Comparing the Acute Effects of Hatha Yoga and Meditation on Executive Function

by

Kimberley Luu

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Authors Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

Background: Prior research demonstrates that acute and chronic bouts of Hatha yoga, a moving meditation, shows promise for improving executive function (EF) and mood outcomes in a variety of populations. However, more evidence is warranted to further elucidate these findings.

Objective: To compare the acute effects of Hatha yoga and meditation on executive function and mood, gaining a clearer understanding of the physical and mental subcomponents.

Methods: Using a within-subject experimental design, 31 moderately experienced Hatha yoga practitioners (M_{age} = 27.71, *SD* = 8.32) completed 3 counterbalanced sessions: Hatha yoga, meditation and a reading control task. Executive function (primary outcome) was assessed using the Stroop task at baseline and at 2 follow-up points (5 minutes post- and 10 minutes post-session). Self-reported mood (secondary outcome) was measured using the Profile of Mood States (POMS) before and immediately following each session.

Results: Hatha yoga (p = .002) and meditation (p = .044) both resulted in significantly improved Stroop interference scores, though the 2 conditions did not differ significantly from each other (p = .73). The cognitive benefits in both cases were evident at the 10 minute post-session delay but not at the 5 minute post-session delay. With respect to mood outcomes, Hatha yoga (p < .001) and meditation (p = .050) also both resulted in significantly improved POMS total mood scores. Again, Hatha yoga and meditation did not differ significantly from each other, though there was a marginal advantage for Hatha yoga (p = .079).

Conclusions: Hatha yoga and meditation both improved executive function and mood to a similar degree. The cognitive benefits of Hatha yoga and meditation may be discernible after a 10 minute delay, whereas the mood benefits may be apparent relatively immediately.

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List of Abbreviations

Analysis of Variance = ANOVA

Executive Function = EF

Focussed Attention = FA

Open Monitoring = OM

Profile of Mood States-2 Adult Short = POMS 2A-Short

General Introduction

Yoga and Meditation

History and Philosophy

Yoga is an ancient philosophy originally designed to foster non-violence within Indian tribes called the Vedas (Bryant, 2009). The Vedas resided in the Indus Valley, otherwise known as modern-day northwest India and Pakistan (Bryant, 2009). It is estimated that yoga was practiced by the Indus civilization over 4000 years ago based on archeological sites of the Indus Valley, marked by artworks containing figures in the traditional meditation posture (Bryant, 2009). A lineage of Vedic gurus passed on the teachings of yoga throughout Eastern countries to eventually travel around the world (Bryant, 2009).

Though heavily intertwined with Buddhism and Hinduism, the philosophical pillars of yoga are distinctly their own and can be summarized in two categories: (1) maintenance of ethical standards and (2) personal self-growth. The ethical standards are specifically non-violence, truthfulness, refrainment from stealing, celibacy, and renunciation of all unnecessary material possessions (Bryant, 2009). Meanwhile, the pillars of self-growth include cleanliness, strict health behavior maintenance, mindful contentment within the present moment, self-discipline, and devout study of yogic scripture (Bryant, 2009). Moreover, "cultivating mastery of the mind," that is, the ability to control thoughts, emotions, and sense perceptions with austerity, is a central facet of yogic philosophy (Bryant, 2009).

Practice

The practices of yoga are supportive exercises meant to cultivate states of being that allow the practitioner to engage in the philosophical aspects with ease (Muktibodhananda, 2012).

Hatha yoga is the most popular style of yoga practiced in Western culture and involves both physical and mental training components, including movement through postures, breath regulation, and meditation (Muktibodhananda, 2012). The postural movements typically involve a certain degree of aerobic exercise, resistance training, stretching, and balance training. Breath control practices are performed both in synchronized concert with postural movements as well as on their own (e.g., self-directed counting of inhale and exhale length). Finally, meditation involves the practice of sustaining concentration on a desired attentional set. Meditation can either involve focussing on a more specific set ("focussed attention meditation") such as an intention (e.g., gratitude) or object (e.g., a candle flame), or a broader set, that is attuning to the present moment with acceptance and equanimity ("mindfulness meditation"; Semple, 2010).

Hatha Yoga, Meditation, and Brain Function

Researchers have become increasingly interested in the effects of Hatha yoga and meditation on the brain. Early studies focused on Hatha yoga and meditation interventions from a therapeutic perspective in regards to improving mental health. Perhaps the most well-established effect cited in both modalities and close variations of (e.g., mindfulness-based stress reduction) is decreases in both physiological and perceived distress (Michalsen et al., 2005; Berger & Owen, 1988; Smith, Hancock, Blake-Mortimer, & Eckert, 2007; Waelde, Thompson, & Gallagher-Thompson, 2004; Jun, 1992; Grossman, Niemann, Schmidt, & Walach, 2004) and maladaptive forms of anxiety (Peterson, & Pbert, 1992; Miller, Fletcher, & Kabat-Zinn, 1995; Schwartz., Davidson, & Goleman, 1978; Streeter et al., 2010).

More recently studies have investigated Hatha yoga and meditation's effects on cognitive functions, with the majority of reports revealing positive benefits in the domains of sustained attention, memory, and the executive functions (Gothe & McAuley, 2015; Tang, Hozel, & Posner, 2015). While the Hatha yoga and cognition literature is still in its infancy and inherently vies for more attention (Gothe & McAuley, 2015), the meditation and cognition literature is slightly more robust (Tang, et al., 2015; Fox et al., 2014). However, that is not to say it is without its caveats; many studies on meditation and cognition are non-experimental and thus cannot infer causality (Fox et al., 2014). For instance, studies involving comparisons between expert meditators against non-meditators on various cognitive measures are inherently cross-sectional, and this was the approach of many early studies in this area. Despite the existence of a few well-executed experimental studies, it remains unclear whether meditation improves cognitive functioning, or if individuals who already maintain certain qualities, including high cognitive functioning, are attracted to meditation practices (Fox et al., 2014). Additional experimental studies are required in order to draw more definitive conclusions about the cognitive effects of meditation.

Executive Function and Public Health

As mentioned, some studies have begun to analyze Hatha yoga and meditation's effects on a particular set of cognitive abilities called the executive functions (EFs; Luu & Hall, 2015). EF's allow for the self-regulation of thoughts, emotions, and behaviors and operate through means of top-down (i.e., non-stimulus driven) control (Miyake & Friedman, 2012). The three main facets of executive function as modelled by Miyake & Friedman (2012) include inhibitory control, working memory, and mental flexibility. Inhibitory control is the ability to deliberately override automatic or pre-potent responses (Miyake et al., 2000). Working memory involves monitoring, insertion and deletion of goal relevant information (Miyake & Friedman, 2012).

Meanwhile, mental flexibility is the capacity to shift between mental sets or tasks (Miyake & Friedman, 2012). The EF's have both distinct and unifying aspects; that is, while they have their own unique properties, they also rely on each other to function (Miyake & Friedman, 2012). Inhibitory control is thought to be the most exemplary facet of EF because its presence is necessary for both working memory and mental flexibility to function. Overall, the EFs collaborate with one another to moderate and perform goal-directed behavior (Hofmann, Schmeichel, & Baddeley, 2012).

From a public health perspective, the maintenance of strong EFs are implicated in coordinating activities of daily life, managing mood (Ownsworth & Fleming, 2005; Sarason & Sarason, 1981), and implementing long-term desired goals (Gilbert & Burgess, 2008)-- including those that are health behavior related (Hall & Fong, 2007). These contribute to enhancements in personal well-being, and as predicted, strong EF has been found to be correlated with higher health related quality of life (Brown & Landgraf, 2010). Therefore, it is of great importance to investigate modalities such as Hatha yoga and meditation, which may enhance EF.

Project Objectives

The overall objectives of this project are: (1) to assess the current state of literature regarding Hatha yoga's effects on EF and (2) to compare the acute effects of Hatha yoga and meditation on EF and mood in a new empirical study. These objectives will be addressed through two studies. Study 1 is a systematic review which analyzed the current empirical literature regarding the effects of Hatha yoga on EF. This systematic review is intended to build a comprehensive knowledge base for a deeper investigation that is Study 2, which is an experimental study analyzing the effects of a single bout of Hatha yoga against meditation on EF and mood.

Study 1: Hatha yoga and Executive Function: A Systematic Review

Introduction

Yoga is an ancient Indian practice designed to "still the fluctuations of the mind" and facilitate meditative absorption, a psychological state marked by feelings of self-transcendence and unceasing happiness (Bryant, 2009). The most common style of yoga practiced in Western countries is Hatha yoga, which includes synchronized movements through postures with breath, meditation, breathing exercises, and supine rest to conclude (Muktibodhananda, 2012). Examples of Hatha yoga include Ashtanga yoga, Iyengar yoga, and Yin/ Yang yoga.

As an integrative mind-body practice, much research has accumulated regarding improvements in emotion-regulation following Hatha yoga practice. An overview study of meta-analytic, systematic, and narrative reviews pertaining to the health benefits of Hatha yoga concluded that Hatha yoga is moderately beneficial in the context of chronic pain management, decreasing fatigue, relieving anxiety and depressive disorders, and conjunctively supporting standard treatments for post-traumatic stress disorder (Bussing, Michalsen, Khalsa, Telles, & Sherman, 2012). In more recent years, interest has shifted from merely investigating Hatha yoga from a directly psychiatric standpoint to also include examination of Hatha yoga's effects on cognitive functions such as attention, memory, problem solving, decision making, and the executive functions (EFs) (Gothe & McAuley, 2015).

For the past two decades, there has been emerging evidence suggesting that Hatha yoga may enhance EF. EF's refer to a set of higher-order cognitive processes that enable top-down (i.e. non-stimulus driven) control over behavior, emotion and thought; most typically involving inhibitory control, working memory and mental flexibility, arising from the operation of the prefrontal cortex and other closely connected centers (Miyake & Friedman, 2012). Other cognitive functions such as attention control, decision making, planning, and problem solving are often in addition classified as EFs because they are highly correlated with EF or functionally dependent on them (Funahashi & Andreau, 2013).

Although reviewers have discussed the effects of seated meditation on cognition and EF (Chiesa, Calati, & Serretti, 2011; Raffone & Srinivasan, 2010; Lutz, Slagter, Dunne, & Davidson, 2008; Canter & Ernst, 2003), a comprehensive review of Hatha yoga as a whole (i.e. yoga inclusive of meditation plus physical posturing) has yet to be undertaken. The purpose of this systematic review is to summarize the effects of Hatha yoga on EF. The question to be addressed is as follows: are there beneficial effects of Hatha yoga on EF? For the purposes of this review, an “acute bout” of Hatha yoga refers to a single practice session, “short-term training” refers to 1 week to 6 months of regular practice, while “long-term” training refers to more than 6 months of regular practice.

Given that Hatha yoga involves three main components; physical activity, meditation, and breathing exercises, we will first review the literature pertaining to each of these components in turn. In the context of Hatha yoga, aerobic and resistance exercise is manifest in the form of continuous movements through postures which stretch and strengthen the body; meditation and breathing exercises are integrated into Hatha yoga practices both independently and in concert with movement.

Physical Activity

Enhancements in EF have been well established following aerobic exercise. For instance, acute bouts of aerobic exercise have been shown to improve inhibitory control (Sibley, Etnier, & Masurier, 2006; Barella, Etnier, & Chang, 2010; Yanagisawa, Dan & Tsuzuki, 2010), working memory (Sibley & Beilock, 2007), and planning (Chang et al., 2011), while one meta-analyses supports the positive effects of exercise on EF (Smith, Blumenthal, & Hoffmann, 2010). Some studies have documented structural and physiological brain changes associated with enhanced cognition following aerobic training. For example, one intervention study found increases in gray matter volume in frontal regions of the brain among older adults following aerobic exercise training (Colcombe, Erickson, & Scalf, 2006). Furthermore, a recent review by Erickson, Hillman, and Kramer (2015) concluded that higher fit children and older adults tend to exhibit greater hippocampal and basal ganglia volumes, greater white matter integrity, and superior performance on cognitive tasks. Another systematic review revealed increases in serum and plasma levels of brain-derived neurotrophic factor, a neurotrophin which supports physiological mechanisms involved in neuroplasticity, following acute bouts of aerobic exercise (Knaepen, Goekint, Heyman, & Meeusen, 2010); other studies involving animal models have documented enhanced localized glycogen storage in the cortex of rats following acute aerobic training (Matsiu & Soya, 2013).

Though results are mixed, many studies have begun to support EF-enhancing abilities of resistance training. For example, studies have found significant improvements in inhibitory control (Chang & Etnier, 2009) and planning (Chang, Ku, Tomporowski, Chen, & Huang, 2012), but not working memory (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009) following acute bouts of resistance training in healthy adults. Investigators report significant improvements in working memory (Cassilhas, Viana, & Grassmann, 2007) and inhibitory control (Nagamatsu, Handy, Hsu, Voss, & Liu-Ambrose, 2012) following 6 months of resistance training while significant improvements in inhibitory control were found following a 12 month resistance training program compared to a balance and tone training control group (Liu-Ambrose, Nagamatsu, Graf, Beattie, Ashe, Handy, 2010). A review on older adult populations found that resistance exercise interventions with a substantive number of sets (7 movements in 2 sets), load (60-80% one-repetition maximum), and duration (2 to 12 months) may positively enhance cognitive functions such as attention, memory, and inhibitory control, but effects are not as pronounced for working memory and mental flexibility (Chang, Pan, Chen, Tsai, & Huang, 2012).

Meditation

Meditation has been revealed to provide EF enhancements, and can be categorized under focused attention (FA) and open monitoring (OM; Semple, 2010). FA meditation consists of directing awareness to a chosen object, detecting distractions as they arise, and subsequently redirecting awareness to the chosen object (Semple, 2010). OM meditation, commonly known as "mindfulness," involves sustained metacognitive awareness of internal and external experiences such as emotions, thoughts, and sensory stimuli, without engaging in further cognitive reconstruction (Semple, 2010). Raghavendra and Telles (2012) found that an acute bout of FA meditation improved attention and concentration task performance, while MacLean, Ferrer, & Aichele (2010) found that three months of intensive FA meditation training significantly improved vigilance during a visual attention task in novice meditators. However, one systematic review critically examined transcendental meditation, a form of FA meditation which asks the practitioner to allow the mind to wander but simultaneously concentrate on repeated mantras and sound vibrations, and found that transcendental meditation does not seem to improve cognitive functions (Canter & Ernst, 2003). On the other hand, there is evidence that OM training improves attention (Zeidan, Johnson, Diamond, David, & Goolkasian) and working memory (Mrazek, Franklin, Phillips, Baird, & Schooler, 2013), while decreasing mind-wandering (Mrazek et al., 2013). Experienced OM meditators show significantly superior inhibitory control and selective attention compared to meditation naïve controls (Moore & Malinowski, 2009).

Moreover, studies analyzing brain scans of meditators who practice both FA and OM meditation found thicker brain regions in Brodmann areas 9/10 of the prefrontal cortex, right anterior insula, somatosensory cortex, and auditory cortex; areas associated with attention, interoception, and sensory processing (Lazar et al., 2005), as well as the right orbito-frontal cortex and right hippocampus, associated with emotion-regulation and response control (Luders, Toga, Lepore, & Gaser, 2009; Fox et al., 2014). However, it should be noted that these studies were cross-sectional and therefore cannot infer causality. Other limitations of this literature base include the fact that many researchers are passionate meditators themselves and present a publication bias towards positive findings (Tang et al., 2015).

Breathing Exercises

Studies investigating the effects of breathing exercises on EF reveal mixed results. For instance, Telles, Raghuraj, Arankalle, and Naveen (2008) found improvements in selective attention and concentration immediately after kapalabhati, a high frequency forceful exhalation breathing exercise, in groups of medical students, middle aged adults, and older adults. Conversely, Pradhan (2013) found no significant changes in working memory and selective attention following kapalabhati breathing. Another study assessed three breathing exercises: alternate nostril breathing, where each nostril is alternately plugged by the index finger and thumb as so inhales flow through one nostril and exhales flow out through the other per breath cycle; right nostril breathing, where the left nostril is plugged; and left nostril breathing, where the right nostril is plugged (Telles, Raghuraj, Maharana, & Nagendra, 2007). Improvements in attention were found following the right and alternate nostril breathing exercises (Telles et al., 2007). Finally, Telles, Singh, and Puthige (2013) found increases in peak amplitudes and decreases in latencies in P300 event-related potentials using the oddball paradigm following an alternate nostril breathing exercise in subjects who did 3 months of breathing exercise training prior, suggesting increases in attentional resources and stimulus processing speed and efficiency.

With acknowledgment that the separated subcomponents of Hatha yoga may have substantive effects on cognition and EF, the current study aims to investigate the effects of Hatha yoga, as a whole, on EF.

Methods

A search was done using MEDLINE, Scopus, and PsycINFO in March 2015 using the following terms: “yoga”, “cognition”, “executive function”, “inhibitory control”, “working memory”, “set shifting”, “updating,” “attention”, “problem solving”, “decision making”, “prefrontal cortex”. Studies written in English dated from database inception to March 2015 were assessed.

Inclusion/ Exclusion Criteria

Experimental studies that analyzed the effects of Hatha yoga on EF were searched for. To be included, studies needed to involve strictly Hatha yoga interventions/ manipulations, defined by the use of mindful postural movements with breath synchronization. Studies were required to include at least one non-self-report measure of EF (i.e. using computerized tasks or neuropsychological tests, rather than self- or other-report measures). All participant population types were included.

Studies which investigated the separate effects of physical activity, meditation, breathing exercises, and other Hatha yoga related techniques (e.g. chanting, progressive muscle relaxation) alone were excluded from this review. Moreover, studies that analyzed multimodal interventions (e.g., Hatha yoga with tai chi, integrative yoga philosophy and practice modules) were excluded. Finally, studies that analyzed Hatha yoga interventions as a control group, and in a case-series were excluded.

Risk of Bias Assessment

Study quality was determined using the Cochrane risk of bias tool (Higgins et al., 2011) by two raters (K. L. and C. V.); any disagreements were resolved via discussion with the senior author (P. H.) and a consensus rating was assigned. Agreement between the raters was achieved for 90.9% of the ratings. According to these protocols, in order to maintain "low risk" of selection bias, between-subject studies must have reported use of random sequence generation, while within-subject studies must have involved counterbalancing of trial sessions. In addition, allocation concealment procedures must have been employed so that primary researchers could not influence random assignment; examples of these procedures include the utilization of a third party to conduct the randomization process and the sequential drawing of numbers from sealed papers or envelopes. High performance bias is assumed to be inevitable for studies reviewed here, as participants typically understand that they are practicing the Hatha yoga intervention (i.e. intervention status is salient by default). However, it could be minimized if treatment personnel such as exercise instructors were blinded; in these cases, risk of performance bias was rated as "unclear." Detection bias was determined by whether individuals executing EF outcome assessments were personnel whom were blinded to the study hypothesis and/ or if the EF outcome was administered using computerized tasks. Attrition bias was considered "low" if the participant dropouts did not significantly differ in either treatment group and for similar reasons. Moreover, dropout must have been lower than 20%. To achieve "low risk" of reporting bias, results of all EF outcome measures must have been reported sufficiently.

Results

Overview

Excluding duplicates, the search yielded 825 citations. Of these, 120 citations analyzed relationships between exercise modalities and cognition. The full texts of these articles were examined, and 11 articles met inclusion criteria. Three studies involved healthy adult samples, 1 involved children and adolescent samples, 2 involved older adult samples, 1 involved impulsive prisoners, one involved type-2 diabetes mellitus patients, and 3 involved multiple sclerosis patients. The heterogeneity of participant characteristics across studies precluded the use of meta-analytic methods; as such a systematic review was completed. Figure 1 demonstrates the filtering process of included and excluded studies. Table 1 summarizes the research interventions, measures, and results of included studies.

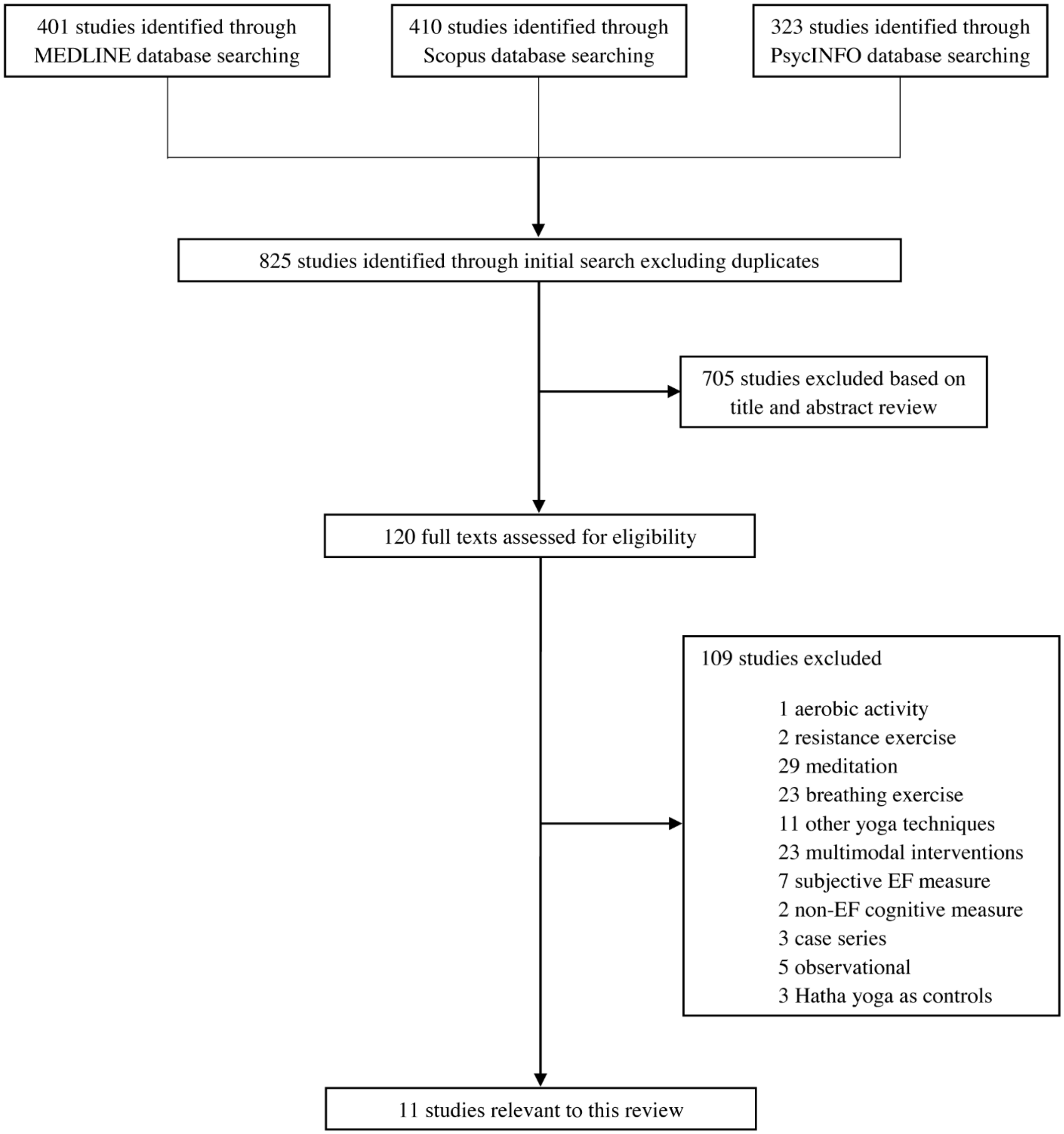

Figure 1: Study filtering process.

Study Quality

The majority of studies indicated methods of randomization to treatment groups or counterbalancing sessions; however, allocation concealment was often unreported. With the exception of 2 studies which reported blinding personnel (Kyizom, Singh, Singh, Tandon, & Kumar, 2010; Telles, Singh, Bhardwaj, Kumar, & Balkrishna, 2013), most trials were by default judged to be at high risk of performance bias because of the highly salient nature of the intervention itself. On the other hand, the majority of studies did not appear to suffer from detection bias as the outcome measures were often computer administered. Attrition bias varied, where 2 studies had a high dropout rate (Oken et al., 2006; Gothe, Pontifex, Hillman, & McAuley, 2014), 1 study had dropout rates which were unbalanced between the two intervention groups (Velikonja, Curic, Ozrua, & Jasbec, 2010), and 2 studies did not report dropout rates altogether (Telles, Bhardwaj, Kumar, Kumar, & Balkrishna, 2012; Chaya, Nagendra, Selvam, Kurpad, & Srinivasan, 2012). All studies reported EF outcome data adequately. Table 2 displays the risk of bias summary for each included study.

Table 1: Summary of experimental studies.

Citation	Participants	Intervention	EF Outcome Measure	Results
Bilderbeck, Farias, Brazil, Jakobowitz, & Wilkholm (2013)	Impulsive prisoners; Hatha yoga group N=39 vs. control group N=51.	Ten weeks of Hatha yoga or control group.	Inhibitory control; Go/No-Go task at post intervention.	Significantly superior inhibitory control in ten week Hatha yoga intervention group compared to controls.
Bowden, Gaudry, An, & Gruzelier (2012)	Healthy adults; Iyengar yoga group N=9 vs. brain wave vibration group N=12 vs. mindfulness N=12.	Five weeks of Iyengar yoga, brain wave vibration training, or mindfulness.	Working memory; n-Back task (2-back) at baseline and post intervention.	No significant improvements in working memory following five weeks of Iyengar yoga training.
Gothe, Kramer, & McAuley (2014)	Older adults; Hatha yoga group N=58 vs. stretching control group N=50.	Eight weeks of Hatha yoga or a stretching and strengthening control group.	Mental flexibility; Task Switching Paradigm by Kramer et al. (1999); and working memory; letter version of the Running Memory Span task, n-(1- and 2) Back task.	Significant improvements in mental flexibility and working memory following eight weeks of Hatha yoga compared to stretching controls.

Gothe, Pontifex, Hillman, & McAuley (2013)	Undergraduate females N=30.	Participants underwent three counterbalanced sessions of baseline testing, Hatha yoga, and aerobic exercise on three separate days.	Inhibitory control; the Flanker task and working memory; the n-(0-, 1-, and 2-) Back task at baseline testing session, and after each exercise sessions.	Significantly increases in inhibitory control and working memory following an acute bout of Hatha yoga session as compared with baseline testing and an acute bout of aerobic exercise.
Kyozim, Singh, Singh, Tandon, & Kumar (2010)	Type-2 diabetics; Convention medical therapy N=30 vs. Hatha yoga with conventional medical therapy N=30.	Participants divided into. five days of Hatha yoga intervention followed by forty-five days of home practice or control group.	Working memory and attention; P300 event-related potential using the oddball paradigm at baseline and post intervention.	Significant improvements in working memory and attention following a forty-five day Hatha yoga and conventional medical therapy intervention as compared with conventional medical therapy only.
Oken, Kishiyama, Zajdel, et al. (2004)	Multiple sclerosis patients; Iyengar yoga group N=22 vs. cycling group N=21 vs. control group N=20.	Six months of Iyengar yoga intervention, cycling training, or waitlist controls.	Inhibitory control and attention; Stroop task and a quantitative electroencephalogram measure at baseline and post intervention.	No significant improvements in inhibitory control and attention following six months of Iyengar training.
Oken, Zajdel, Kishiyama, et al. (2006)	Older adults; Iyengar yoga group N=38 vs. walking group N=38 vs. control group N=42.	Six months of Iyengar yoga intervention, walking class, or waitlist controls.	Inhibitory control and attention; Stroop task and a quantitative electroencephalogram measure at baseline and post intervention.	No significant improvements in inhibitory control and attention following six months of Iyengar yoga training.
Sandroff, Hillman, Benedict, & Motl (2015)	Multiple sclerosis patients N=24.	Participants underwent four counterbalanced twenty minute sessions of treadmill walking,	Inhibitory control; modified Flanker task before and after each session.	Significant increases in inhibitory control following twenty minutes of Hatha yoga treadmill walking, cycle ergometry compared to quiet rest.

		cycle ergometry, Hatha yoga, and quiet rest.		
Telles, Bhardwaj, Kumar, Kumar, & Balkrishna (2012)	Healthy adult males; Hatha yoga group N=70 vs. breath awareness group N=70 vs. meditation music control group N= 20.	Forty-five minute sessions of Hatha yoga, breath awareness, or listening to meditation music control classes.	Working memory and selective attention; Digit Letter Substitution task, at baseline and post intervention.	Significant improvements in working memory and selective attention following forty-five minutes of Hatha yoga training.
Telles, Singh, Bhardwaj, Kumar, & Balkrishna (2013)	Children and adolescents ages eight to thirteen; Hatha yoga N=49 vs. physical exercise N=49.	Three months of Hatha yoga or physical exercise intervention.	Inhibitory control; Stroop task at baseline and post intervention.	Significant improvements in inhibitory control following three months of Hatha yoga.
Velikonja, Čurić, Ožura, & Jazbec (2010)	Multiple sclerosis patients; Hatha yoga group N=10 vs. sports climbing group N=10.	Participants randomized into ten weeks of Hatha yoga intervention or sports climbing.	Executive function; Mazes subtest of Executive module from the Neurophysiological Assessment Battery, planning skills; the Tower of London task, attention; Brickenkamp d2 test at baseline and post intervention.	No significant improvements in executive function and planning skills following a ten week Hatha yoga intervention. Significant improvement in attention following a ten week Hatha yoga intervention.

Healthy Adults

Three published experimental studies have investigated the effects of Hatha yoga on EF in healthy adult populations. Bowden, Gaudry, An, and Gruzelier (2012) found no significant improvements in working memory under the n-Back task following five weeks of an Iyengar yoga intervention. Iyengar yoga is a gentle style of Hatha yoga which allows the use of blocks, straps, and bolsters to aid in proper physical alignment. Researchers discuss that these insignificant findings may have been due to a small sample size via a high attrition rate. Conversely, a within-subjects study conducted by Gothe, Pontifex, Hillman, and McAuley (2013) revealed significant improvements in working memory using the n-Back task and inhibitory control using the Flanker task immediately following Hatha yoga as compared with the aerobic exercise and baseline control sessions in an undergraduate female sample. Furthermore, one randomized control trial revealed significant improvements in working memory and selective attention using the Digit Letter Substitution task following an acute bout of Hatha yoga (Telles, Bhardwaj, Kumar, Kumar, & Balkrishna, 2012).

Children and Adolescents

One study addressed the effects of Hatha yoga on the EF in children and adolescents. Telles, Singh, Bhardwaj, Kumar, and Balkrishna (2013) revealed significant improvements in inhibitory control using the Stroop task following three months of Hatha yoga in children and adolescents. These findings may support Hatha yoga as an alternative means to improve cognitive abilities in children and adolescent populations for both educational and general settings.

Older Adults

Two studies have investigated the effects of Hatha yoga on EF in older adults, a population at risk for cognitive decline. One randomized control trial conducted by Oken, et al. (2006) found no significant improvements in inhibitory control and attention using the Stroop task and quantitative electroencephalogram measures following a 6 month Iyengar yoga intervention. They did however, find increases in well-being, energy levels, and physical functionality. Researchers discuss that these findings may have been due to ceiling effects as the older adults were relatively healthy. Conversely, Gothe, Kramer, and McAuley (2014) found significant improvements in working memory using a letter version of the Running Memory Span and n-Back tasks, and mental flexibility using a task-switching paradigm following an eight week Hatha yoga intervention in older adults, as compared with a stretching only control group. Though further investigation is needed, these studies give us some preliminary data on how Hatha yoga may affect EF in older adults.

Impulsive Prisoners

A randomized control study conducted by Bilderbeck, Farias, Brazil, Jakobowitz, & Wilkholm (2013) found superior performance in inhibitory control using the Go/No-Go task on prisoners who scored high on impulsivity measures following a 10 week Hatha yoga intervention compared to a lifestyle as per usual control group. In addition, the Hatha yoga group showed significant increases in positive affect and decreases in perceived stress. However, it should be noted that EF was measured only after the intervention was completed and no baseline scores were available for pre-post comparisons.

Type-2 Diabetes Mellitus Patients

One study analyzing the effects of Hatha yoga on individuals living with type-2 diabetes mellitus revealed significant increases in amplitude and decreases in latency in P300 event-related potentials when using an auditory oddball paradigm following a 45 day intervention as compared to a conventional therapy only control group (Kyizom, Singh, Singh, Tandon, & Kumar, 2010). These findings suggest higher and faster neuronal recruitment in frontal regions of the brain responsible for working memory and attention allocation in patients with type-2 diabetes mellitus, a population with a weakened P300 event-related potential, following a short-term Hatha yoga intervention.

Multiple Sclerosis Patients

Studies have investigated the effects of Hatha yoga on EF in multiple sclerosis patients. A randomized control trial conducted by Oken et al. (2004) found no significant improvements in inhibitory control and attention using the Stroop task and a quantitative electroencephalogram following a six month Iyengar yoga intervention. Similarly, Velikonja, Čuric, Ožura, and Jazbec (2010) reported no significant improvements in EF using the Mazes subtest of the Executive module from the Neurophysiological assessment battery or planning skills using the Tower of London task following a 10 week Hatha yoga intervention. However, improvements in attention were found under the Brickenkamp d2 test (Velikonja et al., 2010). Finally, a recent study by Sandroff, Hillman, Benedict, and Motl (2015) found improvements in inhibitory control under a modified Flanker task following an acute 20 minute bout of Hatha yoga. More research for this population is warranted in order to provide conclusive statements.

Table 2: Risk of bias summary.

	Random sequence generation or counterbalancing of sessions (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of EF outcome assessments (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting of EF outcome results (reporting bias)
Bilderbeck, Farias, Brazil, Jakobowitz, & Wilkholm (2013)	(+)	(?)	(-)	(+)	(-)	(+)
Bowden, Gaudry, An, & Gruzelier (2012)	(+)	(+)	(-)	(+)	(-)	(+)
Gothe, Kramer, & McAuley (2014)	(+)	(?)	(-)	(+)	(-)	(+)
Gothe, Pontifex, Hillman, & McAuley (2013)	(+)	(?)	(-)	(+)	(+)	(+)
Kyizom, Singh, Singh, Tandon, & Kumar (2010)	(?)	(?)	(-)	(+)	(?)	(+)
Oken, Kishiyama, Zajdel, et al. (2004)	(+)	(+)	(?)	(+)	(+)	(+)
Oken, Zajdel, Kishiyama, et al. (2006)	(+)	(+)	(?)	(+)	(+)	(+)
Sandroff, Hillman, Benedict, & Motl (2015)	(+)	(?)	(-)	(+)	(+)	(+)
Telles, Bhardwaj, Kumar, Kumar, & Balkrishna (2012)	(-)	(?)	(-)	(?)	(+)	(+)
Telles, Singh, Bhardwaj, Kumar, & Balkrishna (2013)	(+)	(+)	(-)	(+)	(+)	(+)
Velikonja, Čurić, Ožura, & Jazbec (2010)	(+)	(?)	(-)	(?)	(?)	(+)

(+) = low risk of bias; (-) = high risk of bias; (?) = unclear risk of bias

Discussion

The purpose of the current study was to address the question of whether or not Hatha yoga improves EF. A systematic review methodology was employed and yielded a total of 11 studies involving healthy adults (*n* = 3), children and adolescents (*n* = 1), older adults (*n* = 2), impulsive prisoners (*n* = 1), type-2 diabetes mellitus patients (*n* = 1) and multiple sclerosis patients (n = 3). In healthy subjects, 2 studies revealed that acute bouts of Hatha yoga significantly improved EF in the realms of inhibitory control (Gothe et al., 2013), working memory (Gothe et al., 2013; Telles et al., 2012), and attention (Telles et al., 2012), while 1 study on short-term training found no improvements in working memory (Bowden et al., 2006). In children and adolescents, significant improvements in inhibitory control (Telles et al., 2013) were found following Hatha yoga training. In older adults, 1 study found significant improvements in mental flexibility and working memory (Gothe et al., 2014), however, another found no improvements in inhibitory control and attention (Oken et al., 2006) following short-term interventions. Impulsive prisoners who underwent a short-term Hatha yoga intervention performed significantly greater in an inhibitory control task as compared to controls (Bilderbeck et al., 2013). In type-2 diabetes mellitus patients, 1 study suggested improved working memory and attention abilities following a short-term intervention (Kyizome et al., 2010). Finally, studies on multiple sclerosis patients yielded mixed findings, where 2 found increases in attention and inhibitory control (Sandroff et al., 2015; Velikonja et al., 2010), and 2 found no improvements in inhibitory control and EF (Velikonja et al., 2010; Oken et al., 2004). Thus, the study concluded that while there is some evidence that Hatha yoga improves EF, more quality studies must be executed to draw confident conclusions.

Theorized Mechanisms

Based on the current systematic review, there appears to be some preliminary evidence that Hatha yoga can enhance EF. An important further question is: *How* could Hatha yoga potentially exert cognitive benefits? The nature of Hatha yoga leaves some clues: First, mindfulness is a central feature of Hatha yoga, and can be defined as a present focused state where the mind attunes to moment-by-moment sensations rather than “wander” or dwell on matters of the past or future (Froeliger, Garland, & McClernon, 2012). Therefore, conceptually speaking, increases in mindfulness may improve focus on presented tasks while minimizing internal distractibility. Furthermore, the absolute concentration required to balance and coordinate movement through unfamiliar, challenging postures while synchronizing breath patterns may also facilitate attentional enhancement (Froeliger, Garland, & McClernon, 2012).

Many researchers also speculate that the improvements in emotional stability may have implications for increasing cognitive function (Rocha et al., 2012; Granath, von Thiele, & Lundberg, 2006). For instance, studies have shown decreases in both perceived stress and cortisol levels following Hatha yoga (West, Otte, Geher, Johnson, & Mohr, 2004; Granath et al., 2006; Rocha et al., 2012). These outcomes may explain the positive findings on memory since hypercortisolism has been associated with smaller hippocampal volumes and memory impairment (Lindauer, Olff, Van Miejel, Carlier, & Gersons, 2006) and decreases in cortisol levels have in turn been found to reverse hippocampal atrophy (Starkman et al., 1999). Furthermore, one pilot study reported a 27% increase in gamma-aminobutryic acid, a major inhibitory neurotransmitter, in the brain under magnetic resonance spectroscopic imaging following a single bout of Hatha yoga (Streeter et al., 2007), indicating Hatha yoga's anti-anxiety properties as gamma-aminobutryic acid deficiency is linked to anxiety disorders (Nemeroff, 2003). It is further possible that Hatha yoga encourages homeostasis following acute stress by increasing parasympathetic nervous system activity and decreasing hypothalamic-pituitary-adrenal axis activity; Streeter, Gerbarg, Saper, Ciraulo, & Brown, 2012). Additionally, Hatha yoga's breathing exercises during engagement in strenuous, complex, and novel movements may teach safety processing amidst stressful situations through top-down regulation of vagus nerves (Streeter, Gerbarg, Saper, Ciraulo, & Brown, 2012). Finally, one review suggests that Hatha yoga shows potential for being a supplemental treatment option for major depression, a disease which debilitates cognition (Pilkington, Kirkwood, Rampes, & Richardson, 2005). In summary, Hatha yoga induced cognitive enhancements may be due to decreased interruption from emotional reactivity, and in turn, enhancements in cognitive centers may deter interruptive emotional reactivity through its inhibitory projections to emotion centers (Rosenkratz, Moore, & Grace, 2003).

However, despite these plausible mechanisms, at present there is incomplete evidence to confidently support the empirical link between Hatha yoga and EF. More good quality studies which examine the effects of Hatha yoga on EF are imperative to build a substantive evidence base worthy of extrapolating for health professionals to make confident decisions when prescribing Hatha yoga interventions.

Implications

Given the importance of EF for fostering achievement, health promotion, and prosocial behavior (Hall & Marteau, 2014; Hofmann et al., 2012), there may be substantial clinical and societal implications if the EF-enhancing benefits of yoga are confirmed in future studies and meta-analyses. Such benefits may be especially important for special subpopulations such as children, older adults, medical populations and forensic populations. For children, strong EF enables the behavioral self-discipline required to effectively adapt to educational settings (Davis et al., 2011). In older adults, prevention of aging-related EF decline is imperative for maintaining overall quality of life and functional independence (Davis, Marra, Najafzadeh, Liu-Ambrose, 2010). In addition, strong EFs are theorized to prevent progression of chronic disease via successful self-control of health behaviors, as one prospective cohort study found that chronically ill older adults with high EF had a lower mortality rate at a 10 year follow-up (Hall, Crossley, & D’Arcy, 2010). In impulsive prisoners, strengthening specific EF’s such as inhibitory control might positively impact aggression management and impulse control in the criminal rehabilitation context (Bilderbeck et al., 2013). Finally, EF deficits are highly prevalent in multiple sclerosis patients (Prakash, Snook, Lewis, Motl, & Kramer, 2008), and use of Hatha yoga to improve or reduce such deficits might be key to maintaining physical and social function in this group (Annett et al., 1999; Chiaravalloti & DeLuca, 2008).

Conclusion

There appears to be some evidence that Hatha yoga improves EF, though existing studies vary in quality and there is insufficient evidence to draw definitive conclusions for many populations and modalities of Hatha yoga. In healthy adults, studies suggest that acute bouts of Hatha yoga improve inhibitory control and working memory; however, there is insufficient evidence in the current literature which support improvements in EF following short and long-term interventions. Some evidence supports Hatha yoga’s ability to enhance inhibitory control in children and adolescents following short-term interventions, while improvements in working memory and mental flexibility have been reported in older adults. Short-term intervention studies have found improvements in inhibitory control in impulsive prisoners, and working memory and attention in type-2 diabetes mellitus patients. The majority of studies conducted on multiple sclerosis patients did not suggest improvements in EF. The beneficial effects of Hatha yoga on EF may have downstream implications for preventing and treating cognitive decline and chronic diseases.

More studies should evaluate the efficacy of Hatha yoga’s effects on EF, especially in populations who encompass cognitive deficits. Future studies should continue to analyze the effects of Hatha yoga on EF in both healthy and special populations, investigate the neurophysiological pathways of Hatha yoga induced EF enhancement, and dissociate Hatha yoga's subcomponent effects on cognition. As such, the purpose of Study 2 will be to differentiate the effects of the physical versus the mental components of Hatha yoga on EF.

Study 2: Comparing the Acute Effects of Hatha yoga and Meditation on Executive Function

Introduction

Yoga is an ancient Indian practise which traditionally aims to cultivate mind-body awareness and higher states of consciousness (Bryant, 2009). Hatha yoga is the most common style of yoga practised in Western societies, and involves mindful physical posturing, breathing exercises, and meditation (Muktibodhananda, 2012). Meditation can be defined as a type of mental training which engages attentional and emotion-regulation abilities through (self- or other-) guided focus on specific objects, intentions, or internal and external environments (Tang, Holzel, & Posner, 2015; Raffone & Srinivasan, 2010). A survey of a nationally representative sample estimated that approximately 21 million US citizens practised Hatha yoga in 2012 (Cramer et al., 2015); this represents a tripling of the number of Hatha yoga practitioners in a 15 year span (1998-2012; Saper, Eisenberg, Davis, Culpepper & Phillips, 2004). These statistics suggest that Hatha yoga is becoming an increasingly popular modality of exercise in North America.

Moreover, Hatha yoga has been of increasing interest to mental health professionals, as it has been shown to be a beneficial adjunctive treatment modality for various mood disorders involving psychological distress (Chong, Tsunaka, & Chan, 2011), anxiety (Kirkwood, Rampes, Tuffrey, Richardson, & Pilkington, 2005), and trauma (Telles, Singh, & Balkrishna, 2012). More recently, researchers have begun investigating Hatha yoga's effects on cognitive functions such as memory, attention, and the executive functions (EF; Gothe & McAuley, 2015).

EF's are a set of cognitive abilities that allow for self-regulation of thought, emotions, and behaviors, and most typically involve inhibitory control, mental flexibility, and working memory (Miyake & Friedman, 2012). EFs are thought to arise from neural networks primarily based in the prefrontal cortex that send projections to other cortical and subcortical regions, thus potentiating modulatory control over these same areas (Funahashi & Andreau, 2013). A recent systematic review found that both acute and chronic bouts of Hatha yoga showed promise for improving EF in a variety of healthy and clinical populations (Luu & Hall, 2015). However, more rigorous studies of high methodological quality are needed in order to further clarify the cognitive benefits of Hatha yoga. Likewise, studies are needed that allow for an examination of the joint and independent effects of the physical posturing and meditative components. Currently no existing studies have attempted to unpack the relative influence of physical posturing and meditation on cognitive outcomes.

Prior studies have also examined mood as an outcome of Hatha yoga practise, with findings supporting a positive effect (Cramer, Lauche, Langhorst, & Dobos, 2013; Lin, Hu, Chang, Lin, Tsauo, 2011). However, there is reason to believe that cognitive and mood benefits are not entirely separable. It has been theorized that reductions in negative mood states (i.e., distress, anxiety) following Hatha yoga may mitigate disruptions to certain cognitive functions (Nangia & Malhotra, 2012; Rocha et al., 2012). Moreover, some mood dimensions map clearly onto cognitive functions themselves, and may represent alternative operationalisations of them. For instance, Stuss (2011) identifies alerting and orienting as one of the primary functions of the prefrontal cortex, and this has a close conceptual link with the mood dimension of vigor-activity. Yet many existing studies examine Hatha yoga effects on broader mood dimensions (e.g., positive and negative affect). Investigation of the acute effects of Hatha yoga and its meditative components on specific mood dimensions that are theoretically linked (or not) to prefrontal functions might be illuminating.

Using a within-subjects experimental design, the current study is the first to directly compare the acute effects of Hatha yoga to meditation using both cognitive and a variety of mood outcomes. Because prior research has shown that meditation is beneficial for improving cognitive function (Semple, 2010; Raghavendra & Telles, 2012; Zeiden, Johnson, Diamond, David, & Goolkasian, 2010; Mrazek, Franklin, Phillips, Baird, & Schooler, 2013) and mood (Lane, Seskevich, & Pieper, 2007; Zeidan, Johnson, Gordon, & Goolkasian, 2010; Speca, Carlson, Goodey, Angen, 2000; Carlson, Ursuliak, Goodey, Angen, & Speca, 2001), it is important to understand if the physical additions unique to Hatha yoga offer further benefits. It was hypothesized that Hatha yoga and meditation would result in cognitive and mood improvements, but that the effects would be stronger for Hatha yoga due to the addition of its physical preparatory components. The results of this study will lead to a more nuanced understanding of both interventions (Hatha yoga and meditation), and what components are necessary and sufficient to induce cognitive and mood benefits.

Methods

Participants

Thirty-one healthy adult females ages 18-48 were sought out via poster advertisements placed within the University of Waterloo and greater Kitchener-Waterloo community between June 2014 and July 2015. To be eligible, participants must have had 4 months to 5 years of prior Hatha yoga experience. Naïve practitioners were excluded due to the notion that any cognitive challenge via learning novel tasks may potentially affect EF in itself (Hall & Marteau, 2014) and thereby limit the ability to attribute EF changes to Hatha yoga or meditation specifically per se. Furthermore, beginners to Hatha yoga could potentially be disadvantaged from performance anxiety, which impairs EF (Eysenck, Derakshan, Santos, & Calvo, 2007). On the other hand, experts at Hatha yoga were excluded due to the possibility of ceiling effects, i.e. advanced Hatha yoga and meditation practitioners pre-emptively maintain superior cognitive functioning and emotion-regulation at baseline (Froeliger, Garland, & McClernon, 2012; Moore & Malinowski 2009; Lazar. Kerr, Wassman, et al., 2005; Luders, Toga, Lepore, Gaser, 2009; Hozel, 2007). Informed and written consent was obtained by eligible participants. This study was reviewed and received approval from the University of Waterloo Research Ethics Board, and was conducted as stated in the standard ethical protocols. See figures 2 and 3 for study and session overviews.

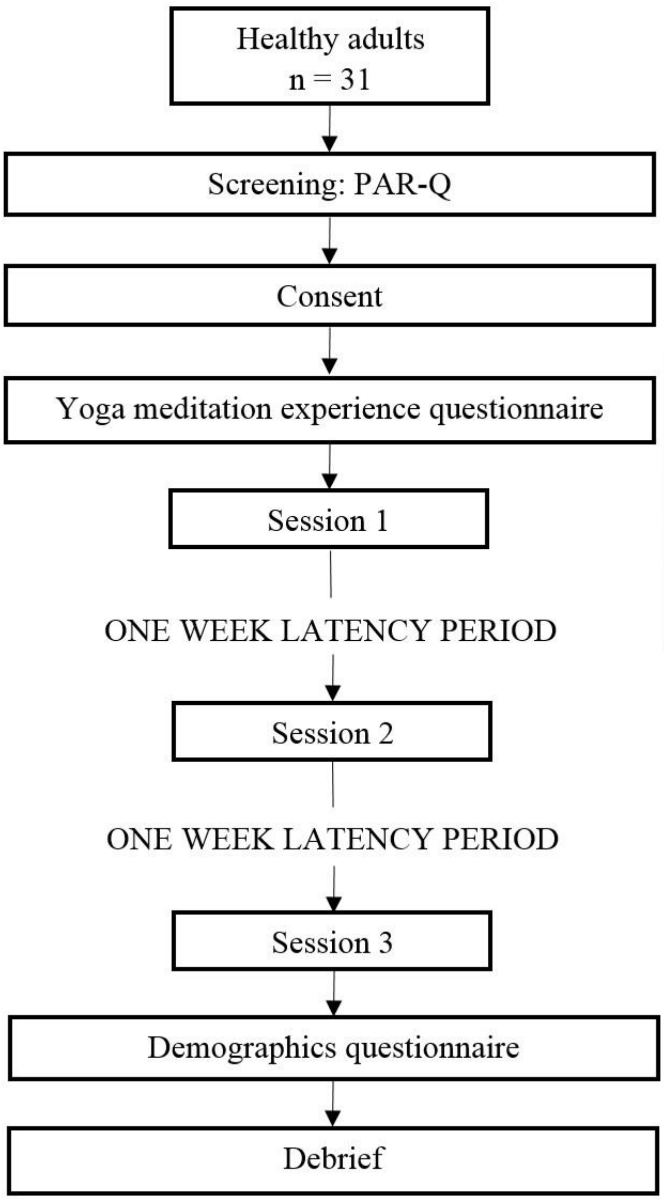

Figure 2: Study overview.

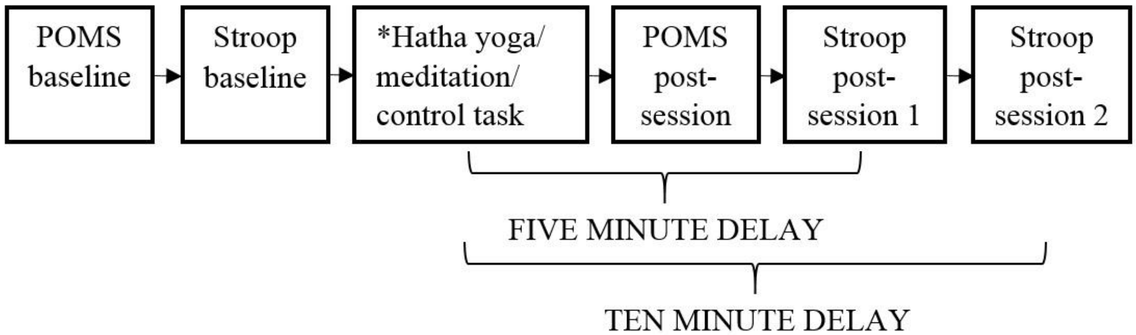

Figure 3: Session overview, *counterbalanced in order across participants.

Procedure

Pre-Screen Measures. Eligible participants were tested in 3 laboratory sessions for 1 hour each set 1 week apart. Participants received an e-mail reminder to abstain from alcohol and caffeinated beverages 3 hours prior to each laboratory session. All sessions were held during the same time in evening slots of either 4:00–5:00 PM, 5:00-6:00 PM, or 6:00–7:00 PM. Upon arrival to the first laboratory session, participants completed the Physical Activity Readiness Questionnaire to ensure that they could safely perform physical activity (Canadian Society for Exercise Physiology, 2002). Participants then completed a Yoga Meditation Experience questionnaire, a non-standardized measure of prior Hatha yoga and meditation experience developed by the researcher coordinator and further reviewed by 5 certified yoga instructors in the Kitchener-Waterloo community. Ten statements (5 for yoga, 5 for meditation) such as "During yoga practice, I feel a sense of balance between effort and ease" and "During meditation practice, I feel immersed in the present experience rather than dwelling on the past or future" are scored on a 10-point Likert scale ranging from 1 = never and 10 = all the time. Each participant was scored out of 50 each for yoga and meditation to give a rough estimate of prior experience. In addition, the questionnaire classified participants into quartiles based on actual years of regular Hatha yoga and meditation practice (4 months – 1 year; 1 – 2 years; 2 – 3 years; 3 – 5 years).

Conditions. Each participant completed three 25 minute counterbalanced exercise sessions of Hatha yoga, meditation, and a control task of reading yoga culture magazines. Exercise sessions were taught privately by a certified yoga instructor in the Prevention Neuroscience Laboratory at the University of Waterloo. Participants were provided with a yoga mat, props (i.e. cork yoga blocks and bolster), and water bottle. The Hatha yoga condition consisted of mindful movement through postures, breathing exercises, and meditation (See Table 3 for Hatha yoga session details). Participants were told that they should feel a balance of effort and ease throughout the class, and to move into a level of postural expression where a steady breath rhythm could be maintained. In the meditation condition, participants lied supine and were guided through mindful body awareness and breath focussed practices. During the control condition, participants were given yoga culture magazines which they casually browsed through.

Table 3: Hatha yoga session details.

Exercise	Duration
Deep breathing	2 minutes
Mindfulness meditation	3 minutes
Cat-cow	2 minutes
Sun salutation A x 2	4 minutes
Sun salutation B	3 minutes
Warrior B	2 minutes
Tree pose	2 minutes
Bridge pose	1 minutes
Supine twist	1 minutes
Focused attention meditation	2 minutes
Corpse pose	3 minutes

Outcome Measures

Executive Function. The Stroop task (Stroop, 1992) was used to measure EF, specifically inhibitory control (Miyake & Friedman, 2012). The Stroop task is highly reliable (test-retest coefficient = 0.82, Cronbach's alpha = 0.97; Wostmann, Aichert, Costa, Rubia, Moller, & Ettinger, 2013) and the most commonly used measure for inhibitory control for acute bout exercise studies (Etnier & Chang, 2009). Moreover, the Stroop task demonstrates validity as Stroop interference scores were significantly differentiated between children with and without attention deficit hyperactivity disorder and impulsivity problems (Homack & Riccio, 2004). The version used was a standard computerized variant to the original Stroop task (Miyake et al., 2000) using E-Prime software (Psychology Software Tools, Inc). In this version, a series of color words (blue, green, orange, purple, red, or yellow) were subsequently presented. Following 10 practice trials, the task presented a mixed block of trials consisting of 12 congruent color words (i.e. color words are displayed in the same color as their semantic meaning), 60 incongruent color words (i.e. color words are displayed in a different color as their semantic meaning), and 72 strings of colored asterisks. Stoop interference scores represent the ability to deliberately override automatic responses and were calculated as incongruent trial reaction time - asterisk trial reaction time, with scores reverse coded (i.e., multiplied by -1), such that higher values indicated stronger inhibitory abilities. The Stroop task was completed at baseline, 5 minutes post-, and 10 minutes post-sessions.

Mood. The Profile of Mood States-2 Adult Short (POMS) is a 35-item standard questionnaire used to measure mood disturbance under 7 dimensions: friendliness, vigor-activity, tension-anxiety, anger-hostility, fatigue-inertia, confusion-bewilderment, and depression-dejection in individuals 18 years or older (McNair, Lorr, & Droppleman, 1992). The POMS-2A

Short is adapted from the original 65-item POMS, and is an efficient yet dependable means to identify mood state (Heuchert & McNair, 2014). Cronbach alphas were computed based on the current study's data for each of the POMS subscales and revealed strong internal consistencies, as follows: friendliness (.897), vigor-activity (.922), tension-anxiety (.858), anger-hostility (.967), fatigue-inertia (.920), and confusion-bewilderment (.810). The depression-dejection subscale demonstrated poor reliability, possibly because of invariance on the helplessness item (.204); when this item was removed, reliability increased to acceptable levels (.838). Subsequent analyses utilized this updated version of the scale. The validity of the POMS is supported by psychotherapy studies and outpatient drug trials where treatment groups exhibited significant decreases in mood disturbance following corresponding interventions (McNair, et al,. 1992). Participants were presented a list of words which describe mood (e.g., Nervous, good-natured, vigorous) and asked to describe to what extent they were feeling the certain emotion in the present moment. Negatively affective words are scored as 0 = not at all to -4 = extremely. Conversely, positive affect words are scored as 0 = not at all to 4 = extremely. Answers were tallied to yield a score for total mood disturbance (containing all dimensions) and individually separate dimensions. Mood was measured at baseline and immediately after each session.

Exercise engagement. Immediately following each exercise session, participants were asked to rate their level of engagement on a scale from 1-10 (1 = very bored, 10 = very engaged). The simple exercise engagement scale gives an idea of whether or not participants are practicing the mental aspects of Hatha yoga and meditation properly; which is difficult to gauge through direct observation, especially during meditation. In addition, this allowed for the identification of bored participants, as prior evidence suggests that boredom can impair cognition (Barker, D'Mello, Rodrigo, & Graesser, 2010). It was possible that participants would have not wanted to admit their bored feelings; to minimize social desirability effects, it was stressed that the participant would not be judged based on their answer.

Demographics. Demographic variables such as age, BMI (height and weight), socioeconomic status (education and income), ethnicity, and relationship status were collected in another brief questionnaire to obtain crucial information about the sample set.

Data Analytic Approach

Data analyses were performed using IBM SPSS Statistics 22.0 software. Prior to the primary analyses, outliers—defined as values exceeding 3x the interquartile range—were identified on the Stroop variable (n = 3) within the pre-session reading control condition. These outliers were dropped and missing values were imputed using a maximum likelihood estimation procedure. In the primary analyses, repeated measures Analyses of Variances (ANOVAs) were performed using Stroop interference and POMS scores as dependents in separate analyses, with condition as the between-subjects variable, and time (baseline, 5 min post-, and 10 min post-session) as the within-subjects variable. Planned contrasts using t-tests were then computed to compare the effects of condition against each other.

Hypotheses

Several hypotheses were formulated prior to conducting the current study. It was expected that improvements in Stroop task performance would emerge following both Hatha yoga and meditation conditions, while remaining unchanged following the control task. Moreover, it was expected that Hatha yoga would have a stronger beneficial effect on Stroop task performance compared to meditation. Similarly, it was hypothesized that mood would significantly improve following the Hatha yoga and meditation conditions, but not in the control condition. Once again, these effects may be more pronounced following Hatha yoga over meditation. It was predicted that the physical aspects of Hatha yoga would provide additional benefits for EF and mood enhancement compared to meditation alone.

Results

Demographics

Table 4 presents participant demographic information. Participants were a mix of university students (n = 18) and community members (n = 13) with an age range of 21–46 (M = 27.71, SD = 8.32). Body mass index was predominantly in the normal range (M = 21.12, SD = 2.19); 4 were mildly underweight, and none were overweight or obese. The majority of participants were Caucasians with a University level of education.

Table 4: Participant demographics.

Characteristic	**Mean (*SD*)**	**% (*n*)**
Age	27.71 (8.32)	
Body Mass Index	21.12 (2.19)	
Ethnicity		
Caucasian		77.42 (24)
Asian		16.13 (5)
Middle Eastern		3.23 (1)
Hispanic		3.23 (1)
Level of Education		
Graduate		35.48 (11)
Undergraduate		61.29 (19)
High School		3.23 (1)

Baseline Group Comparisons

ANOVAs were conducted to compare baseline scores across conditions. Conditions were not significantly different with respect to baseline Stroop interference (F(1.65, 49.39) = 1.15, p = .32) and POMS total mood scores (F(2, 60) = .63, p = .54), indicating that counterbalancing was successful.

Stroop Performance

Mean Stroop interference scores and standard deviations are presented in Table 5. An omnibus 3x3 factorial repeated measures ANOVA was first conducted to examine differences in Stroop interference by time (baseline, 5 minutes post-, and 10 minutes post-session) and condition. There was a significant main effect of time (F(2, 60) = 4.913, p = .011) but not condition (F(2, 60) = .213), p = .81). These effects were qualified by a significant interaction between time and condition (F(3.07, 92.11) = 2.792, p = .044).

Table 5: Mean Stroop interference scores in milliseconds (reverse coded); standard deviations are in parentheses.

	Pre	Post 5 min.	Post 10 min.
Hatha Yoga	-60.93 (56.91)	-41.98 (61.00)	-21.33 (43.19)
Meditation	-61.43 (69.67)	-41.35 (60.56)	-28.39 (50.07)
Control	-42.25 (45.29)	-49. 01 (64.54)	-50.62 (53.01)

Three repeated measures ANOVAs were then conducted to examine the main effects of time for each condition separately. There was a significant main effect of time for Hatha yoga (F(2, 60) = 7.143, p = .002) and meditation, (F(2, 60) = 3.282, p = .044), but not control (F(2, 60) = .364, p = .70).

Further repeated measures ANOVAs were completed to examine condition effects separately for 5 and 10 minute post-session delays. From baseline to 5 minutes post-session, there was no significant main effect of time for Hatha yoga ($F(1, 30) = 2.55$, $p = .12$), meditation ($F(1, 30) = 2.66$, $p = .11$), or control ($F(1, 30) = .31$, $p = .58$). However, a significant main effect of time emerged from baseline to 10 minutes post-session for both Hatha yoga ($F(1, 30) = 16.88$, $p < .001$) and meditation ($F(1, 30) = 4.921$, $p = .034$), but not control ($F(1, 30) = .738$, $p = .40$).

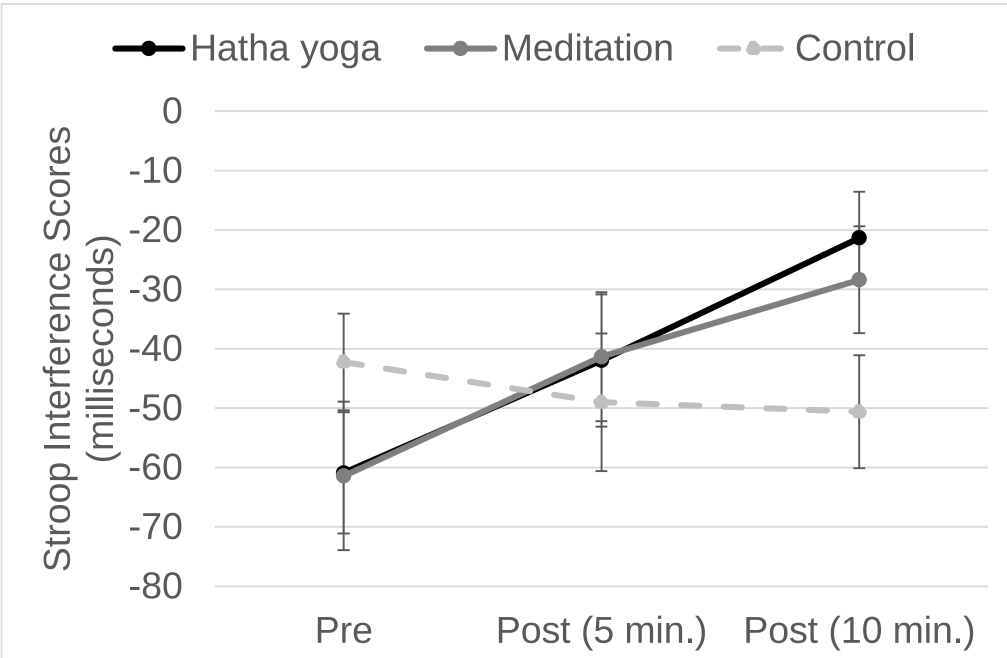

Figure 4: Mean Stroop interference scores in milliseconds (reverse coded).

To compare the effects of condition to each other from baseline to 10 minutes post-session, Stroop interference change scores were computed and then subjected to paired sample t-tests. Results revealed that Hatha yoga did not significantly differ from meditation ($t(30) = .351$, $p = .73$), but did significantly differ from control ($t(30) = 3.590$, $p = .001$). Likewise, meditation significantly differed from control ($t(30) = 2.065$, $p = .048$).

Mood

Table 6 presents the means and standard deviations for the POMS total mood and subscale scores. Changes in POMS total score were compared across conditions using a 2x3 repeated measures ANOVA; there was a significant main effect of time ($F(1, 30) = 16.28$, $p = .001$), indicating that POMS total mood improved from baseline ($M = -16.36$, $SD = 21.94$) to post-session ($M = -9.37$, $SD = 18.59$) across conditions. There was also a significant main effect of condition, $F(2, 60)$, $p = .005$, indicating that the three conditions differed in overall levels of POMS total mood (Hatha yoga; $M = -8.79$, $SD = 20.44$, meditation; $M = -12.50$, $SD = 18.90$, control; $M = -17.31$, $SD = 21.47$) across time points. The above main effects were qualified by a significant time by condition interaction ($F(2, 60) = 4.470$, $p = .016$).

Table 6: Mean profile of mood states total mood and subscale scores; standard deviations are in parentheses.

	Pre-HY	Post-HY	Pre-M	Post-M	Pre-C	Post-C
Total Mood	-15.00 (23.69)	-2.58 (17.18)	-15.52 (19.70)	-9.48 (18.09)	-18.55 (22.43)	-16.06 (20.50)
Friendliness	12.03 (4.08)	13.45 (3.59)	11.81 (3.66)	12.42 (4.66)	11.48 (3.79)	11.32 (3.83)
Vigor-Activity	7.77 (4.54)	9.61 (4.00)	7.77 (4.18)	6.83 (3.68)	8.13 (4.89)	6.58 (4.37)
Tension-Anxiety	-3.81 (3.28)	-0.87 (1.89)	-3.06 (3.28)	-0.90 (2.40)	-3.03 (3.64)	-1.65 (3.25)
Anger-Hostility	-1.71 (3.67)	-0.39 (1.45)	-0.61 (1.26)	-0.39 (1.14)	-1.03 (1.94)	-0.48 (1.09)
Fatigue-Inertia	-5.42 (3.88)	-1.97 (2.33)	-5.71 (4.21)	-2.77 (2.96)	-5.90 (4.74)	-4.42 (3.78)
Confusion-Bewilderment	-2.94 (2.86)	-1.23 (2.54)	-2.81 (3.21)	-1.52 (2.39)	-3.35 (3.36)	-1.97 (2.97)
Depression-Dejection	-1.12 (2.00)	-0.35 (1.11)	-1.06 (2.39)	-0.32 (1.05)	-1.00 (1.63)	-0.61 (1.45)

HY = Hatha yoga, M = Meditation, C = Control

Three repeated measures ANOVAs were then conducted to examine the main effects of time for each condition separately. There was a significant main effect of time for Hatha yoga ($F(1, 30) = 20.39$, $p < .001$) and meditation ($F(1, 30) = 4.162$, $p = .050$) but not control ($F(1,30) = 1.539$, $p = .22$). To compare the effects of condition to each other, POMS total mood change scores were computed and then followed up with paired sample t-tests. Results revealed that

Hatha yoga did not significantly differ from meditation ($t(30) = 1.821$, $p = .079$), but did significantly differ from control ($t(30) = 2.975$, $p = .006$). However, meditation was not significantly different from control ($t(30) = 1.092$, $p = .284$).

Changes in mood for each of the POMS subscales were analyzed using separate 2x3 ANOVAs. To control for familywise error (i.e., discovering a false positive when executing multiple hypothesis tests), the alpha was adjusted to a more conservative value of .01 (i.e., .05/7 = .01). There were no significant time by condition interaction effects for the POMS subscales: friendliness ($F(2, 60) = 1.654$, $p = .20$), tension-anxiety, ($F(2, 60) = .216$, $p = .14$), anger-hostility ($F(2, 60) = 2.361$, $p = .10$), fatigue-inertia ($F(2, 60) = 2.118$, $p = .13$), confusion-bewilderment ($F(2, 60) = .333$, $p = .72$), and depression-dejection ($F(2, 60) = .632$, $p = .54$). However, there was a significant time by condition interaction for the vigor-activity subscale ($F(2, 60) = 8.158$, $p = .001$). To decompose these findings, three repeated measures ANOVAs were conducted to examine the main effects of time for each condition separately. There a significant main effect on time for Hatha yoga ($F(1, 30) = 4.318$, $p = .046$), indicating that energy levels increased from pre- to post-session. There was no significant main effect of time for meditation ($F(1, 30) = 1.609$, $p = .214$), indicating that energy levels did not increase or decrease from pre- to post- session. However, there was a significant main effect of time for the control task ($F(1, 30) = 8.147$, $p = .008$), indicating a decrease in energy levels from pre- to post-session. Once again, to compare the effects of condition against each other, vigor-activity change scores were computed and then followed up with paired sample t-tests. Results showed that Hatha yoga significantly differed from meditation ($t(30) = 2.927$, $p = .006$) and control ($t(30) = 3.591$, $p = .001$). Meditation did not significantly differ from control ($t(30) = .786$, $p = .438$).

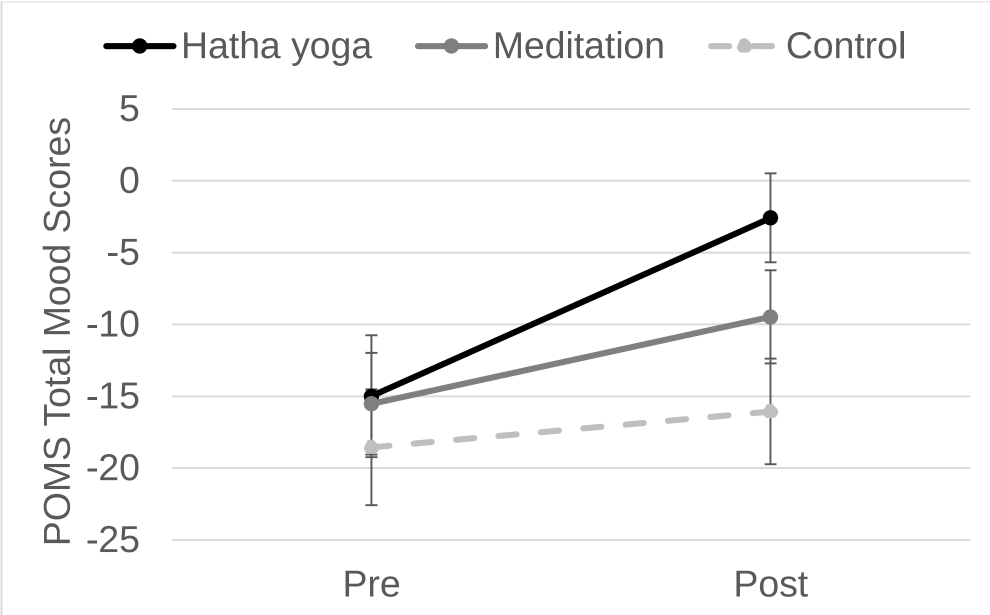

Figure 5: Mean total POMS scores.

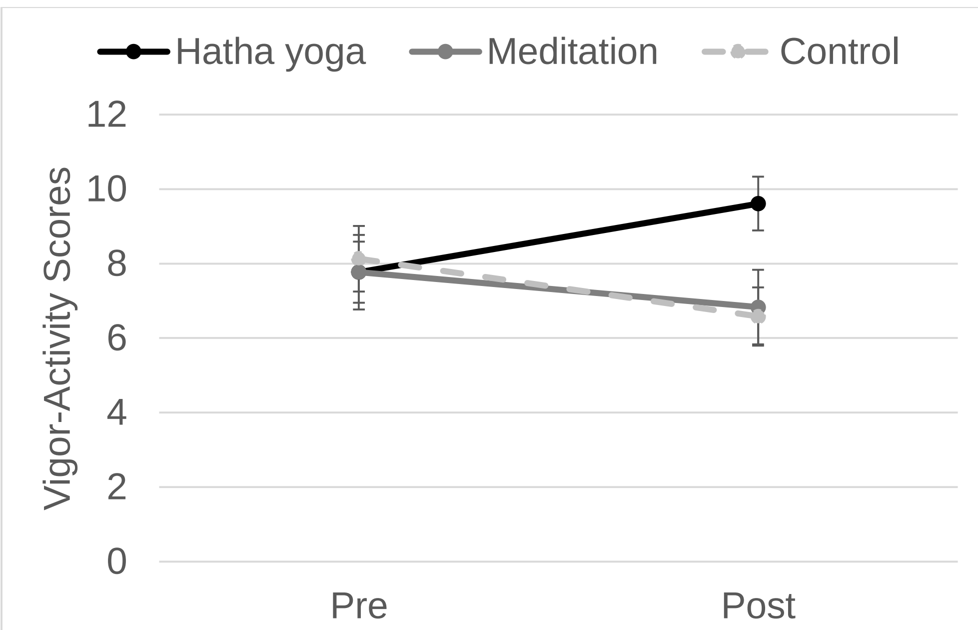

Figure 6: Mean vigor-activity scores.

Exercise Engagement

Paired sample t-tests were used to compare mean levels of perceived engagement between exercise treatment conditions. Participants perceived themselves to be significantly more engaged during Hatha yoga (M = 8.69, SD = 1.11) over meditation (M = 7.94, SD = 1.48); $t(30) = 2.64$, $p = .013$, and reading yoga culture magazines (M = 6.92, SD = 2.33); $t(30) = 4.615$, $p = .001$. Moreover, participants felt more engaged during meditation than reading yoga culture magazines ($t(30) = 2.30$, $p = .029$).

Yoga Meditation Experience

The Yoga Meditation Experience Questionnaire was not used for analyses due to the exceptionally low response rate; the majority of participants did not respond to more than half of the items in the questionnaire. This may have been due the traditional mentality which posits that yoga and meditation are not inherently designed to be competitive exercises, and thus participants refused to put an experience level to their personal practice. However, participants did answer the section of which asked them to give the approximate number of years they had practiced; this was used as a variable in the maximum likelihood estimate model. Table 7 presents the number of participants in each category of experience level viewed from a temporal perspective. Overall, participants had practiced Hatha yoga longer than meditation.

Table 7: Participant prior yoga and meditation experience (*n*).

	4 months – 1 year	**1 – 2 years**	**2 – 3 years**	**3 -5 years**
Hatha yoga experience	8	9	4	10
Meditation experience	19	5	4	3

Discussion

The current study examined the acute effects of Hatha yoga versus meditation on EF and mood, using a within-subjects experimental design. Results revealed that 25 minutes of Hatha yoga and meditation significantly improved EF task performance. These effects emerged following a 10 minute, but not a 5 minute, post-session delay. EF improvements via Hatha yoga and meditation did not significantly differ from each other. Furthermore, overall mood immediately improved following both Hatha yoga and meditation. Hatha yoga exhibited a marginal advantage for improving mood compared to meditation, mostly driven by the vigor-activity dimension of the POMS. Overall, this study suggests that a single session of Hatha yoga and meditation may have similar cognitive and mood benefits for moderately experienced Hatha yoga practitioners.

The current findings are largely consistent with other studies examining the benefits of Hatha yoga and meditation. For instance, prior studies found that 20 minutes of Hatha yoga improved inhibitory control in samples of healthy undergraduates (Gothe, Pontifex, Hillman, & McAuley, 2013) and multiple sclerosis patients (Sandroff, Hillman, Ralph, Benedict, & Motl, 2015). Likewise, acute meditation has also been shown to restore inhibitory abilities following a self-regulatory fatigue manipulation (Friese, Messner & Schaffner, 2012). As well, a recent systematic review (Luu & Hall, 2015) and meta-analysis (Gothe & McAuley, 2015) documented moderately beneficial effects of Hatha yoga on cognitive outcomes in general, including inhibitory control.

Regarding mood, prior studies have shown that a single session of Hatha yoga improved POMS scores in psychiatric inpatients (Lavey et al., 2005) and decreased psychological distress in healthy university students (West, Otte, Geher, Johnson, & Mohr, 2004). One study reported that both 15 minutes of Hatha yoga and meditation significantly decreased psychological and physiological markers of stress in office workers (Melville, Chang, Colagiuri, Marshall, & Cheema, 2012). Furthermore, 1 hour of meditation was found to increase positive affect and decrease negative affect in experienced meditators (Harte, Eifert, & Smith, 1995). Lastly, a meta-analysis concluded that meditation interventions are moderately beneficial for alleviating symptoms of affective disorders (Hofmann, Sawyer, Witt & Oh, 2010).

Theorized Mechanisms

Due to the the observed effects on cognition and mood that seemed general across both Hatha yoga and meditation, it is important to consider potential neural mechanisms. Some possibilities include increases in blood flow to the brain, improved blood oxygenation, increases in brain-derived neurotropic factor, HPA-axis modulation, acute stress reduction, autonomic nervous system regulation, increases in gamma-aminobutyric acid, or a combination of any of these (Tang et al., 2015; Streeter, Gerbarg, Saper, Ciraulo, & Brown, 2012). Given the fact that acute stress impairs functional connectivity and activation in prefrontal regions associated with executive control (Maier, Makwana, & Hare, 2015; Qin, Hermans, van Marle, Luo, & Fernández, 2009), it is highly possible that improvements in Stroop performance were found due to acute stress reduction, as short single sessions of both Hatha yoga and meditation have been shown to decrease perceived and physiological markers of stress (Melville, Chang, Colagiuri, Marshall, & Cheema, 2012; West, Otte, Geher, Johnson, & Mohr, 2004).

Overall, it has been suggested that the above physiological effects may induce dendritic branching, synaptogenesis, myelinogenesis and neurogenesis as well as mitigating neuronal degeneration (Tang et al., 2015). Some of these effects are shared with proposed mechanisms of action for longer term meditation practise (Tang et al., 2015). Future research will be required to unpack these biological pathways.

Dissociating Physical and Mental Training

This study supports the important role of the mental training components (i.e. mindful focus) in integrative mind-body interventions, as meditation appeared to be similarly beneficial to Hatha yoga for improving EF and mood. However, when considering generalizability, the specific sample used should be considered; in the current study, participants already had some Hatha yoga and meditation experience, and it could be the case that postural and breath centered preparations were not as necessary for them to successfully obtain present moment focus and attention control. Likewise, all participants were highly enthusiastic meditators, and thus may maintain particular brain structures that pre-determined their interest and motivated expertise for the mental practises (Fox et al., 2014). Therefore, the current participants may have gained greater benefits from meditation compared to other potential populations of study.

Strengths and Limitations

Strengths of the current study included the use of a stringent within-subjects experimental design, standardization of time of day and other variables that might influence response to conditions, and the novel comparison of Hatha yoga and meditation to each other to identify the specific contribution of the physical preparatory components to any observed effects. Additionally, this study was the first to examine the particular time line of which the cognitive and mood effects emerged. Despite these strengths, there were several limitations to the current study. First, performance biases were possible, and potentially unavoidable, as it is difficult to blind participants to interventions of this nature. Motivational effects may have also been present as participants were by default interested in Hatha yoga and meditation. Second, our results are limited in generalizability due to a relatively homogenous sample of primarily educated, Caucasian females of middle to high socioeconomic status. Due to various potential sex differences in cognition and other brain functions (Caplan, Crawford, Hyde, & Richardson, 1997), it may be difficult to generalize these findings to male populations. It should likewise be noted that the generalizability of the current findings to group settings has yet to be demonstrated, given that the current sessions were individually taught in a private setting. Moreover, due to the low response rate of the Yoga Meditation Experience Questionnaire, this data could not be used in the analysis as a moderating variable. Logistical limitations also precluded the use of longer Hatha yoga and meditation sessions; the 25 minute session duration used in the current study would be considered relatively short when compared to typical Western public classes which are approximately 60 to 90 minutes in length. The effect of duration is unclear, though it is possible that our use of shorter sessions may have led to an under-estimation of the effect of Hatha yoga, meditation, or both on the outcomes of interest.

Conclusion

To summarize, findings suggested that 25 minute bouts of Hatha yoga and meditation improved EF and mood to a similar degree. The EF benefits were detectable after a 10 minute post-session delay, while mood benefits were evident immediately following the sessions. Future studies should examine the influence of experience level, clinical status, temperamental factors, and baseline cognitive function on the relative contribution of each of these modalities (Hatha yoga and meditation) on brain and mood benefits. Furthermore, future studies should examine the full time course by which acute Hatha yoga and meditation benefits last.

General Discussion

The purpose of this thesis was to explore the cognitive and mood benefits of Hatha yoga and to analyze the relative contributions of its physical and meditative components. In doing so, a systematic review was first conducted, which examined the current literature on the effects of Hatha yoga on EF. Within- and between-subjects experimental studies were searched for, and results revealed that acute and chronic bouts of Hatha yoga practice might indeed enhance EF. These findings were evident in healthy populations, children, older adults and in some (but not all) medical populations. It became clear at this point however, that the field was in its early stages and more good quality experimental studies on virtually all populations were needed to consolidate these findings. For example, there were only 1 to 3 studies per population type in the review, thus making it very difficult to draw any confident conclusion for any particular one. Moreover, it was not clear as to which aspect of Hatha yoga contributed to the EF benefits, as Hatha yoga is highly multifaceted, containing both physical and mental exercises.

The imprecision of these conclusions led into the development of Study 2, which was an experimental study comparing the acute effects of Hatha yoga and meditation on EF. This within-subject experimental methodology allowed for a direct contrast between the two interventions which essentially decomposed the physical and mental contributions to any potential EF benefits. Furthermore, this design was the first to take into consideration the time frame of which EF benefits emerge. Overall, this study revealed that a single session of both Hatha yoga and meditation improved EF and mood to a similar degree in a population of moderately experienced practitioners. Hatha yoga had a slight, though not significant advantage for improving mood over meditation, primarily driven by the vigor-activity subscale of the POMS. The cognitive benefits were statistically detectable 10 minutes post-session, while the mood benefits were evident immediately post-session. These findings contributed interesting and novel details about Hatha yoga and meditations effects on EF and mood, and provided a more sophisticated perspective on both interventions.

Public Health Implications

From a public health standpoint, the current studies (and more broadly, studies on the brain effects of Hatha yoga and meditation in general) seek to answer two very crucial questions: (1) how exactly should Hatha yoga and meditation be promoted to the public? and (2) How should they be prescribed in clinical settings? The practical implications of this research come in the form of generating prescriptive guidelines for both healthy (prevention-based) and clinical (treatment-based) populations. By gaining a better understanding of the effects of both interventions, more informed suggestions can be made for individuals in the general public and medical settings, with aims to improve cognitive function, mood, thus overall quality of life. This proposed study specifically provides a necessary base from which comparative Hatha yoga and meditation research studies can proliferate.

The studies included in this thesis are of particular significance for complementary and alternative practices such as Hatha yoga and meditation; supporters of such therapies are sometimes described as overstating health benefits without sufficient empirical findings to back up their claims (Sampson, 2001). All the while, studies have shown that there is a general trend of increasing interest in complementary and alternative medicine in North America (Su & Li, 2011); for this reason, the efficacy issue in relation to such treatments cannot be ignored. Although there is reason to believe that some alternative therapies have the potential to be beneficial in relation to various health outcomes, the alternative medicine movement will be hindered if more objective, well-designed empirical studies are not undertaken to test the claims of alternative medicine practitioners—and with the same critical standards of traditional medicine.

Future Directions

While the studies included in this thesis were methodologically rigorous and revealed some practical and illuminating findings, they were not without limitations. For example, Study 2 suffers from restricted generalizability due to the highly homogenous sample; likewise, performance, motivational, and expectancy biases may have influenced the findings (as would be the case with any design of this nature). Further, it is also not yet known how long acute cognitive benefits last beyond 10 minutes; additional follow up intervals in future studies would help to examine this important question.

Future studies are needed not only to get around these limitations but also to uncover other, more nuanced, brain health and mood effects of Hatha yoga and meditation. For instance, more studies on essentially all types of populations are warranted. It would be wise to examine the effects of Hatha yoga and meditation in relation to EF and mood in populations of various age groups and health status categories. It is arguably most important to investigate if Hatha yoga and meditation induced EF and mood benefits are promising for medical populations with cognitive deficits and mood disorders.

Furthermore, durational comparisons should be examined in both acute and chronic bout studies to see if a dose-response relationships exist. It may also be interesting to uncover potential moderating influences of cultural, genetic, temperamental (e.g. introversion and extroversion), and personality factors on the effects of Hatha yoga/meditation. Furthermore, the physiological mechanisms of which Hatha yoga and meditation induced brain benefits occur are important to understand as well; few studies have actually aimed to unpack these biological pathways and at present, mostly hypotheses dominate the literature. Finally, studies which utilize a variety of cognitive and mood measures might uncover a larger array of potential brain benefits; a combination of computerized testing, brain-imaging techniques, and physiological measures of cognition and mood would be fascinating.

General Conclusions

Based on a systematic review of the literature, Hatha yoga practice has been shown to be beneficial for improving cognition and mood. The meditative components associated with Hatha yoga appear to play a substantial role in facilitating these benefits, as acute bouts of both Hatha yoga and meditation were revealed to boost EF and mood to a similar degree. Moreover, EF benefits from acute Hatha yoga and meditation emerge after a period of delay, while mood benefits arise rather immediately. These findings are highly substantial for developing a greater knowledge base of the two mind-body practices, which hold great promise for boosting EF, mood, and the quality of life of many individuals. More generally, studies of this field are implicated in providing an empirical basis for public health promotions and interventions involving Hatha yoga and meditation. Thus, it is hoped that more research continues to proliferate in order to gain a fuller understanding on the brain effects of these captivating Eastern practices, that are yoga and meditation.

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Appendix A: Study 1 Article Abstracts

Bilderbeck, A. C., Farias, M., Brazil, I. A., Jakobowitz, S., & Wikholm, C. (2013). Participation in a 10-week course of yoga improves behavioural control and decreases psychological distress in a prison population. *Journal of Psychiatric Research, 47*(10), 1438-1445.

Background: Few scientific studies have examined movement-based embodied contemplative practices such as yoga and their effects on cognition. The purpose of this randomized controlled trial was to examine the effects of an 8-week Hatha yoga intervention on executive function measures of task switching and working memory capacity.
Methods: Community-dwelling older adults (N = 118; mean age = 62.0) were randomized to one of two groups: a Hatha yoga intervention or a stretching–strengthening control. Both groups participated in hour-long exercise classes 3×/week over the 8-week study period. All participants completed established tests of executive function including the task switching paradigm, n-back and running memory span at baseline and follow-up.
Results: Analysis of covariances showed significantly shorter reaction times on the mixed and repeat task switching trials (partial $\eta^2 = .04$, $p < .05$) for the Hatha yoga group. Higher accuracy was recorded on the single trials (partial $\eta^2 = .05$, $p < .05$), the 2-back condition of the n-back (partial $\eta^2 = .08$, $p < .001$), and partial recall scores (partial $\eta^2 = .06$, $p < .01$) of running span task.
Conclusions: Following 8 weeks of yoga practice, participants in the yoga intervention group showed significantly improved performance on the executive function measures of working memory capacity and efficiency of mental set shifting and flexibility compared with their stretching–strengthening counterparts. Although the underlying mechanisms need to be investigated, these results demand larger systematic trials to thoroughly examine effects of yoga on executive function as well as across other domains of cognition, and its potential to maintain or improve cognitive functioning in the aging process.

Bowden, D., Gaudry, C., An, S.C., Gruzelier, J. (2012). A comparative randomised controlled trial of the effects of brain wave vibration training, iyengar yoga, and mindfulness on mood, well-being, and salivary cortisol. *Evidence-Based Complementary and Alternative Medicine*, 1-13.

This randomised trial compared the effects of Brain Wave Vibration (BWV) training, which involves rhythmic yoga-like meditative exercises, with Iyengar yoga and Mindfulness. Iyengar provided a contrast for the physical components and mindfulness for the "mental" components of BWV. 35 healthy adults completed 10 75-minute classes of BWV, Iyengar, or Mindfulness over five weeks. Participants were assessed at pre- and postintervention for mood, sleep, mindfulness, absorption, health, memory, and salivary cortisol. Better overall mood and vitality followed both BWV and Iyengar training, while the BWV group alone had improved depression and sleep latency. Mindfulness produced a comparatively greater increase in absorption. All interventions improved stress and mindfulness, while no changes occurred in health, memory, or salivary cortisol. In conclusion, increased well-being followed training in all three practices, increased absorption was specific to Mindfulness, while BWV was unique in its benefits to depression and sleep latency, warranting further research.

Gothe, N. P., Kramer, A. F., & McAuley, E. (2014). The effects of an 8-week Hatha yoga intervention on executive function in older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *69*(9), 1109-1116.

Background: Few scientific studies have examined movement-based embodied contemplative practices such as yoga and their effects on cognition. The purpose of this randomized controlled trial was to examine the effects of an 8-week Hatha yoga intervention on executive function measures of task switching and working memory capacity.
Methods: Community-dwelling older adults (N = 118; mean age = 62.0) were randomized to one of two groups: a Hatha yoga intervention or a stretching–strengthening control. Both groups participated in hour-long exercise classes 3×/week over the 8-week study period. All participants completed established tests of executive function including the task switching paradigm, n-back and running memory span at baseline and follow-up.
Results: Analysis of covariances showed significantly shorter reaction times on the mixed and repeat task switching trials (partial $\eta^2 = .04$, $p < .05$) for the Hatha yoga group. Higher accuracy was recorded on the single trials (partial $\eta^2 = .05$, $p < .05$), the 2-back condition of the n-back (partial $\eta^2 = .08$, $p < .001$), and partial recall scores (partial $\eta^2 = .06$, $p < .01$) of running span task.
Conclusions: Following 8 weeks of yoga practice, participants in the yoga intervention group showed significantly improved performance on the executive function measures of working memory capacity and efficiency of mental set shifting and flexibility compared with their stretching–strengthening counterparts. Although the underlying mechanisms need to be investigated, these results demand larger systematic trials to thoroughly examine effects of yoga on executive function as well as across other domains of cognition, and its potential to maintain or improve cognitive functioning in the aging process.

Gothe, N.P., & McAuley, E. (2015). Yoga and cognition: A meta-analysis of chronic and acute effects. *Psychosomatic Medicine*, *77*(7), 784-797.

Introduction: Despite an increase in the prevalence of yoga exercise, research focusing on the relationship between yoga exercise and cognition is limited. The purpose of this study was to examine the effects of an acute yoga exercise session, relative to aerobic exercise, on cognitive performance.
Methods: A repeated measures design was employed where 30 female college-aged participants (Mean age = 20.07, SD = 1.95) completed 3 counterbalanced testing sessions: a yoga exercise session, an aerobic exercise session, and a baseline assessment. The flanker and n-back tasks were used to measure cognitive performance.
Results: Results showed that cognitive performance after the yoga exercise bout was significantly superior (ie, shorter reaction times, increased accuracy) as compared with the aerobic and baseline conditions for both inhibition and working memory tasks. The aerobic and baseline performance was not significantly different, contradicting some of the previous findings in the acute aerobic exercise and cognition literature.
Conclusion: These findings are discussed relative to the need to explore the effects of other nontraditional modes of exercise such as yoga on cognition and the importance of time elapsed between the cessation of the exercise bout and the initiation of cognitive assessments in improving task performance.

Kyizom, T., Singh, S., Singh, K. P., Tandon, O. P., & Kumar, R. (2010). Effect of pranayama & yoga-asana on cognitive brain functions in type 2 diabetes-P3 event related evoked potential (ERP). *The Indian Journal of Medical Research, 131*, 636-640.

A distinguishable feature of type 2 diabetes besides hyperglycemia and deranged lipid profile is an impaired insulin secretion, peripheral insulin resistance and obesity which has become a major health concern worldwide. India with an estimated 31million diabetics in 2000 and 79mllions by the yr 2030 has the highest number of type 2 diabetics in the world. In this study, we aimed to see if yoga-asanas and pranayamas have any influence in modifying certain biochemical parameters. Sixty patients of uncomplicated type 2 diabetes (age 35–60 yrs of 1–10 yrs duration) were divided into two groups: Group 1 (n=30): performed yoga along with the conventional hypoglycemic medicines and group 2 (n=30): patients who only received conventional medicines. Duration of the study was 45 days. Basal recordings of blood glucose (fasting and post-prandial), lipid profile and serum insulin were taken at the time of recruitment and the second reading after forty five days. Results showed a significant improvement in all the biochemical parameters in group 1 while group 2 showed significant improvement in only few parameters, thus suggesting a beneficial effect of yoga regimen on these parameters in diabetic patients.

Oken, B. S., Kishiyama, S., Zajdel, D., Bourdette, D., Carlsen, J., Haas, M., . . . Mass, M. (2004). Randomized controlled trial of yoga and exercise in multiple sclerosis. *Neurology, 62*(11), 2058-2064.

Objective: To determine the effect of yoga and of aerobic exercise on cognitive function, fatigue, mood, and quality of life in multiple sclerosis (MS).
Methods*:* Subjects with clinically definite MS and Expanded Disability Status Score less than or equal to 6.0 were randomly assigned to one of three groups lasting 6 months: weekly Iyengar yoga class along with home practice, weekly exercise class using a stationary bicycle along with home exercise, or a waiting-list control group. Outcome assessments performed at baseline and at the end of the 6-month period included a battery of cognitive measures focused on attention, physiologic measures of alertness, Profile of Mood States, State-Trait Anxiety Inventory, Multi-Dimensional Fatigue Inventory (MFI), and Short Form (SF)-36 health-related quality of life.
Results*:* Sixty-nine subjects were recruited and randomized. Twelve subjects did not finish the 6-month intervention. There were no adverse events related to the intervention. There were no effects from either of the active interventions on either of the primary outcome measures of attention or alertness. Both active interventions produced improvement in secondary measures of fatigue compared to the control group: Energy and Fatigue (Vitality) on the SF-36 and general fatigue on the MFI. There were no clear changes in mood related to yoga or exercise.
Conclusion*:* Subjects with MS participating in either a 6-month yoga class or exercise class showed significant improvement in measures of fatigue compared to a waiting-list control group. There was no relative improvement of cognitive function in either of the intervention groups.

Oken, B. S., Zajdel, D., Kishiyama, S., Flegal, K., Dehen, C., Haas, M., . . . Leyva, J. (2006). Randomized, controlled, six-month trial of yoga in healthy seniors: Effects on cognition and quality of life. *Alternative Therapies in Health and Medicine, 12*(1), 40-47.

Context: There are potential benefits of mind-body techniques on cognitive function because the techniques involve an active attentional or mindfulness component, but this has not been fully explored.
Objective: To determine the effect of yoga on cognitive function, fatigue, mood, and quality of life in seniors.
Design: Randomized, controlled trial comparing yoga, exercise, and wait-list control groups.
Participants: One hundred thirty-five generally healthy men and women aged 65–85 years.
Intervention: Participants were randomized to 6 months of Hatha yoga class, walking exercise class, or wait-list control. Subjects assigned to classes also were asked to practice at home.
Main Outcome Measures: Outcome assessments performed at baseline and after the 6-month period included a battery of cognitive measures focused on attention and alertness, the primary outcome measures being performance on the Stroop Test and a quantitative electroencephalogram (EEC) measure of alertness; SF-36 health-related quality of life; Profile of Mood States; Multi-Dimensional Fatigue Inventory; and physical measures related to the interventions.
Results: One hundred thirty-five subjects were recruited and randomized. Seventeen subjects did not finish the 6-month intervention. There were no effects from either of the active interventions on any of the cognitive and alertness outcome measures. The yoga intervention produced improvements in physical measures (eg, timed 1-legged standing, forward flexibility) as well as a number of quality-of-life measures related to sense of well-being and energy and fatigue compared to controls.
Conclusion: There were no relative improvements of cognitive function among healthy seniors in the yoga or exercise group compared to the wait-list control group. Those in the yoga group showed significant improvement in quality-of-life and physical measures compared to exercise and wait-list control groups.

Sandroff, B. M., Hillman, C. H., Benedict, R. H., & Motl, R. W. (2015). Acute effects of walking, cycling, and yoga exercise on cognition in persons with relapsing-remitting multiple sclerosis without impaired cognitive processing speed. *Journal of clinical and experimental neuropsychology*, *37*(2), 209-219.

Introduction: Cognitive impairment is a highly prevalent, disabling, and poorly managed consequence of multiple sclerosis (MS). Exercise training represents a promising approach for managing cognitive impairment in this population. However, there is limited evidence supporting an optimal exercise stimulus for improving cognition in MS. The current study compared the acute effects of moderate-intensity treadmill walking, moderate-intensity cycle ergometry, and guided yoga with those of quiet rest on executive control in 24 persons with relapsing-remitting MS without impaired cognitive processing speed using a within-subjects, repeated measures design.
Methods*:* Participants completed four experimental conditions that consisted of 20 minutes of moderate-intensity treadmill walking exercise, moderate-intensity cycle ergometer exercise, guided yoga, and quiet rest in a randomized, counterbalanced order. Participants underwent a modified-flanker task as a measure of executive control immediately prior to and following each condition.
Results*:* Repeated measures analyses of variance (ANOVAs) indicated general pre-to-post improvements in reaction time, but not accuracy, on the modified-flanker task for all three exercise modalities compared with quiet rest. However, there were additional, selective pre-to-post reductions in the cost of interfering stimuli on reaction time on the modified-flanker task for treadmill walking, $F(1, 23) = 4.67$, $p = .04$, $\eta_p^2 = .17$, but not cycle ergometry, $F(1, 23) = 0.12$, $p = .73$, $\eta_p^2 < .01$, or guided yoga, $F(1, 23) = 0.73$, $p = .40$, $\eta_p^2 = .03$, compared with quiet rest.
Conclusions*:* The present results support treadmill walking as the modality of exercise that might exert the largest beneficial effects on executive control in persons with relapsing-remitting MS without impaired cognitive processing speed. This represents an exciting starting point for delineating the appropriate exercise stimulus (i.e., modality and intensity) for inclusion in a subsequent longitudinal exercise training intervention for improving cognitive performance in this population.

Telles, S., Bhardwaj, A. K., Kumar, S., Kumar, N., & Balkrishna, A. (2012). Performance in a substitution task and state anxiety following yoga in army recruits. *Psychological Reports*, *110*(3), 963-976.

140 men (M age = 30.3 yr., SD = 5.7) from the Indian army in north India participated in the study. They were naive to yoga and were assigned to yoga and breath awareness groups randomly, with 70 in each group. 20 healthy males of comparable age (M age = 33.7 yr., SD = 7.0) formed a comparison group. Their performance in a digit-letter substitution task and a state anxiety subscale was assessed immediately before and after two 45-min. sessions. The two groups of soldiers practiced either yoga or breath awareness. The comparison group listened to meditation music. Digit-letter substitution scores increased in both groups of army personnel and in the comparison group. State anxiety decreased after yoga and listening to meditation music, but not after breath awareness. This suggests that even in army personnel naive to yoga, a yoga-based intervention or listening to meditation music could reduce anxiety while increasing performance on an attention task.

Telles S., Singh N., Bhardwaj, A.K., Kumar, A., & Balkrishna A. (2013). Effect of yoga or physical exercise on physical, cognitive and emotional measures in children: a randomized controlled trial. *Child and Adolescent Psychiatry and Mental Health*, 7(1), 37.

Background: Previous studies have separately reported the effects of physical exercise and yoga in children, showing physical, cognitive and emotional benefits. Objectives: The present randomized controlled trial assessed the effects of yoga or physical exercise on physical fitness, cognitive performance, self-esteem, and teacher-rated behavior and performance, in school children.

Methods: 98 school children between 8 to 13 years were randomized as yoga and physical exercise groups {n = 49 each; (yoga: 15 girls, group mean age 10.4 ± 1.2 years), (physical exercise: 23 girls, group mean age 10.5 ± 1.3 years)}. Both groups were blind assessed after allocation, using: (i) the Eurofit physical fitness test battery, (ii) Stroop color-word task for children, (iii) Battle's self-esteem inventory and (iv) the teachers' rating of the children's obedience, academic performance, attention, punctuality, and behavior with friends and teachers. After assessments the yoga group practiced yoga (breathing techniques, postures, guided relaxation and chanting), 45 minutes each day, 5 days a week. During this time the physical exercise group had jogging-in-place, rapid repetitive movements and relay races or games. Both groups were assessed at the end of 3 months. Data were analyzed with RM ANOVA and post-hoc tests were Bonferroni adjusted.

Results: There was one significant difference between groups. This was in social self-esteem which was higher after physical exercise compared to yoga ($p < 0.05$). All the changes reported below are based on after-before comparisons, within each group. Both groups showed an increase in BMI, and number of sit-ups ($p < 0.001$). Balance worsened in the physical exercise group, while plate tapping improved in the yoga group ($p < 0.001$). In the Stroop task both groups showed improved color, word- and color-word naming ($p < 0.01$), while the physical exercise group showed higher interference scores. Total, general and parental self-esteem improved in the yoga group ($p < 0.05$).

Conclusion: Yoga and physical exercise are useful additions to the school routine, with physical exercise improving social self-esteem.

Velikonja, O., Curic, K., Ožura, A., & Jazbec, S. Š. (2010). Influence of sports climbing and yoga on spasticity, cognitive function, mood and fatigue in patients with multiple sclerosis. *Clinical Neurology and Neurosurgery*, *112*(7), 597-601.

Objective: Spasticity, cognitive impairment, depression and fatigue significantly reduce the quality of life in multiple sclerosis (MS) patients. To find out whether nonpharmalogical treatment approaches can reduce these symptoms we investigated effects of sports climbing (SC) and yoga on spasticity, cognitive impairment, mood change and fatigue in MS patients. Sports climbing (SC) and yoga are aerobic physical activities comprised a series of stretching techniques, implementation of which demands body control and planning of complex movements.
Methods: 20 subjects with relapsing–remitting or progressive MS, 26–50 years of age, with EDSS ≤ 6 and EDSS pyramidal functions score (EDSSpyr) > 2 were enrolled in a randomized prospective study. The participants were randomly divided into SC and yoga group. We evaluated spasticity, cognitive function, mood and fatigue before and after both programs, that lasted 10 weeks, with standardized assessment methods.
Results: There were no significant improvements in spasticity after SC and yoga. In the SC group we found a 25% reduction ($p = 0.046$) in EDSSpyr. There were no differences inexecutive function after the completion of both programs. There was a 17% increase in selective attention performance after yoga ($p = 0.005$). SC reduced fatigue for 32.5% ($p = 0.015$), while yoga had no effect. We found no significant impact of SC and yoga on mood.
Conclusion: Yoga and SC might improve some of the MS symptoms and should be considered in the future as possible complementary treatments.

Appendix B: Physical Activity Readiness Questionnaire

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____________________

SIGNATURE ____________________ DATE ____________________

SIGNATURE OF PARENT ____________________ WITNESS ____________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

Appendix C: Consent Form

Information and Consent Letter

Study Title: **Comparing the acute effects of Hatha yoga and meditation on inhibition**

Principal Investigator: Dr. Peter Hall (pahall@uwaterloo.ca, 519-888-4567 ext. 38110)
Student Investigators: Kimberley Luu (kluu@uwaterloo.ca, 519-888-4567 ext. 38180); Cassandra Lowe (c2lowe@uwaterloo.ca, 519-888-4567 ext. 38180).

You have been invited to participate in a pilot research project for Kimberley Luu's Master's thesis, which will compare the acute effects of Hatha yoga and meditation on cognitive function in healthy adults. Cognitive functions are brain processes which perceive, transform, store, and conceptualize sensory information (ex. memory, planning, and attention). The study consists of three in-laboratory sessions completed on the same day of three consecutive weeks. Each session will take approximately 1 hour to complete.

Eligibility: We are looking for adult women ages 18-48 with 4 months to 5 years of Hatha yoga experience.

Procedure:
During the first laboratory session, you will be asked to complete computer tasks designed to measure cognitive function. You will be asked to complete these tasks prior to and following the exercise sessions. In addition, you will fill out questionnaires on mood, prior yoga meditation experience, and demographics (ex. Age, income, education, ethnicity, height, and weight). Please note that you are not required to respond to any questions in the listed questionnaires or complete any tasks if undesired. Together, the tasks and questionnaire will take about thirty minutes to complete.

During the exercise phase of the study, you will be randomly assigned to one of the following exercise activities: (1) Hatha yoga (2) Meditation, and (3) Reading yoga culture magazines. For the physical Hatha yoga class, you will be provided a mat (of which will have been sanitized thoroughly with a natural disinfectant) and be instructed through a series of postures in synchronization with breath. For the mental Hatha yoga class, you will be provided with a wooden block as a seat and be instructed through meditation and breathing exercises. These will be individual classes instructed by the research coordinator, Kimberley Luu, who is a certified yoga instructor. For the reading yoga culture magazines control session, you will be free to enjoy Yoga Journal magazines. Exercise sessions are 25 minutes long. During your second and third laboratory session, the procedure will be the same; however, you will complete a different randomly assigned exercise.

You will be asked to abstain from caffeine and alcohol 3 hours prior to your laboratory session.

Furthermore, you will be asked to wear or bring comfortable exercise clothes to each session. An e-mail reminder will be sent to you one day prior to the study.

Remuneration: You will receive a free class pass to Queen Street Yoga and Moksha Yoga Waterloo for your participation following completion of the third session.

Participation: Your participation is completely voluntary and you may withdraw from this study or decline answering any questions with no penalty. Withdrawal from the study may occur at any time and you will still receive a free class pass to Queen Street Yoga and Moksha Yoga Waterloo as remuneration for your time in the study.

Confidentiality and security of data: All information that is gathered during this study will remain confidential; at no time will your name be associated with any of the data or information. You will be asked to fill out a questionnaire pertaining to your demographic information (ex. Age, income, education, ethnicity, height, and weight), however please note that you have the right to refrain from answering any questions. All information acquired will be kept for seven years in the University of Waterloo Social Neuroscience and Health Lab (BMH 1013) where only authorized researchers will have access. Any electronic information will be retained on a secure password protected server. The questionnaires administered (Yoga meditation experience, mood, demographics) use Survey Monkey™ which is a United States of America company. Consequently, USA authorities under provisions of the PATRIOT Act may access this survey data. If you prefer not to submit your data through Survey Monkey™, please contact one of the researchers so you can participate using an alternative method of paper-based questionnaire.

Risks: It is possible that, during the physical Hatha yoga session, you may experience musculoskeletal discomfort or fatigue. If you experience discomfort during the physical Hatha yoga session, you are encouraged to stop the exercise and inform the research coordinator/ certified yoga instructor who is with you.

Benefits: This study may provide you with temporary physical and mental health benefits of Hatha yoga practice. Physical health benefits may include but are not restricted to improved muscular strength, flexibility, and balance. Mental benefits include decreased stress and anxiety, as well as potential cognitive enhancements. In addition, you will learn about the cognitive benefits of Hatha yoga.

Questions and Research Ethics Clearance: If after receiving this letter, you have any questions about this study, or would like additional information to assist you in reaching a decision about participation, please feel free to ask the student investigator or a faculty supervisor listed at the top of this sheet.

I would like to assure you that this study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, please contact Dr. Maureen Nummelin, the Director, Office of Research Ethics, at 1-519-888-4567, Ext. 36005 or maureen.nummelin@uwaterloo.ca.

By signing this consent form, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

Thank you for your interest in our research and for your assistance with this project.

Consent of Participant: I have read the information presented in the information letter about a study being conducted by Kimberley Luu and Cassandra Lowe under the supervision of Dr. Peter Hall of the Department of Health Studies and Gerontology at the University of Waterloo. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted. I am aware that I may withdraw from the study without loss of participation remuneration at any time by advising the researchers of this decision.

This project has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact the Director, Office of Research Ethics, at 1-519-888-4567, Ext. 36005.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

____

Print Name

____

Signature of Participant

____

Dated at Waterloo, Ontario

____

Witnessed

Appendix D: Yoga Meditation Experience Questionnaire

Below are 10 questions about your personal experience of doing yoga and meditation. Please call to mind how you usually feel during yoga and meditation practice. You will not be judged on your scores, so please be as honest as possible in your responses.

I have practiced yoga for:
a) 4 months – 1 year
c) 1 - 2 years
d) 2 – 3 years
e) 3 - 5 years

During yoga practice, I…

1. Feel a sense of balance between effort and ease.

1	2	3	4	5	6	7	8	9	10
Never				Sometimes					All the time

2. Listen to my body's inner intelligence and practice accordingly (ex. By modifying postures, executing specific breathing exercises as needed).

1	2	3	4	5	6	7	8	9	10
Never				Sometimes					All the time

3. Mindfully notice how my body feels in each moment, in posture *and* throughout transitions.

1	2	3	4	5	6	7	8	9	10
Never				Sometimes					All the time

4. Am able to synchronize my movements with breath.

1	2	3	4	5	6	7	8	9	10
Never				Sometimes					All the time

5. Accept myself and my limitations when I cannot complete a certain exercise.

1	2	3	4	5	6	7	8	9	10
Never				Sometimes					All the time

I have practiced meditation for:
a) 4 months – 1 year
b) 1 – 2 years

c) 2 - 3 years
d) 3 – 5 years

Note: This answer may overlap with the number of years you have practiced yoga.

During meditation practice, I…

1. Am able to detect distractions as they arise and redirect my attention to the chosen object or intention.

1	2	3	4	5	6	7	8	9	10
Never				Sometimes					All the time

2. Am able to monitor my emotions, thoughts, and muscular tension.

1	2	3	4	5	6	7	8	9	10
Never				Sometimes					All the time

3. Feel competent in executing breathing exercises.

1	2	3	4	5	6	7	8	9	10
Never				Sometimes					All the time

4. Feel immersed in the present experience rather than dwelling on the past or future.

1	2	3	4	5	6	7	8	9	10
Never				Sometimes					All the time

5. Accept myself and my limitations when I am unable to focus my mind.

1	2	3	4	5	6	7	8	9	10
Never				Sometimes					All the time

Appendix E: Profile of Mood States 2 - Adult Short

POMS2 – Adult Short

By Juvia P. Heuchert, Ph.D. & Douglas M. McNair, Ph.D.

Below is a list of words that describe feelings that people have. Please read each word carefully, then shade in the circle that best describes:

how you feel RIGHT NOW.

Shade circles like this:

Not like this:

		Not at all	A little	Moderately	Quite a bit	Extremely
1.	Friendly	0	1	2	3	4
2.	Tense	0	1	2	3	4
3.	Angry	0	1	2	3	4
4.	Worn out	0	1	2	3	4
5.	Lively	0	1	2	3	4
6.	Confused	0	1	2	3	4
7.	Considerate	0	1	2	3	4
8.	Sad	0	1	2	3	4
9.	Active	0	1	2	3	4
10.	Grouchy	0	1	2	3	4
11.	Energetic	0	1	2	3	4
12.	Panicky	0	1	2	3	4
13.	Hopeless	0	1	2	3	4
14.	Uneasy	0	1	2	3	4
15.	Unable to concentrate	0	1	2	3	4
16.	Fatigued	0	1	2	3	4
17.	Helpful	0	1	2	3	4
18.	Nervous	0	1	2	3	4
19.	Miserable	0	1	2	3	4
20.	Muddled	0	1	2	3	4
21.	Bitter	0	1	2	3	4
22.	Exhausted	0	1	2	3	4
23.	Anxious	0	1	2	3	4
24.	Good-natured	0	1	2	3	4
25.	Helpless	0	1	2	3	4
26.	Weary	0	1	2	3	4
27.	Bewildered	0	1	2	3	4
28.	Furious	0	1	2	3	4
29.	Trusting	0	1	2	3	4
30.	Bad-tempered	0	1	2	3	4
31.	Worthless	0	1	2	3	4
32.	Vigorous	0	1	2	3	4
33.	Uncertain about things	0	1	2	3	4
34.	Drained	0	1	2	3	4
35.	Enthusiastic	0	1	2	3	4

Appendix F: Demographics Questionnaire

Hatha Yoga & Executive Function: Demographics Questionnaire

*1. Participant ID#:

2. Age (in years):

3. Height (ft., in.):

4. Weight (lbs):

5. Level of education (some, current, or completed):

- High school
- College/ University
- Graduate studies

6. Estimated household income (all sources, including living assistance and/ or social security):

- $0 - $19,999
- $20,000 - $39,999
- $40,000 - $59,999
- $60,000 - $79,999
- $80,000 - $99,999
- $100,000+

7. Ethnicity (e.g., Asian, Black, Caucasian/ White, Middle Eastern):

8. Relationship Status:

- Single
- In a relationship
- Married/ Common Law
- Divorced/ Separated

Appendix G: Feedback Letter

Feedback Letter

Study Title: Comparing the acute effects of Hatha yoga and meditation on inhibition

Principal Investigator: Dr. Peter Hall (pahall@uwaterloo.ca, 519-888-4567 ext. 38110)
Student Investigators: Kimberley Luu (kluu@uwaterloo.ca, 519-888-4567 ext. 38180); Cassandra Lowe (c2lowe@uwaterloo.ca, 519-888-4567 ext. 38180).

Thank you for participating; your participation is greatly appreciated! The purpose of this study was to compare the acute effects of Hatha yoga and meditation on cognitive function in healthy adults.

In this study, you were asked to come in for three laboratory sessions, in which you completed an exercise activity (Hatha yoga, meditation, and reading yoga culture magazines). Before and after each exercise activity, you completed tasks designed to measure cognitive function. These tasks measures executive functions, which are higher order cognitive abilities including inhibitory control. The reason we had you complete the tasks before and after the exercise activity is because we wanted to compare baseline (before) scores to your experimental scores (after), to determine if a single session of Hatha yoga or meditation can improve executive function and if there were any differences in the effect of the two exercises. Previous research has demonstrated that a single session of Hatha yoga and meditation can improve executive function. Given the above, it is anticipated that a single session of both Hatha yoga and meditation will improve executive function; with Hatha yoga exhibiting stronger effects due to the added physical component of the practice.

If any of the questions or exercises in this study caused you to feel uncomfortable, please feel free to contact Kimberley Luu anytime at 519-888-4567 ext. 38180 or email at kluu@uwaterloo.ca. You can also contact Dr. Peter Hall at 519-888-4567 at 519-888-4567 ext. 38110 or email at pahall@uwaterloo.ca. Also, please feel free to contact the Director of the Office of Research Ethics at 519-888-4567, Ext. 36005, if you have concerns or comments resulting from your participation.

The information you provided will be kept confidential by not associating your name with the responses. The data will be stored with all identifying or potentially identifying information removed. Electronic data will be stored on a password protected computer in BMH 1013 . Printed data will be kept in a locked room in BMH 101. No one other than the researchers will have access to the data.

We very much appreciate your participation in this investigation.