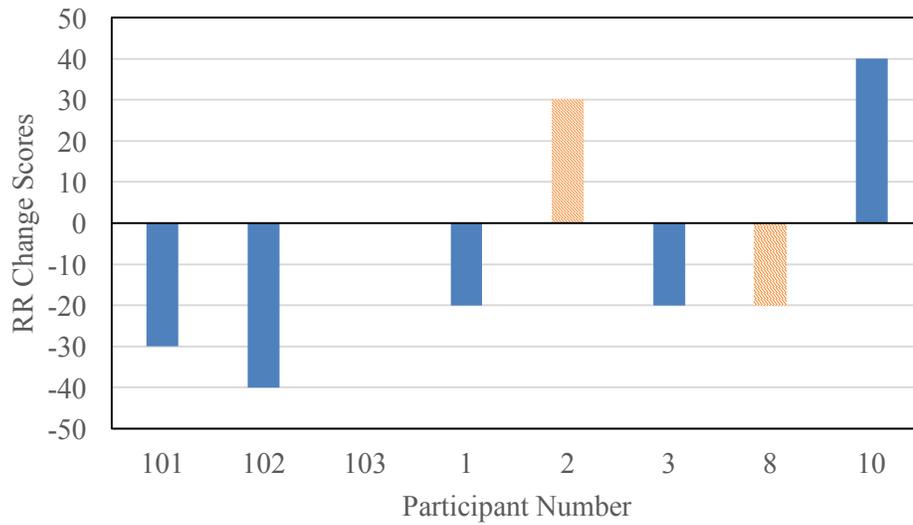


Figure 6.8. Overall change in Relaxation Rating Scale scores. Blue, solid bars indicate SDC+ participants; Orange, striped bars indicate SDC participants. RR = Relaxation Ratings Scale, scores, ranged from 0 (*not relaxed*) to 100 (*very relaxed*). Change scores were based on baseline measurement minus final measurement. Higher values indicate RR decreased from baseline to final measurement. Missing data from Participants 7 and 13.

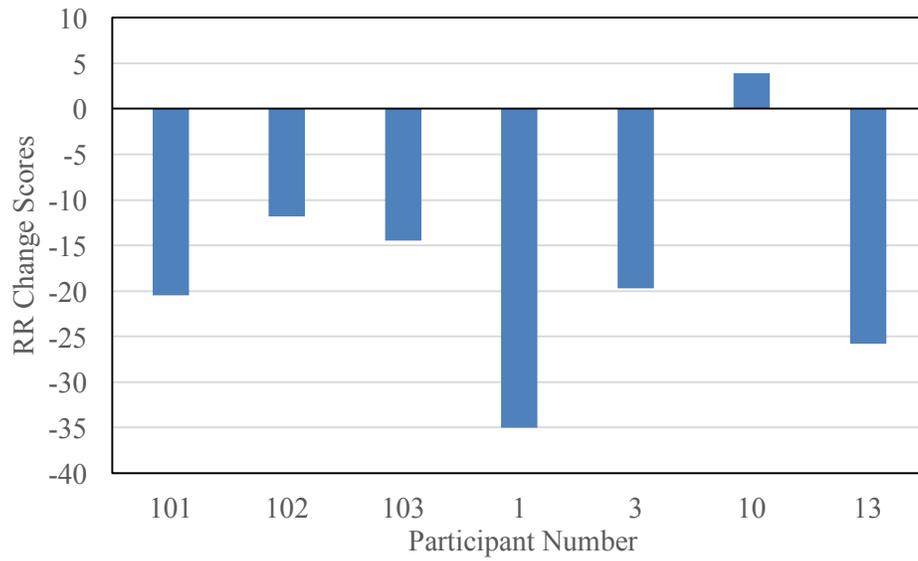


Figure 6.9. Treatment change in Relaxation Ratings Scale scores for SDC+ participants. RR = Relaxation Ratings Scale, scores ranged from 0 (*not relaxed*) to 100 (*very relaxed*). Change scores were based on pre-practice measurement minus post-practice measurement. Higher values indicate RR decreased from before using the mHealth app to after using the mHealth app. Missing data from Participant 7.

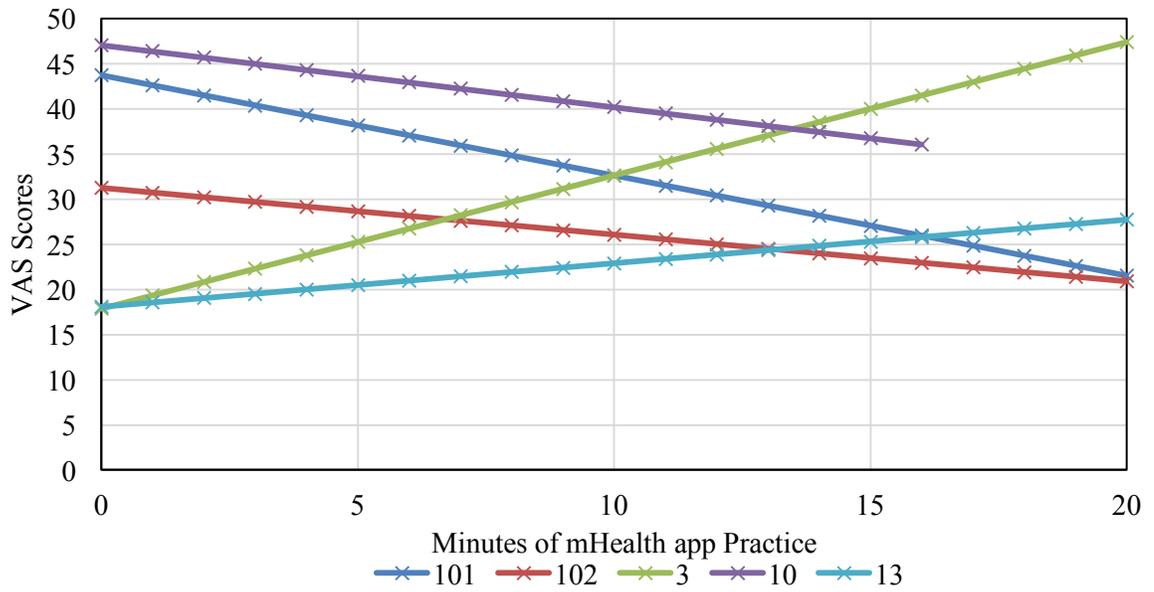


Figure 6.11. Estimated change in Visual Analog Scale for pain scores with mHealth app practice for SDC+ participants. VAS = Visual Analog Scale for Pain (Gracely, 1983) scores ranged from 0 (no pain) to 100 (worse pain imaginable). Missing data from Participants 103, 1, and 7.

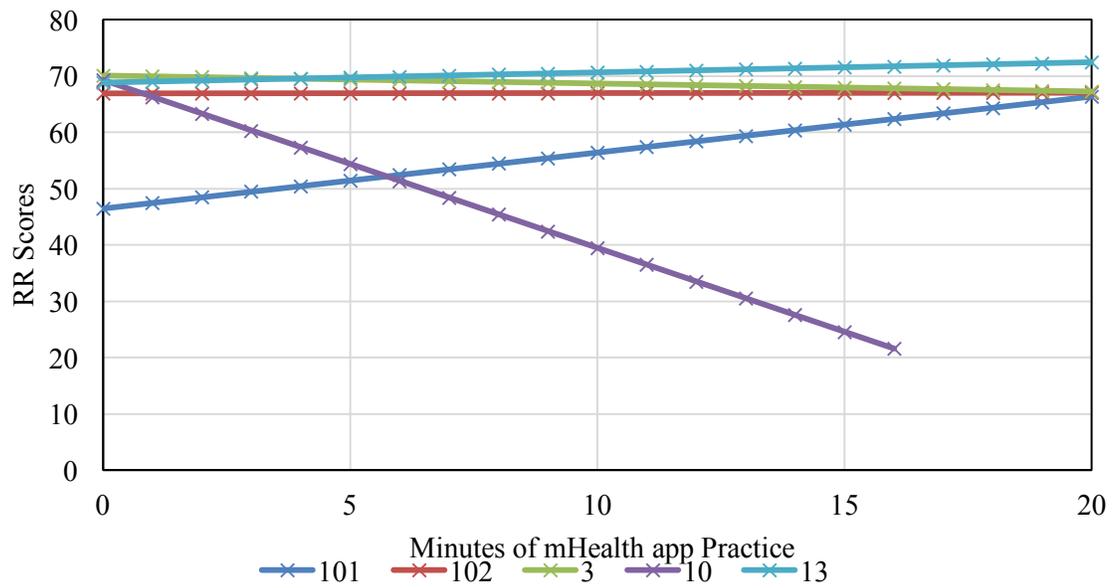


Figure 6.13. Estimated change in Relaxation Ratings Scale scores with mHealth app practice for SDC+ participants. RR = Relaxation Ratings Scale, scores ranged from 0 (*not relaxed*) to 100 (*very relaxed*). Missing data from Participants 103, 1, and 7.

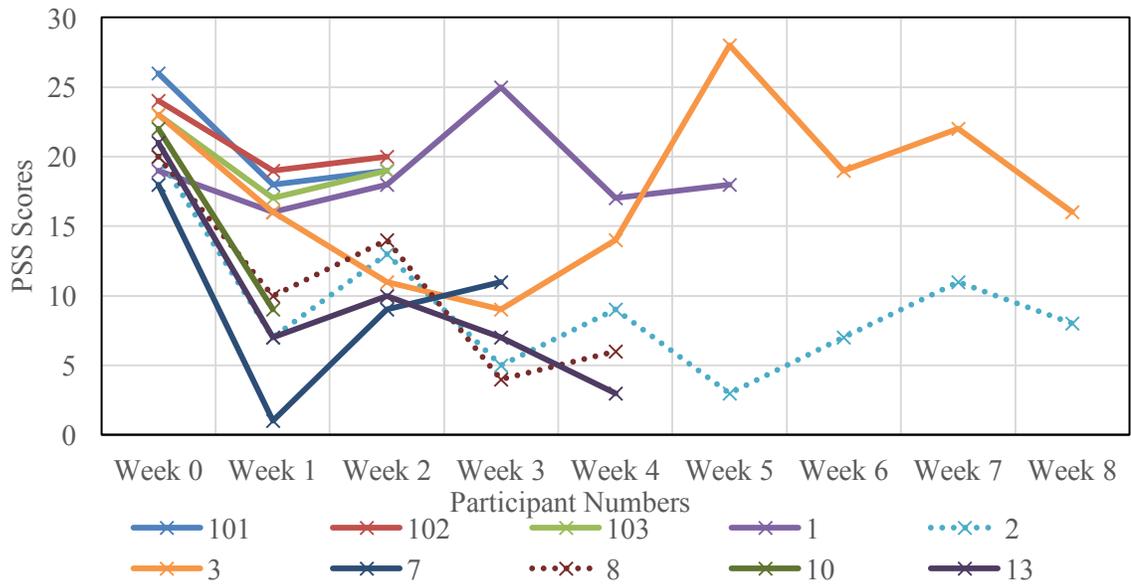


Figure 6.14. Change in perceived stress scale scores across time. Solid lines indicate participants in the SDC+ condition; Dotted lines indicate participants in the SDC condition. PSS = Perceived Stress Scale (Cohen et al., 1983). Scores ranged from 0 (*no perceived stress*) to 40 (*high perceived stress*).

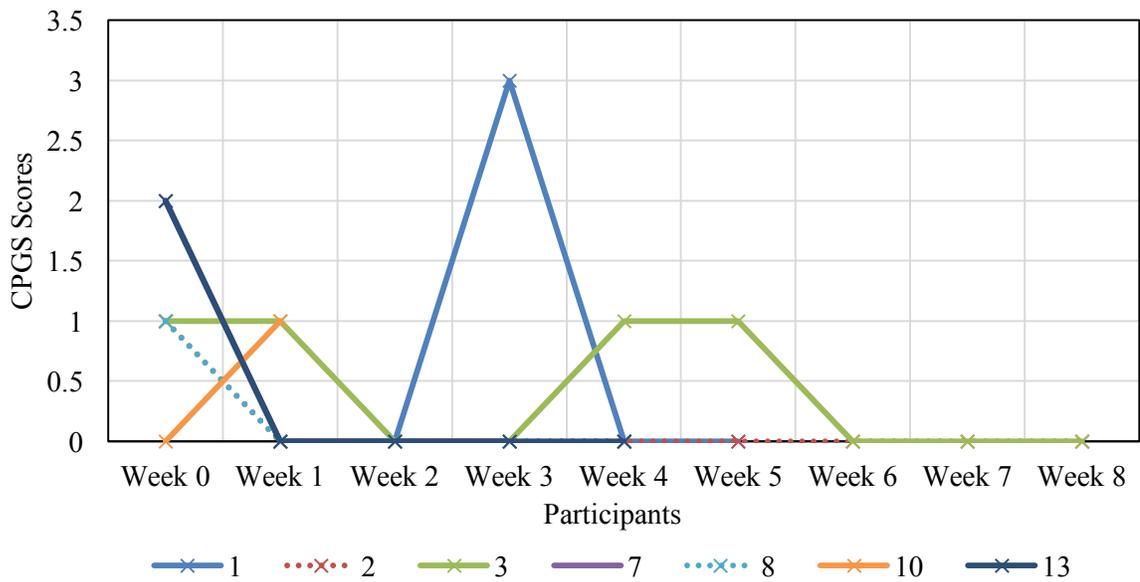


Figure 6.15. Change in Chronic Pain Grade Scale scores across time. Solid lines indicate participants in the SDC+ condition; Dotted lines indicate participants in the SDC condition. CPGS = Chronic Pain Grade Scale (Von Korff, Ormel, Keefe, & Dworkin, 1992). Scores range from 0 (no TMD pain) to 4 (high disability-severely limiting pain). Participants 101, 102, and 103 had only one data point and are not represented.

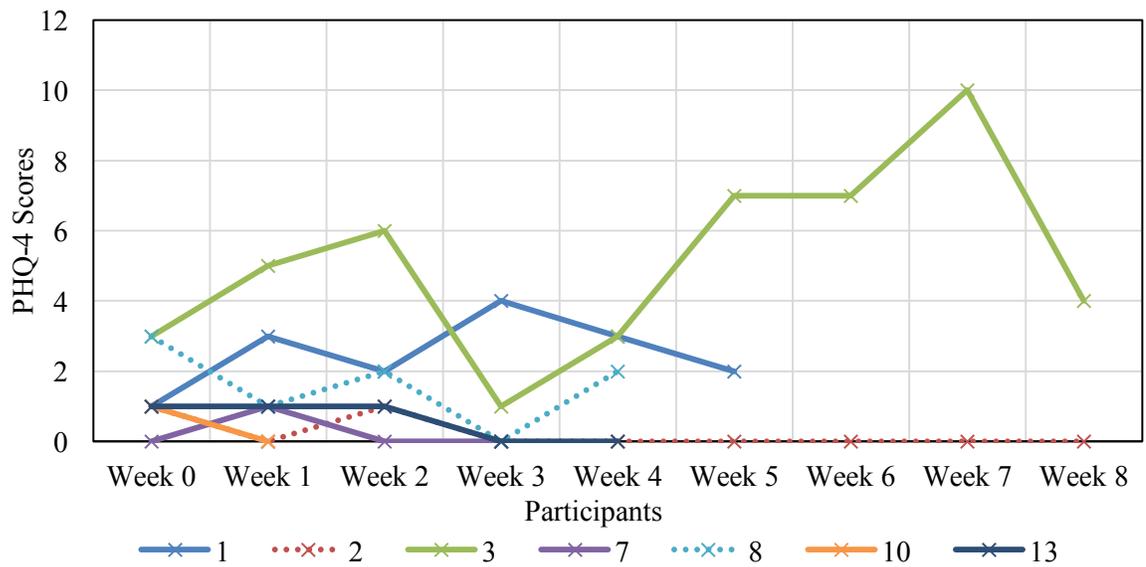


Figure 6.16. Change in Patient Health Questionnaire 4 scores across time. Solid lines indicate participants in the SDC+ condition; Dotted lines indicate participants in the SDC condition. PHQ-4 = Patient Health Questionnaire 4 (Kroenke et al., 2009). Scores range from 0 (*normal*) to 12 (*severe symptoms of depression and anxiety*). Participants 101, 102, and 103 had only one data point and are not represented.

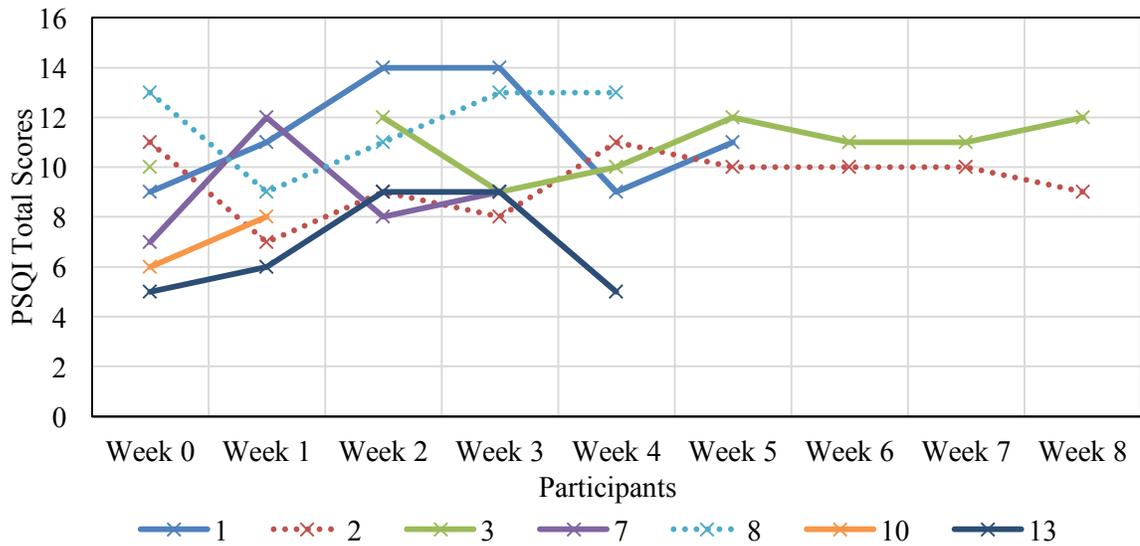


Figure 6.17. Change in Pittsburgh Sleep Quality Index total scores across time. Solid lines indicate participants in the SDC+ condition; Dotted lines indicate participants in the SDC condition. PSQI Total = Pittsburgh Sleep Quality Index total (Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989). Scores ranged from 0 (*better sleep*) to 21 (*worse sleep*). Participants 101, 102, and 103 had only one data point and are not represented; Participant 3 was missing data from weeks 0-1.

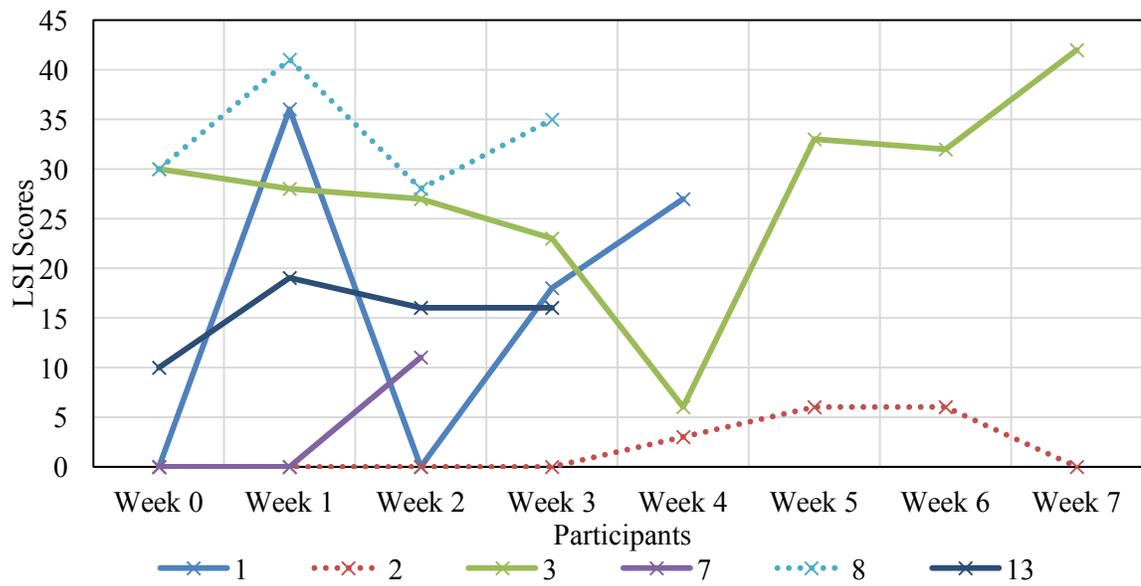


Figure 6.18. Change in Godin Leisure-Time Exercise Questionnaire total scores across time. Solid lines indicate participants in the SDC+ condition; Dotted lines indicate participants in the SDC condition. LSI = Godin Leisure-Time Exercise Questionnaire (Godin & Shephard, 1985). Scores begin at 0 (*no exercise*) with higher scores indicating more physical activity over the past week. Missing data from participants 101, 102, and 103; Participant 10 had only one data point and is not represented.

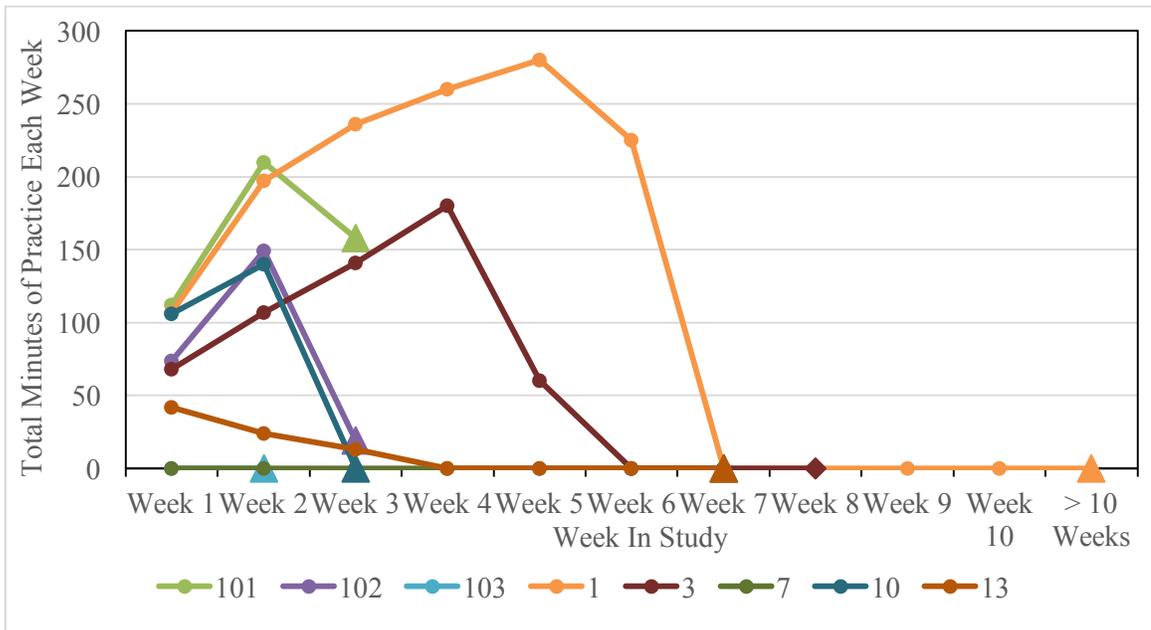


Figure 6.19. SDC+ participants' total practice time in minutes over each week in the study.

Chapter Seven: Study Two Discussion

The focus of Study Two was to explore the feasibility, tolerability, necessary treatment dosage, and clinical efficacy of a mHealth based conjunctive treatment for persistent TMDs with a primary diagnosis of chronic myofascial pain. The current results represent a small sample size not investigated with inferential statistics, but aimed to guide future clinical trials using mHealth based behavioral interventions within this population. The discussion, therefore, will focus on identifying general themes, presenting potential conclusions, and providing considerations for future research directions.

Interpretation of Results

Consistent with hypotheses, the mHealth app reduced breathing rates and produced moderate effects in improving diaphragm over thoracic engagement during respiration. The majority of participants (i.e. 101, 102, 103, 1, and 7) who showed the most improvement in diaphragm engagement and reductions in BPM also experienced the largest reductions in VAS measures. Of note, Participant 1, who was the most SDC+ treatment-adherent, experienced the greatest relief in pain, increase in relaxation from pre- and post-mHealth app practices, and the fourth highest overall reduction in VAS pain ratings. Despite most participants experiencing a reduction in BPM and an increase in diaphragm engagement, results did not uniformly support the mHealth app's ability to increase HRV indices. In addition, little change was observed in ETCO_2 . As participants' baseline ETCO_2 recordings were within the healthy range of 35 to 45mmHG, results were consistent with the initial hypothesis. The mHealth app demonstrated the ability to teach deep diaphragmatic breathing while avoiding over-breathing identified through ETCO_2 recordings below 35mmHG. Overall, the mHealth app appears to have assisted in the reduction of pain, but the added efficacy of the combined use of the mHealth app with standard dental care remains unclear.

Inability to produce consistent effects on HRV indices are potentially explained by several factors. First, for many SDC+ participants several days ($M = 10.33$ days) between their

last use of the mHealth app and their second OFPC visit may have served as a wash out period. The long-term effects of breathing based interventions on baseline levels of HRV remain unclear. It, therefore, seems important for participants to continue their use of the mHealth app through their second physiological recording in order to assess the intervention's efficacy. An additional consideration is the temporal stability of HRV. Although HRV is thought to remain stable under stable conditions over time, HRV is capable of fluctuating during measurement due to body position, mental stresses, recent physical exertion or consistent exercise habits, controlled respiration, cold stimulation to the face, certain medications (e.g. beta-adrenergic or antiarrhythmic medications), or fluctuations in hormone levels (Berntson et al., 1997; Malik, 1996). Although research guidelines were consulted to avoid the influences of these factors, the effects on HRV indices were complicated by the use of controlled breathing, the prediction of changes in mental and physical stress through reduction of pain, and the wide variability in time between participants' first and second physiological recordings. Given the challenges of requiring participants to return for multiple in-person physiological recordings, future research should consider the use of more frequent HRV assessments through validated smart phone technologies.

During breathing at rest, results suggested the mHealth app was successful at increasing participant's engagement of the diaphragm muscle. As six of the eight SDC+ participants experienced an increase in the ratio of diaphragm over thoracic muscle engagement, it can be concluded the mHealth app was successful in teaching diaphragmatic breathing mechanics. It is important to note participants' ETCO_2 recordings remained within a healthy range, which indicated the mHealth app was able to successfully teach diaphragmatic breathing without causing hyperventilation (i.e. deep breathing at too fast a pace).

Through treatment, all participants in the study except one SDC participant experienced an overall reduction in VAS pain ratings. Seven SDC+ participants found the mHealth app resulted in an increased state of relaxation following each breathing practice. Of note, the one

participant who failed to experience an increase in relaxation had an increase in BPM over the course of their participation.

Data suggested a strong clinical effect of the mHealth app on VAS and RR ratings immediately following practice. Results supported the use of the mHealth app for temporary relief of pain and increased relaxation but did not support a sustained effect on HRV indices. The lack of consistent effects may have resulted from limited treatment adherence within the SDC+ condition and variable treatment length. SDC+ participants practiced with the mHealth app for almost half as long as was suggested for each day (40 minutes) to reach a clinical effect ($M = 23.8$ minutes, $SD = 9.71$). Although a portion of this is due to the upward titration program that started SDC+ participants at five minutes of health practice, examination of participant practice logs revealed frequent days where participants failed to use the mHealth app even once (an average of 43% of the days in the study).

Results failed to show consistent improvements for SDC+ participants in general health outcomes such as perceived stress, psychological distress, or sleep. Failure to support our hypotheses may have resulted from participants' missing data, variable lengths in treatment, poor treatment adherence, or the small sample size. Given the difficulties with participant recruitment and retention, future research would benefit from using a one session intervention to test the clinical effect for patients with persistent TMDs on VAS and RR ratings. Future work should focus on delivery of questionnaires in a manner that facilitates greater treatment engagement such as providing links to the questionnaires within the mHealth app.

After the mHealth app has proven clinical efficacy, research can shift to testing the effects of prolonged exposure to the mHealth app and the necessary dosage to produce a persistent clinical effect on pain. There is also a need to investigate methods to improve participant adherence to treatment and the role of the clinician versus the mHealth app in teaching behavioral self-regulation skills. Results did indicate the mHealth app was tolerated well by SDC+ participants and did not precipitate any negative outcomes. Yet, it is important to consider

how to improve the current project in future examinations of mHealth apps within clinical populations.

Lessons in Feasibility

A major obstacle of the study was participant recruitment and attrition. Although the OFPC sees over 30 new patients a month, the present project's recruitment was limited by the specific inclusion criteria used to create a homogeneous sample. Given the goal of recruiting treatment seeking patients, no outside advertisement was used. The benefits of recruiting community participants who meet inclusion criteria but are not actively seeking treatment for persistent TMDs should be considered. Concerns with sample size were compounded by a 47% dropout rate. Drop out participants reported no intentions of returning for further treatment at the OFPC and time constraints as the primary reasons for discontinuing their participation in the project. As most participants were not local residents, it is likely that travel time and the cost of their ongoing treatment at the OFPC played a significant role in discontinuing treatment. When compared to participants who completed the protocol, drop out participants were found to be slightly older than SDC+ participants ($M = 4.92$ years) and SDC participants ($M = 7.67$ years). Drop out participants also had slightly higher baseline VAS from SDC+ participants ($M = 5.98$) and SDC participants ($M = 5.78$). As the present study required considerable time commitment from participants, we believe participant retention would be helped with future protocols being no longer than two to three weeks. If possible, collaboration with the participant's local dental providers should also be sought to limit participant travel burden. Lastly, the effects of providing a variety of dental procedures for study participants should be explored.

An additional consideration for future work is adjusting the titration schedule with the mHealth app. SDC+ participants were asked to begin at five minutes for each practice and add one minute each day. As participants generally failed to adhere to the titration schedule, the benefits for treatment adherence of beginning mHealth app practices at various lengths is of interest. Examination of participants' use of the mHealth app indicated use noticeably declined

following week two and participants who were not initially using the mHealth app were unlikely to begin use later in their time of participation. The use of regular reminder notifications through the app and phone check-ins for improved adherence should also be explored.

Finally, the approach to recruiting and the rationale provided to new participants needs further consideration. The purposeful inclusion of motivational interviewing techniques during recruitment to facilitate participant engagement represents an area of future improvement.

Another consideration is the added confidence in the efficacy of the mHealth app that would be achieved through a single in-person training session with personalized clinician feedback.

Overall, the results suggest future exploration of mHealth app use with individuals suffering persistent TMDs is warranted.

Future Directions

Results from the current study indicate further research is needed to examine the potential benefits of including mHealth interventions that target autonomic dysregulation. The continued exploration of mHealth apps with individuals suffering persistent pain conditions is paramount given the burden of care currently placed on providers and the stressors on patients associated with frequent clinic visits. Although the present study outcomes did not support the positive effects of the mHealth app on indices of HRV, previous literature has demonstrated the ability of technology assisted protocols to produce meaningful changes in HRV indices (Russell et al., 2014; Russell et al., 2017). It is important to note the positive effects of the intervention on self-reported levels of pain over the course of the study and immediately following each use of the mHealth app. Thus, it would be valuable to pursue the study of a breathing app to improve symptom management with several key refinements to the research protocol.

First, the high participant dropout rate limited results and raised significant concerns regarding participant retention and engagement in mHealth app conjunctive treatments. Future research on strategies to limit participant dropout are important and examination of dropout participants' perceptions towards mHealth app based conjunctive treatments should be explored.

Based on participant qualitative feedback, the present study would have benefited from limiting the length of participation to two weeks. There were significant time commitments required to adhere to the study protocol, which likely impacted participant treatment adherence and participant retention. In addition, the costs associated with receiving dental care during the study must be managed and followed more carefully.

Chapter Eight: Overall Discussion

Study One

Study One supported the use of a CBT based protocol teaching slow paced diaphragmatic breathing to influence respiration rates and HRV indices. The DB condition showed lower breathing rates and significantly higher improvements on both HF-HRV and SDNN than the MB or C conditions. No significant differences were found between conditions for the behavioral self-regulation task suggesting the effects of the breathing interventions were limited in duration or strength. The training period for each condition was brief by design (~six minutes) with only five minutes for participants to practice the new skill before being exposed to the behavioral self-regulation task. The brief nature of the intervention likely limited the long-term effects on participants' behavioral self-regulation. Therefore, it is important to consider practice duration before exposure to self-regulatory tasks. In addition, the behavioral self-regulation task suffered from a ceiling effect with a sample of relatively healthy young adults. Taken together, results suggested the next step was to examine the DB condition training protocol with a population suffering persistent TMDs.

Study Two

Study Two evaluated the impact of including the DB training protocol delivered through a mHealth app with standard dental treatments. Results did not indicate the mHealth app significantly improved treatment outcomes overall above participants receiving dental treatment alone. However, several findings supported further investigation of the DB protocol as a conjunctive treatment for persistent TMDs. First, SDC+ participants reported the mHealth app was tolerable and produced a reliable reduction in pain and increase in feelings of relaxation after each breathing practice. In addition, despite having only one of eight SDC+ participants reach the recommended clinical dose with the mHealth app, all participants experienced a reduction in pain over the course of participation. Taken together, results support continued examination of mHealth app based interventions teaching paced diaphragmatic breathing.

However, several concerns were identified in results that require attention. Consistent with previous literature, a primary issue in the present project was treatment adherence (Schmidt et al., 2012; Schmidt et al., 2013). As the most treatment-adherent participant experienced the greatest average reduction in pain after each breathing practice, it can be theorized improved treatment adherence would result in greater reductions in pain. A lack of treatment adherence is a likely a factor in the intervention's limited effects on physiological factors. For instance, only two SDC+ participants showed large decreases in BPM over the course of treatment. Respiration rates between six to seven BPM are necessary to significantly effect HRV indices (Lehrer et al., 2003; Lehrer & Gevirtz, 2014). Although the mHealth app improved engagement of the diaphragm in the majority of SDC+ participants, future protocols must be adjusted to reduce participants' respiration rates to the six to seven BPM range. Failure of SDC+ participants to reach this threshold is a major concern for future research. In addition, SDC+ participants used the app at least once for only 57% of the days they were involved in the study. SDC+ participants averaged 23.8 minutes of practice per day, which was greatly below the suggested practice length of 40 minutes per day. With limited treatment adherence, it is not surprising to find little difference in overall symptom reduction between SDC+ and SDC participants. Yet, despite the poor overall treatment adherence, participants consistently displayed positive effects of treatment on daily pain and relaxation ratings. Thus, future research is necessary to determine if an increase in "dose" of practice to 40 minutes per day results in improved outcomes on pain and relaxation.

Limitations

There are several limitations that need to be acknowledged. Although the DB condition generally outperformed the two other training approaches in Study One, the potential impact of multiple training sessions needs additional investigation. In addition, despite attempts to limit participant dropouts with the use of limited participant burden, financial incentives, and potential treatment benefits, Study Two results were severely limited by sample size. Although semi-flexible lengths in participation were initially viewed as a means to limit the effects of TMD

symptom severity following various patterns (i.e. persistent or recurrent) and strengthen generalizability to dental practices, it is likely this design led to additional complications in the interpretation of outcomes. Participants were involved in treatment for greatly variable lengths of time ranging from 14 days to 131 days. Future research should consider standardizing participants exposure to the mHealth app and explore the subsequent influence on respiration rates and HRV indices within a clinical population.

A recent meta-analysis of available randomized clinical trials examined the effectiveness of psychosocial and dental treatments for amelioration of persistent TMD symptomology (Roldán-Barraza et al., 2014). Although interpretations of data overall were hampered by a limited number of studies containing standardized measures, results suggested patients experienced greater long-term outcome efficacy following a psychosocial intervention compared to standard dental treatment alone. These findings are consistent with recommendations of others who have suggested the addition of psychosocial interventions for patients with TMDs (Carlson et al., 2001; Gatchel et al., 2007; Roldán-Barraza et al., 2014; Schmidt et al., 2013). Further study of psychosocial interventions exploiting mHealth apps into traditional dental treatments would be of substantial benefit.

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VITA

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EDUCATION

- 8/2012 – 12/2014 **University of Kentucky**
Master of Science, Clinical Psychology
Advisor: Charles R. Carlson, Ph.D.
Master's Thesis: *Diaphragmatic Breathing and Its Effects on Inhibitory Control.*
- 8/2008 – 5/2012 **University of Kentucky**
Bachelor of Science, Psychology, with Honors
Advisor: Charles R. Carlson, Ph.D.
Senior Thesis: *Use of Controlled Diaphragmatic Breathing for the Management of Motion Sickness in a Virtual Reality Environment*

CLINICAL POSITIONS

- 2017 – 2018 **Michael E. DeBakey VA Medical Center, Houston, TX**
Doctoral Psychology Intern
- 2016 – 2017 **Cardinal Hill Rehabilitation Hospital, Lexington, KY**
Behavioral Medicine Trainee
- 2013 – 2017 **Jesse G. Harris, Jr. Psychological Services Center, University of Kentucky**
Center Therapist
- 2014 – 2016 **Bluegrass Health Psychology Private Practice Clinic, Lexington, Kentucky**
Behavioral Health Specialist
- 2015 – 2016 **Jesse G. Harris, Jr. Psychological Services Center, University of Kentucky**
Center Coordinator
- 2013 – 2014 **University of Kentucky Orofacial Pain Clinic, Lexington, KY**
Practicum Therapist
- 2014 **Healthy Relationships, Salvation Army, Lexington, KY**
Co-leader

TEACHING POSITIONS

- 2015 – 2016 Undergraduate Instructor: Professional Development Seminar
- 2012 – 2015 Undergraduate Guest Lecturer: Orientation to Psychology
- 2014 Undergraduate Laboratory Instructor: Introductory Psychology
- 2012 – 2013 Undergraduate Laboratory Instructor: Experimental Psychology

RESEARCH POSITIONS

- 2012 – 2018 **Behavioral Self-Regulation Laboratory, University of Kentucky**
Research Assistant
- 2014 – 2018 **Psychoneuroimmunology Laboratory, University of Kentucky**
Research Assistant
- 2010 – 2012 **Undergraduate Research Assistant, University of Kentucky**
Research Assistant

PROFESSIONAL AWARDS, HONORS, & SCHOLASTIC AWARDS

2017	Kentucky Operation Immersion: <i>Distinguished Service Award</i>
2013 and 2015	<i>Make a Difference Award</i> , University of Kentucky
2016 – 2017	<i>Graduate Student Travel Award</i> , University of Kentucky
2016 – 2017	<i>Department of Psychology Student Travel Award</i> , University of Kentucky
2016	<i>Ruth L. Kirschstein National Research Service Award (NRSA)</i> Individual Predoctoral Fellowship (Parent F31). Submitted to the National Institute of Dental and Craniofacial Research: Technology Assisted Diaphragmatic Breathing Training for Chronic Myalgia. Initial Grant Review Score: 25
2014 – 2016	<i>Lyman T. Johnson Academic Year Fellowship Award</i> , University of Kentucky
2014 – 2016	Research Assistant: Self-Regulation, Immunological Aging, and Health in Older Adults (NIH/NIA #AG026307-R01) PI: Suzanne C. Segerstrom, Ph.D. (University of Kentucky). Orofacial Pain Center Psychology Training Program
2014	
2012	<i>Joseph P. Kennedy: Student Development Council Scholarship</i> , University of Kentucky
2012	CSCAA: Honorable Mention Scholar All American
2011	<i>Captain University of Kentucky Men's Swimming & Diving Team</i>
2008 – 2011	<i>Dean's List</i> , University of Kentucky
2008 SEC	<i>Academic Honor Roll</i> , University of Kentucky
2008 SEC	<i>Freshman Academic Honor Roll</i> , University of Kentucky

PROFESSIONAL PUBLICATIONS

- Russell, M. E. B., Segerstrom, S. C., Okeson, J. P., Fillmore, M. T., & Carlson, C. R. (In preparation). Technology assisted diaphragmatic breathing training for chronic myalgia.
- Russell, M. E. B., C. Alex Brake, Ruth, A Baer, Ph.D. (In preparation). Comparisons between paced diaphragmatic breathing and mindfulness-based breathing techniques on parasympathetic activation, HRV, and self-regulation.
- Russell, M. E. B., Oltmanns, J. R., & Carlson, C. R. (Under Review). Patient Health Questionnaire 4 as an ultra-brief screener for psychological distress in orofacial pain patients.
- Russell, M. E. B., Fillmore, M. T., Baer, R. A., Studts, J. L., & Carlson, C. R. (Under Review). Diaphragmatic breathing and its effects on inhibitory control.
- Gagnon, T. C., Russell, M. E. B., & Carlson, C. R. (Under Review). Examining the effect of breathing and social support on response to thermal stimuli.
- Russell, M. E. B., Scott, A., Boggero, I. A., & Carlson, C. R. (2017). Inclusion of a rest period in diaphragmatic breathing increases high frequency heart rate variability: Implications for behavioral therapy. *Psychophysiology*, *54*(3), 358-365.
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- Russell, M. E. B., Hoffman, B., Stromberg, S., & Carlson, C. R. (2014). Use of controlled diaphragmatic breathing for the management of motion sickness in a virtual reality environment. *Applied Psychophysiology and Biofeedback*, *39*(3-4), 269-277.