THE JOURNAL OF ALTERNATIVE AND COMPLEMENTARY MEDICINE
Volume 22, Number 2, 2016, pp. 125–133
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DOI: 10.1089/acm.2014.0091

Hatha Yoga and Executive Function: A Systematic Review

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Abstract

Introduction: Recent reviews have documented the beneficial effects of seated meditation on executive function (EF). However, there has yet to be a comprehensive review on the effects of Hatha yoga, a moving meditation, on EF.
Objective: To examine the empirical literature on the effects of Hatha yoga on EF.
Methods: MEDLINE, Scopus, and PsycINFO databases were searched for experimental studies (between- or within-subject designs) testing the effects of Hatha yoga (acute bouts, short-term interventions, longer-term interventions) on EF.
Results: A total of 11 published studies met eligibility criteria: Three studies involved healthy adults, 2 studies involved healthy older adults ($n=2$), 1 study involved children and adolescents, and 5 studies involved medical ($n=4$) or forensic ($n=1$) populations. In healthy adults, 2 of 3 studies suggested that acute bouts of Hatha yoga improved EF; however, 1 study using a short-term intervention found no improvements in EF. Among healthy older adults, 1 study provided evidence that Hatha yoga improves EF. In child/adolescent samples, 1 study supported the contention that Hatha yoga improves EF after short-term interventions. Among medical populations, EF improved in patients with type 2 diabetes mellitus and in 1 of 3 studies involving patients with multiple sclerosis. The sole study involving impulsive prisoners showed positive effects on EF with a short-term intervention.
Conclusion: Hatha yoga shows promise of benefit for EF in healthy adults, children, adolescents, healthy older adults, impulsive prisoners, and medical populations (with the exception of multiple sclerosis). However, more good-quality studies that evaluate the efficacy of Hatha yoga's effects on EF are essential to build on this evidence base.

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.[1] 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.[2] 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 concluded that Hatha yoga is moderately beneficial in the context of relieving anxiety and depressive disorders and conjunctively supporting standard treatments for post-traumatic stress disorder.[3] In more recent years, interest has shifted from merely investigating Hatha yoga from a direct psychiatric standpoint to also include examination of Hatha yoga's effects on cognitive functions, such as attention, concentration, memory, and executive function (EF).[4]

For the past two decades, emerging evidence has suggested that Hatha yoga may indeed enhance EF. EFs are a set of higher-order cognitive processes that enable top-down (i.e., non–stimulus driven) control over behavior, emotion, and thought; they most typically involve inhibitory control, working memory, and mental flexibility, arising from the operation of the prefrontal cortex and other closely connected centers.[5] Other cognitive functions, such as attention control, decision making, planning, and problem solving, are often also classified as EFs because they are highly correlated with EF or are functionally dependent on them.[6]

Although reviewers have discussed the effects of seated meditation on cognition and EF,[7–10] a comprehensive review

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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. This review addressed the question: Does Hatha yoga have beneficial effects 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–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—the literature pertaining to each of these components is first reviewed in turn. In the context of Hatha yoga, aerobic and resistance exercise is manifest in the form of continuous movements through postures that 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 after aerobic exercise have been well established. For instance, acute bouts of aerobic exercise improve inhibitory control,[11–13] working memory,[14] and planning,[15] while one meta-analysis supports the positive effects of exercise on EF.[16] Some studies have documented structural and physiologic brain changes associated with enhanced cognition following aerobic training. For example, an intervention study found increases in gray matter volume in frontal regions of the brain among older adults after aerobic exercise training.[17] Furthermore, a recent review by Erickson et al.[18] concluded that more 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 that supports physiologic mechanisms involved in neuroplasticity after acute bouts of aerobic exercise;[19] other studies involving animal models have documented enhanced localized glycogen storage in the cortex of rats after acute aerobic training.[20]

Although 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[21] and planning,[22] but not working memory,[23] after short-term bouts of resistance training in healthy adults. Investigators report significant improvements in working memory[24] and inhibitory control[25] after 6 months of resistance training, while inhibitory control significantly improved after a 12-month resistance training program compared with a balance and tone training control group.[26] A review on older adult populations found that resistance exercise interventions with a substantive number of sets (seven movements in two sets), load (60%–80% one-repetition maximum), and duration (2–12 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.[27]

Meditation

Meditation has been revealed to enhance EF, and can be categorized under focused attention (FA) and open monitoring (OM).[9] FA meditation consists of directing awareness to a chosen object, detecting distractions as they arise, and subsequently redirecting awareness to the chosen object.[9] OM meditation, commonly known as ''mindfulness,'' involves sustained metacognitive awareness of internal and external experiences, such as emotion, thought, and sensory stimuli, without attaching judgment or further explanation of their occurrence.[28] Raghavendra and Telles[29] found that an acute bout of FA meditation improved attention and concentration task performance, while MacLean et al.[30] found that 3 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 that 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.[7]

On the other hand, evidence suggests that OM training improves attention[28] and working memory[31,32] while decreasing mind-wandering.[32] Experienced OM meditators show significantly superior inhibitory control and selective attention compared to meditation-naive controls.[33] 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;[34] and the right orbito-frontal cortex and right hippocampus, associated with emotion regulation and response control.[35]

Breathing exercises

Studies investigating the effects of breathing exercises on EF reveal mixed results. For instance, Telles et al.[36] 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[37] 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.[38] Attention improved after the right- and alternate-nostril breathing exercises.[38] Finally, Telles et al.[39] 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 participants who did 3 months of breathing exercise training previously, 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 review aims to investigate the effects of Hatha yoga, as a whole, on EF.

Methods

In March 2015, a search was done using MEDLINE, Scopus, and PsycINFO with the following terms: ''yoga,''

''cognition,'' ''executive function,'' ''inhibitory control,'' ''working memory,'' ''set shifting,'' ''updating,'' ''attention,'' ''problem solving,'' ''decision making,'' and ''prefrontal cortex.'' Studies reported in English dated from database inception to March 2015 were assessed.

Inclusion and 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 that 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 *t'ai chi*, integrative yoga philosophy and practice modules) were excluded. Finally, studies that analyzed Hatha yoga as a control intervention or in a case series were excluded.

Risk of bias assessment

Study quality was determined using the Cochrane risk of bias tool[40] 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, 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 used so that primary researchers could not influence random assignment; examples of these procedures include a third party to conduct the randomization process and sequentially drawing 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 blinded to the study hypothesis or if the EF outcome was administered by 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

After exclusion of 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, 1 involved patients with type 2 diabetes mellitus, and 3 involved patients with multiple sclerosis. 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.

Study quality

Most studies indicated methods of randomization to treatment groups or counterbalancing sessions, but many did not report allocation concealment. With the exception of 2 studies that reported blinding personnel,[41,42] 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 because the outcome measures were often computer administered. Attrition bias varied: Two studies had a high dropout rate (>20%),[43,44] 1 study had dropout rates that were unbalanced between the intervention groups,[45] and 2 studies did not report dropout rates at all.[46,47] All studies reported EF outcome data adequately. Table 2 displays the risk of bias summary for each included study.

Healthy adults

Three published experimental studies have investigated the effects of Hatha yoga on EF in healthy adult populations. Bowden et al.[43] found no significant improvements in working memory under the n-Back task after 5 weeks of an Iyengar yoga intervention. Iyengar yoga is a gentle style of Hatha yoga that 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-subject study conducted by Gothe et al.[48] revealed significant improvements in working memory using the n-Back task and inhibitory control using the Flanker task immediately after Hatha yoga as compared with the aerobic exercise and baseline control sessions in an undergraduate female sample. Furthermore, a randomized controlled trial revealed significant improvements in working memory and selective attention using the Digit Letter Substitution task after an acute bout of Hatha yoga.[49]

Children and adolescents

One study addressed the effects of Hatha yoga on EF in children and adolescents. Telles et al.[50] reported significant improvements in inhibitory control using the Stroop task after 3 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.[51]

Older adults

Two studies investigated the effects of Hatha yoga on EF in older adults, a population at risk for cognitive decline.

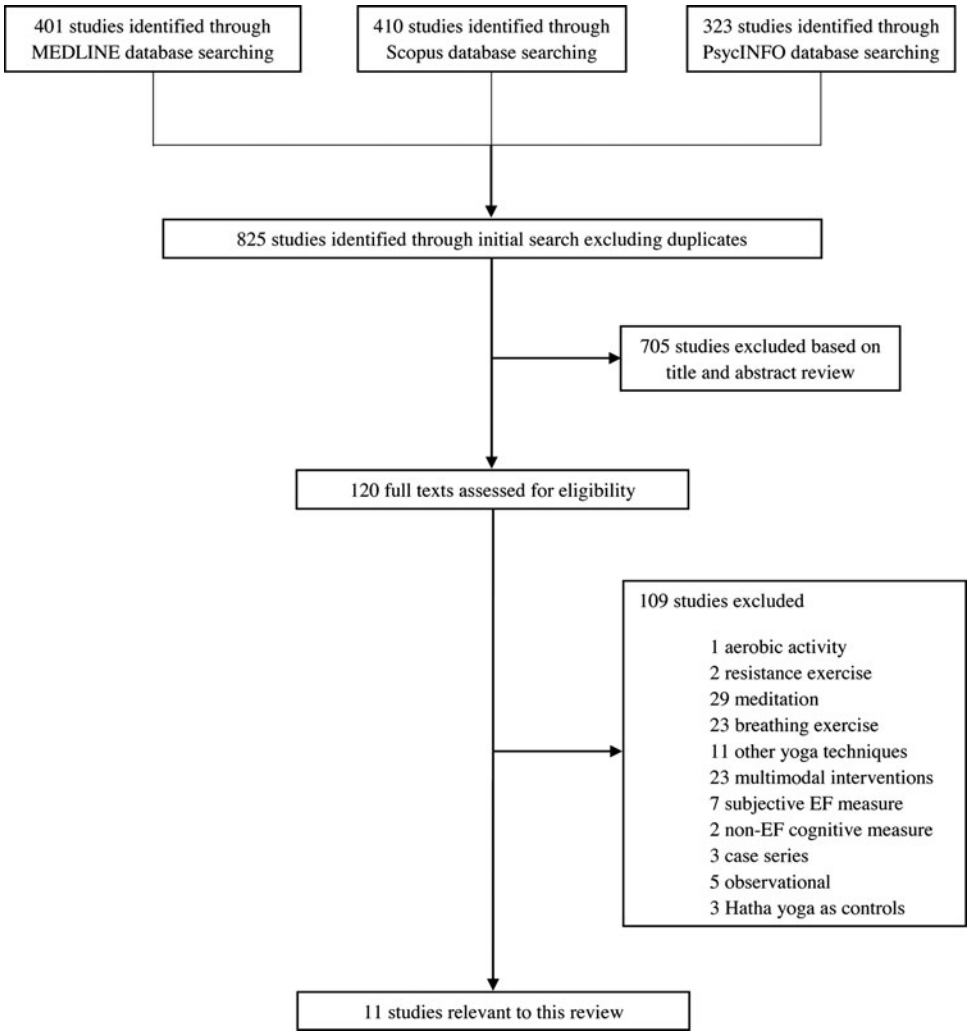

FIG. 1. Study filtering process. EF, executive function.

One randomized controlled trial conducted by Oken et al.[41] found no significant improvements in inhibitory control and attention by using the Stroop task and quantitative electroencephalographic measures after a 6-month Iyengar yoga intervention. They did, however, find increases in well-being, energy levels, and physical functionality. Researchers report that these findings may have been due to ceiling effects because the older adults were relatively healthy. Conversely, Gothe et al.[45] found significant improvements in working memory using a letter version of the Running Memory Span and n-Back tasks and in mental flexibility using a task-switching paradigm after an 8-week Hatha yoga intervention in older adults, as compared with a stretching-only control group. Although 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 controlled study conducted by Bilderbeck et al.[44] found superior performance in inhibitory control using the Go/No-Go task on prisoners who had scored high on impulsivity measures after 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, EF was measured only after the intervention was completed, and no baseline scores were available for pre-post comparisons.

Patients with type 2 diabetes mellitus

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 with use of an auditory oddball paradigm after a 45-day intervention as compared to a conventional therapy–only control group.[46] 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.

Patients with multiple sclerosis

Studies have investigated the effects of Hatha yoga on EF in patients with multiple sclerosis. A randomized controlled trial conducted by Oken et al.[42] found no significant improvements in inhibitory control and attention using the Stroop task and a quantitative electroencephalogram after a

Table 1. Summary of Experimental Studies

Reference (year)	*Participants*	*Intervention*	*EF Outcome Measure*	*Results*
Bilderbeck et al. (2013)	Impulsive prisoners; Hatha yoga group ($n=39$) vs. control group ($n=51$)	10 wk of Hatha yoga or control group	Inhibitory control; Go/No-Go task at post-intervention	Significantly superior inhibitory control in 10-wk Hatha yoga intervention group compared to controls
Bowden et al. (2012)	Healthy adults; Iyengar yoga group ($n=9$) vs. brain wave vibration group ($n=12$) vs. mindfulness ($n=12$)	5 wk 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 after 5 wk of Iyengar yoga training
Gothe et al. (2014)	Older adults; Hatha yoga group ($n=58$) vs. stretching control group ($n=50$)	8 wk 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 after 8 wk of Hatha yoga compared to stretching controls
Gothe et al. (2013)	Females undergraduate students ($n=30$)	Participants underwent 3 counterbalanced sessions of baseline testing, Hatha yoga, and aerobic exercise on 3 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	Significant increases in inhibitory control and working memory after short-term Hatha yoga sessions as compared with baseline testing and short-term aerobic exercise
Kyizom et al. (2010)	Patients with type 2 diabetes; conventional medical therapy ($n=30$) vs. Hatha yoga with conventional medical therapy ($n=30$)	Participants divided into 5 days of Hatha yoga intervention followed by 45 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 after a 45-d Hatha yoga and conventional medical therapy intervention as compared with conventional medical therapy only
Oken et al.(2004)	Patients with multiple sclerosis; Iyengar yoga group ($n=22$) vs. cycling group ($n=21$) vs. control group ($n=20$)	6 mo of Iyengar yoga intervention, cycling training, or waitlist control	Inhibitory control and attention; Stroop task and quantitative electroencephalographic measure at baseline and post-intervention	No significant improvements in inhibitory control or attention after 6 mo of Iyengar training
Oken et al. (2006)	Older adults; Iyengar yoga group ($n=38$) vs. walking group ($n=38$) vs. control group ($n=42$)	6 mo of Iyengar yoga intervention, walking class, or waitlist control	Inhibitory control and attention; Stroop task and quantitative electroencephalographic measure at baseline and post-intervention	No significant improvements in inhibitory control or attention after 6 mo of Iyengar yoga training
Sandroff et al. (2015)	Patients with multiple sclerosis ($n=24$)	Participants underwent 4 counterbalanced 20-minute sessions of treadmill walking, cycle ergometry, Hatha yoga, and quiet rest	Inhibitory control; modified Flanker task before and after each session.	Significant increases in inhibitory control after 20 min of Hatha yoga treadmill walking, cycle ergometry compared to quiet rest
Telles et al. (2012)	Healthy men; Hatha yoga group ($n=70$) vs. breath awareness group ($n=70$) vs. meditation music control group ($n=20$)	45-min 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 after 45 min of Hatha yoga training
Telles et al. (2013)	Children and adolescents age 8–13; Hatha yoga ($n=49$) vs. physical exercise ($n=49$)	3 mo of Hatha yoga or physical exercise intervention	Inhibitory control; Stroop task at baseline and post-intervention	Significant improvements in inhibitory control after 3 mo of Hatha yoga
Velikonja et al. (2010)	Patients with multiple sclerosis; Hatha yoga group ($n=10$) vs. sports climbing group ($n=10$)	Participants randomly assigned to 10 wk weeks of Hatha yoga intervention or sports climbing	EF; 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 EF or planning skills after a 10-wk Hatha yoga intervention Significant improvement in attention after a 10-wk Hatha yoga intervention

EF, executive function.

Table 2. Risk of Bias Summary

Study (year)	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 et al. (2013)	+	?	–	+	–	+
Bowden et al. (2012)	+	+	–	+	–	+
Gothe et al. (2014)	+	?	–	+	–	+
Gothe et al. (2013)	+	?	–	+	+	+
Kyizom et al. (2010)	?	?	–	+	?	+
Oken et al. (2004)	+	+	?	+	+	+
Oken et al. (2006)	+	+	?	+	+	+
Sandroff et al. (2015)	+	?	–	+	+	+
Telles et al. (2012)	–	?	–	?	+	+
Telles et al. (2013)	+	+	–	+	+	+
Velikonja et al. (2010)	+	?	–	?	?	+

+, low risk of bias; –, high risk of bias; ?, unclear risk of bias.

6-month Iyengar yoga intervention. Similarly, Velikonja et al.[47] 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 after a 10-week Hatha yoga intervention. However, improvements in attention were found with use of the Brickenkamp d2 test.[47] Finally, a recent study by Sandroff et al.[52] found improvements in inhibitory control through use of a modified Flanker task after an acute 20-minute session of Hatha yoga. More research for this population is warranted in order to provide conclusive statements.

Discussion

The purpose of the current study was to address the question of whether Hatha yoga improves EF. A systematic review method was used, yielding a total of 11 studies involving healthy adults ($n=3$), children and adolescents ($n=1$), older adults ($n=2$), impulsive prisoners ($n=1$), patients with type 2 diabetes ($n=1$), and patients with multiple sclerosis ($n=3$).

In healthy persons, 2 studies revealed that acute bouts of Hatha yoga significantly improved EF in the realms of inhibitory control,[48] working memory,[48,49] and attention,[49] while 1 study on short-term training found no improvements in working memory.[43] In children and adolescents, inhibitory control significantly improved[50] after Hatha yoga training. In older adults, 1 study found significant improvements in mental flexibility and working memory;[45] however, another found no improvements in inhibitory control and attention[41] after short-term interventions. Impulsive prisoners who underwent a short-term Hatha yoga intervention performed significantly better on an inhibitory control task as compared to controls.[44] In patients with type 2 diabetes mellitus, 1 study suggested improved working memory and attention abilities after a short-term intervention.[46] Finally, studies among patients with multiple sclerosis yield mixed findings: Two found increases in attention and inhibitory control[47,52] and 2 found no improvements in inhibitory control and EF.[42,47] Thus, the study concluded that while there is some evidence that Hatha yoga improves EF, more high-quality studies must be executed to draw confident conclusions.

Theorized mechanisms

On the basis of 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 ''wandering'' or dwelling on the past or future.[53] 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.[53]

Many researchers also speculate that the improvements in emotional stability may have implications for increasing cognitive function.[4,54,55] For instance, studies have shown decreases in both perceived stress and cortisol levels after Hatha yoga.[55–57] These outcomes may explain the positive findings on memory because hypercortisolism has been associated with smaller hippocampal volumes and memory impairment[58] and decreases in cortisol levels in turn have reversed hippocampal atrophy.[59] Furthermore, a pilot study reported a 27% increase in γ-aminobutyric acid, a major inhibitory neurotransmitter, in the brain under magnetic resonance spectroscopic imaging after a single session of Hatha yoga;[60] this finding indicates that Hatha yoga's anti-anxiety properties as γ-aminobutyric acid deficiency is linked to anxiety disorders.[61]

It is further possible that Hatha yoga supports optimal homeostasis by reducing allostatic load in stress response systems (i.e., increasing parasympathetic nervous system activity and decreasing hypothalamic-pituitary-adrenal axis activity).[62] 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.[62] Prolonged Hatha yoga training also decreased brain activation in the amygdala, as supported by Cohen and colleagues' single-photon emission computed tomography analyses, suggesting potential enhancements in emotion regulation.[54] Finally, a review suggests that Hatha yoga shows potential for being a supplemental treatment option for major depression, a disease that debilitates cognition.[63] 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.[64]

However, despite these plausible mechanisms, at present there is incomplete evidence to confidently support the empirical link between Hatha yoga and EF. This may be due to a lack of studies, rather than a null effect per se. More high-quality studies on the effects of Hatha yoga on EF are imperative to build a substantive evidence base worthy of extrapolating so that health professionals can make confident decisions when prescribing Hatha yoga interventions.

Implications

Given the importance of EF for fostering achievement, health promotion, and prosocial behavior,[65,66] there may be substantial clinical and societal implications if future studies and meta-analyses confirm the EF-enhancing benefits of Hatha yoga. 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.[67] In older adults, prevention of aging-related EF decline is imperative for maintaining overall quality of life and functional independence.[68] 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.[69] In impulsive prisoners, strengthening specific EFs, such as inhibitory control, might positively affect aggression management and impulse control in the criminal rehabilitation context.[44] Finally, EF deficits are highly prevalent in patients with multiple sclerosis,[70] and use of Hatha yoga to improve or reduce such deficits might be key to maintaining physical and social function in this group.[71,72]

Conclusion

There appears to be some evidence that Hatha yoga improves EF, although existing studies vary in quality and there is insufficient evidence to permit definitive conclusions for many populations and modalities of Hatha yoga. In healthy adults, studies suggest that short-term sessions of Hatha yoga improve inhibitory control and working memory; however, there is insufficient evidence to support improvements in EF after short- and long-term interventions. Some evidence supports Hatha yoga's ability to enhance inhibitory control in children and adolescents after 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 among impulsive prisoners and in working memory and attention among patients with type 2 diabetes mellitus. Most studies conducted among patients with multiple sclerosis did not suggest improvements in EF. More studies should evaluate the efficacy of Hatha yoga's effects on EF, especially in populations with cognitive deficits. Future studies should also dissociate Hatha yoga's subcomponent effects on cognition and investigate the neurophysiologic pathways of Hatha yoga–induced EF enhancement.

Acknowledgments

The authors gratefully acknowledge the assistance of Dr. Mark Oremus, Jackie Stapleton, and Corita Vincent, all of whom are faculty, staff, and/ or members of the University of Waterloo's School of Public Health and Health Systems.

Author Disclosure Statement

No competing financial interests exist.

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