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Abstract

Objective: To review and synthesize the existing literature on the effects of yoga on cognitive function by determining effect sizes that could serve as a platform to design, calculate statistical power, and implement future studies.

Methods: Through electronic databases we identified acute studies and randomized controlled trials (RCTs) of yoga that reported cognitive outcomes. Inclusion criteria included: use of an objective measure of cognition and sufficient data reported to estimate an effect size. The meta-analysis was conducted using Comprehensive Meta-analysis software, a random-effects model was used to calculate the overall weighted effect sizes, expressed as Hedge's *g*.

Results: 15 RCTs and 7 acute exposure studies examined effects of yoga on cognition. A moderate effect (g=.33, se=.08, 95%CI=.18 -.48, p <.001) of yoga on cognition was observed for RCTs, with the strongest effect for attention and processing speed (g=.29, p<.001), followed by executive function (g=.27, p=.001) and memory (g=.18, p= .051). Acute studies showed a stronger overall effect of yoga on cognition (g=.56, se=.11, 95%CI=.33 – .78, p<.001). The effect was strongest for memory (g=.78, p<.001), followed by attention and processing speed measures (g=.49, p<.001) and executive functions (g=.39, p<.003).

Conclusions: Yoga practice appears to be associated with modest improvements in cognitive function. Although the studies are limited by sample size; heterogeneous population characteristics; varied doses of yoga interventions; and a myriad of cognitive tests, these findings warrant rigorous systematic RCTs and well-designed counterbalanced acute studies to comprehensively explore yoga as a means to improve or sustain cognitive abilities across the lifespan.

Keywords: executive function, memory, mind-body exercise, effect size

Introduction

The National Institutes of Health define complementary and alternative medicine (CAM) (1) as a group of diverse medical and health care systems, practices, and products that are not presently considered to be part of conventional medicine. CAMs encompass a range of mind-body methodologies, such as yoga, tai-chi, and meditation that may be beneficial to the health of their practitioners. Yoga is an ancient Indian science and way of life that includes the practice of specific postures, regulated breathing and meditation. It is designed to bring balance and health to the physical, mental, emotional, and spiritual dimensions of the individual. Yoga is often depicted metaphorically as a tree and comprises eight aspects: *yama* (universal ethics), *niyama* (individual ethics), *asana* (physical postures), *pranayama* (breath control), *pratyahara* (control of the senses), *dharana* (concentration), *dyana* (meditation), and *samadhi* (bliss) (2). Yoga maybe an alternative form of physical activity which may assist in achieving recommended levels of physical activity for individuals who have disabilities or symptoms that prevent them from performing traditional forms of exercise.

Few systematic and comprehensive reviews of scientific research on yoga have been published recently. Lin et al. (3) conducted a meta-analysis assessing the effects of yoga on psychological health, quality of life and physical health of patients with cancer. They concluded that the yoga groups showed significantly greater improvements in psychological health: anxiety, depression, distress, and stress when compared to the waitlist or supportive groups. Posadzki and Ernst (4) conducted a systematic review to assess the effectiveness of yoga as a treatment option for low back pain. The authors concluded that yoga does lead to a significantly greater reduction in low back pain than usual care, education or conventional therapeutic exercises. The effect of practicing yoga for the management of type II diabetes was assessed in a systematic review and the authors concluded that short-term benefits for patients with diabetes may be achieved from practicing yoga (5). Ross and Thomas (6) reviewed studies comparing the effects of yoga and exercise and concluded that, in both healthy and diseased populations; yoga may be as effective as or better than aerobic exercise at improving a variety of health-related outcome measures. While yoga has been extensively employed as an adjunct therapy for diseased patients and physical symptoms, there are no published reviews that address the effects of this mind-body therapy on cognitive functioning.

Research on physical activity and cognition emerged in the late 1970's with Spirduso's (7) pioneering study suggesting that older adults who regularly participated in physical activity had faster psychomotor speed, relative to their sedentary counterparts, on simple and choice reaction-time tests. Since then, numerous studies have been conducted to examine the relationship between chronic or long term physical activity as well as acute or transient effects of physical activity on cognitive performance. Reviews have concluded that a positive relationship exists between chronic (8-12) as well as acute bouts of physical activity (13,14) and cognition. Physical activity in these reviews has been defined primarily as walking and strength training and little is known about physical activity based CAM therapies like yoga. Mind-body therapies such as yoga involve an active attentional component and therefore may incur cognitive benefits over and above the habitual bodily movements involved in traditional forms of exercise. Hatha yoga is the most common form of yoga practiced in North America and involves the practice of physical postures in conjunction with awareness of the breath to help develop mental focus and to connect the mind, body, and spirit (15). There are many different styles of hatha yoga characterized by the rate at which postures are performed, environmental temperature, physical intensity and level of difficulty, emphasis on body alignment and relaxation, and use of props.

However, postures, breathing and meditative exercises are the three basic elements common to most styles of yoga practice. Yoga therapy enables the practitioner to move slowly and safely into the modified postures concentrating initially on relaxing their body, breathing fully, and developing awareness of the sensations in their body and thoughts in their mind. Yoga requires focused effort in completing the pose, controlling the body, and breathing at a steady rate. In addition, breathing (pranayama) and meditation exercises are practiced to calm and focus the mind and develop greater self-awareness (16). This focused effort and attentional practice of yoga could generalize to conventionally assessed cognitive functions including attention, memory and higher order executive functions.

The purpose of this meta-analysis was to review the existing evidence-base examining the effectiveness of yoga in improving cognitive performance. We examined the overall effect sizes for chronic (long term yoga interventions) and acute (immediate, single bouts) yoga practice as well as the effect sizes for specific domains of cognitive performance, including attention and processing speed, executive function, and memory that could serve as a platform for designing, powering and implementing future studies. We also identify the limitations and methodological issues observed across studies and provide future directions to examine not only the effects of yoga on cognition but also the underlying mechanisms explaining the yoga-cognition relationship.

Method

Literature Search and Study Selection

The following databases were used to locate yoga studies that have examined effects on cognition: MEDLINE, PsycINFO, PubMed, Indian Council of Medical Research, and Cochrane from inception to January 2014. We used the search terms that were constructed around two concepts – yoga and cognition – to identify all the relevant published articles investigating this relationship. Mindfulness and transcendental meditation studies were excluded from this meta-analysis as they have been reviewed elsewhere (17,18). Reference lists of articles were also scanned to locate relevant literature. Unpublished data from dissertations and conference proceedings were also obtained when available.

Study inclusion criteria included: 1) randomized controlled trials or studies using counterbalanced repeated measures designs to examine acute effects of yoga on cognition, 2) objective measures of cognition assessing at least one or more domains using paper-pencil or computer based measures, and 3) sufficient data reported in the studies to estimate an effect size. As the purpose of this review was to examine the state of yoga-cognition literature and provide future direction, we included studies conducted with all age groups and participant characteristics, as long as they met the three basic inclusionary criteria.

Data abstraction and analysis

For each RCT, authors extracted the following study details: participant characteristics, details of the intervention and control groups, blinding, dropout rate and cognitive measures. Except for dropout, similar information was extracted for acute yoga studies. The quality of the RCTs was assessed using the five-point Jadad scale (19), however blinding of subjects was not considered feasible and the maximum possible score was therefore 4 rather than 5. Cognitive tests used in all studies were classified into 3 categories: i) *attention and processing speed* which is the sustained focus of cognitive resources, selective concentration and rapid processing of information (20), ii) *executive function* which is a set of cognitive skills responsible for the planning, initiation, sequencing, and monitoring of complex, goal-directed behavior, working memory (i.e., short-term storage and manipulation of information) (21), and iii) *memory* which involves retention, recollection, and recognition of previously encountered information.

Comprehensive Meta-Analysis software package (22) was used to conduct the analyses (BioStat, Englewood, New Jersey). In case of multiple intervention groups, the means and standard deviations were averaged across other study conditions and compared against the yoga condition. Hedge's g was calculated for each cognitive test reported in the articles. The majority of studies used multiple cognitive tests, often spanning each of the three cognitive domains. We therefore calculated: i) an *overall* effect size for each study and *overall* cognition, and ii) an average effect size for each of the three cognitive domains. Study-specific effect size estimates were weighted by the study sample size and combined to form the *overall* study effect size. Forest plots were constructed to display overall effect sizes for acute studies and RCTs. Given the small number of acute studies, forest plots by cognitive domain were constructed only for RCTs. All effect sizes were coded such that positive numbers always reflected improvements in performance, and negative numbers reflected deterioration in performance. As the target populations of the studies varied for both acute and RCTs, a random effects analysis was conducted to provide a conservative estimate of treatment effects (23). Homogeneity of treatment effects was also assessed using the Q statistic.

Results

Study Selection

Our search generated a total of 40 references. Fourteen studies were excluded as they did not meet the inclusionary criteria: non-randomized trial (n=3; 24-26), not an acute study with repeated measures across all conditions (n=1; 27), case studies or insufficient information to estimate effect sizes (n=5; 28-32), used self-report or behavioral observation to assess cognitive function (n=2; 33,34) or examined neuroanatomical outcomes such as event related potentials (n=3; 35-37). Four other studies were excluded as they were cross-sectional observational studies conducted with yoga practitioners or teachers (38-41). Thus, a total of 22 studies were retained for the meta-analysis of which 15 were RCTs (42-56) and 7 examined acute yoga effects (57-63) on cognition. One (62) of the 7 acute yoga studies was a peer-reviewed published abstract, but we were able to extract all the necessary data to calculate effect sizes. The overall findings did not differ when the study was included or excluded from the analyses. 11 of the 22 studies were conducted in India, 8 in the US, 2 in the UK and 1 in Slovenia.

Study Characteristics

Table 1 and 2 summarize the study characteristics including participant ages, type and duration of the intervention groups (for RCTs) or conditions (for acute studies) and cognitive measures used in the 15 RCTs and 7 acute yoga studies, respectively. A majority of the studies were conducted with adults (12 RCTs and 5 acute) whereas yoga studies with children (<18 years of age) made up the minority (3 RCTs and 2 acute).

RCTs (Table 1) ranged from 1 month to 6 months in duration and commonly employed Hatha yoga (8 of 15 RCTs) protocols. Three RCTs included Iyengar yoga practice; one studied the Integrated Approach of Yoga Therapy and one focused on Sahaj yoga. No yoga protocol or syllabus was reported for two RCTs. Iyengar yoga is a form of Hatha yoga, which utilizes "props" such as chairs, blankets, or straps that support the practitioner in performing the physical postures of yoga. The Sahaj yoga intervention focused on the meditative aspect of yoga practice and the Integrated Approach of Yoga Therapy involved yoga postures, breathing and meditative practice that was combined with educational lectures on healthy lifestyle domains of diet, exercise and stress management. The comparison groups in these RCTs included waitlist, walking, stretching and strengthening, mindfulness, stationary bike and physical training groups. The frequency and duration of practice also varied widely from 1x/week to 5x/week and classes lasted between 45 to 120 minutes. The format of the intervention varied from group/individual to supervised/home practice within the RCTs.

Among acute studies (Table 2), 5 examined the effects of Hatha yoga and cyclic meditation whereas 2 studies exclusively examined yogic breathing practices. Cyclic meditation is a technique that combines stimulating and calming the mind with the goal of achieving a deeper mental balance or equilibrium. The sessions lasted between 9 rounds of breathing exercises to 45 minutes. Duration of the yoga session was not reported in one acute study.

Table 3 lists the cognitive tests used by study authors to assess attention and processing speed, executive function and memory. The Stroop, Trail Making A and B, Wechsler Adult Intelligence Scale (forward and backward digit span), and Six Letter Cancellation Test were the most commonly used measures that were assessed in 3 studies each. Executive function measures made up the largest pool of measures followed by attention - processing speed and memory tests.

Study Quality

Table 4 summarizes the study quality for the 15 RCTs. Jadad scores for the 15 studies ranged from 1 to 4 with a mean of 2.93/4.00 (±.88). A majority of RCTs (13 of 15) used random sampling by advertising in local media outlets. For the remaining two RCTs, participants were recruited from an outpatient clinic (n=1) and no sampling details were reported for the other RCT. One of the 15 studies lacked appropriate randomization, where authors acknowledged the limitation of using block (senior resident homes) randomization technique without accounting for baseline characteristics of the participants. However, the results did not differ when the study was excluded from the analyses. The remaining 14 studies randomized participants based on age and sex. Blinding of participants to their allotted treatment condition is not feasible in physical activity based trials. This criterion was therefore not evaluated or included in the Jadad scores for the RCTs. Several studies (6 of 15) used a single blind approach by blinding assessors however this was not completely effective as authors reported rare instances where participants disclosed their treatment allocation to their assessors. One study also reported blinding of assessors only at baseline and not at the follow-up time-point. Information about withdrawals and dropouts was reported in 11 of 15 RCTs. This information was inconsistently reported where some studies only included follow up sample sizes, while others followed the Consolidated Standards of Reporting Trials (CONSORT; 64) detailing the flow of the study and reasons for dropout or withdrawal.

Overall Effect Sizes

Overall effect sizes for acute and chronic studies were calculated prior to examining specific cognitive domains. The funnel plot of the 15 ESs versus SEs for the RCTs and 7 ESs and SEs for acute studies suggested against publication bias. As seen in Figure 1, the overall effect size for acute studies was g=.58 (se=.11, 95%CI=.33 - .78, p<.001; Q_6 = 51.51, p<.001) which was higher than the effect size for chronic studies at g=.33 (se=.08, 95%CI=.18 - .48, p<.001; Q_{14} = 20.79, p=.107) seen in Figure 2.

Attention and Processing Speed

Six of the 7 acute studies used cognitive tests measuring attention and processing speed. A single session of yoga was associated with moderate improvements in attention and processing speed g=.49 (se=.14, 95%CI=.22 - .77, *p*<.001). There was significant heterogeneity among the 6 studies (Q_5 = 51.46, p<.001)

Similar results were observed for 11 of 15 RCTs which used attention and processing speed measures. As seen in Figure 3, the effect size was moderate g=.299 (se=.08, 95%CI=.14 - .46, *p*=.001). The effect was consistent across all RCTs (Q_{10} = 14.53, p=.150).

Executive Function

Only 1 of the 7 acute yoga studies examined effects on executive function measures. A significant modest effect was found, g=.39 (se=.13, 95%CI= .14 - .65, *p*=.003).

On the other hand, 13 of the 15 RCTs examined effects of yoga on executive function measures as seen in Figure 4. The effect size was g=.27 (se=.08, 95% CI =.12 - .42, *p*=.001) and consistent across all RCTs (Q_{12} = 16.05, p=.189)

Memory

The acute effects of yoga on memory were examined in only one published abstract. The effect size was large and significant, g=.78 (se=.10, 95%CI=.59-.98, *p*<.001).

As in the acute studies, memory was investigated in only 5 of the 15 RCTs. The effect size was marginally significant, g=.18 (se=.09, 95%CI=0.00 - .35, p=.051) and was consistent across the 5 RCTs (Q_4 = 1.87, p=.760) as seen in Figure 5.

Discussion

The purpose of this review was to evaluate in totality the effectiveness of yoga in improving cognitive function including attention and processing speed, executive function and memory. The overall effect sizes were .33 for RCTs and .56 for acute studies suggesting that yoga practice has a modest effect on cognition regardless of cognitive task and participant characteristics. A closer examination of the three domains of cognition suggested specificity of yoga effects that were also unique to the nature of the study (i.e., RCTs vs. acute). The effect sizes for each of the domains were significant except for RCTs examining memory which was marginally significant. However, taken together, these findings suggest that practice of yoga has the potential to improve specific domains of cognitive functioning. This relationship needs to be systematically studied in the future by overcoming the limitations discussed below and designing methodologically sound and rigorous acute studies and RCTs.

There is merit in investigating both, chronic and acute effects of yoga on cognition. Studies included in this meta-analysis ranged from counterbalanced acute exercise protocols to randomized controlled trials. Among RCTs, attention and processing speed and executive function processes showed the largest benefit from yoga practice. The effect on memory processes was marginally significant. This trend is consistent with the aerobic exercise and cognition literature (65). Acute yoga studies appear to show consistent improvements and stronger effect sizes on cognitive domains in comparison to RCTs. This is also consistent with the physical activity literature where acute aerobic exercise has shown to improve cognition (13,14). However, given the handful of studies, conclusions need to be drawn with caution. One area of future yoga research needs to examine the possibility of its fleeting effects on cognition and include multiple follow up time-points following the acute yoga bout. Additionally, examining the cumulative effects of serial bouts of yoga is warranted.

The foundation of yoga practice lies in the adoption and maintenance of specific body postures and its associated controlled breathing techniques. There are many different forms of yoga; however, all involve physical movement, breathing, and meditative exercises. One of the shortcomings of this literature is insufficient information about the yoga intervention and the proportion of time spent in the practice of each of these common elements. From the studies reviewed here, it appears that the breathing and meditative exercises (particularly: *pranayama* and *kapalabhati*) are consistently associated with improvements in performance on measures of cognition. The yogic breathing technique of *pranayama* involves a slow deep breath inspired with the predominant use of the abdominal musculature and the diaphragm. The breath is held momentarily in full inhalation within the limits of comfort and concludes with a slow and controlled exhalation. *Kapalabhati* is another breath regulation technique that is a part of Hatha yoga practice. It involves changing the rate and depth, of breathing by high-frequency breathing (i.e., approximately at 2.0 Hz) with forceful exhalation. Indeed, kapalabhati in Sanskrit translates to *kapala* = forehead, *bhati* = shining, which symbolically suggests that this practice stimulates the brain (66). Future work in the field needs to parse out the independent effects of each of these elements involved in the holistic practice of yoga.

Studies that have reported significant improvements in cognition have proposed a number of psychosocial and physiological mechanisms that may underlie the yoga - cognition relationship. Preliminary evidence suggests that yoga has a down regulating effect on both the sympathetic nervous system and the hypothalamic-pituitary adrenal (HPA) axis in response to stress (6). Stress, in general, may lead to anxiety and depression, involving chronic sympathetic activation and activation of HPA axis (67). Other analogous mind-body techniques, including mindfulness based stress reduction (68), transcendental meditation (69) and tai-chi (70) have been shown to elicit a similar relaxation response along the sympathetic nervous system and HPA axis activity. Anxiety remains is a critical moderator within the field of cognition because it is associated with adverse effects on two central executive functions involving attentional control: inhibition and set shifting (71). It is plausible that changes in stress-related physiological systems and mood may be among the mechanisms that lead to improved cognitive performance following yoga practice; however, this relationship has yet to be systematically examined within acute studies and RCTs.

In the physical activity-cognition literature, experiencing novel activities (72) and anaerobic interventions have been shown to have unique cognitive benefits on brain structure and function (73). From this neuroscientific perspective, tasks that involve mind wandering, memory consolidation, thought focused inwards to the self (self-referential thinking), and taking the perspective of others into one's own view of the world have been associated with the default mode network (DMN). This is a network of brain regions that are active when the individual is at rest but not focused on the outside world (74,75). There is evidence that supports a relationship between the default mode network and executive function, where increased DMN function has been associated with better working memory performance in young adults (76), and better performance on a range of executive function tasks in older adults (73, 77-79). The breathing and meditative practices of yoga largely parallel the self-referential thoughts and involve learning and consolidation functions that have been associated with the DMN. Future research should explore the structural and functional brain changes as a result of yoga in an effort to identify the neurobiological underpinnings of the yoga-cognition relationship. Although there are no definitive mechanisms studied in the yoga-cognition literature, these models provide a basis for future studies to examine mediators of the yoga-cognition relationship and further establish an evidence base in this area.

Given its simplicity and diverse forms, yoga is easily adaptable for most ages and clinical populations. The sample characteristics in this meta-analysis were diverse ranging from school children to healthy seniors and clinical but cognitively healthy populations. The low intensity and modifiable nature of this exercise maybe the reason why yoga has been primarily perceived as an adjunct therapy for clinical conditions which is evident from the large number of studies conducted with cancer patients (3), diabetics (5), patients with heart related conditions (80) and arthritis (81). Given the various modifiable forms of yoga and its suitability for individuals with different functional abilities, it appears to be a promising cost effective and feasible mode of activity to promote physical and psychological well-being in older adults. This is evident from the majority of RCTs in this meta-analysis that were conducted with healthy aging older adults. Its potential to sustain cognitive functions and ward off age related cognitive declines need to be fully explored. In spite of its growing popularity, yoga-related injuries have also come into the spotlight suggesting the need to exercise caution during yoga practice. An extensive survey conducted with 1336 yoga therapists, teachers and clinicians across 34 countries found that the most common yoga injuries related to poor technique or alignment, previous injury, excessive effort, and improper or inadequate instruction (82).

The current meta-analysis is challenged by several limitations. The study quality and methodologies differed within the RCTs and acute yoga studies. Different combinations of type, frequency and duration of yoga were employed making it difficult to arrive at an optimal recommendation of yoga for improving cognitive performance. The small number of studies also makes it difficult to conduct moderator analyses to examine effect sizes for different doses of yoga. A majority of the studies were conducted in India where researchers more consistently incorporated breathing and meditative protocols compared to other countries. The heterogeneity of cognitive measures and insufficient descriptions of the yoga interventions for replication are two major limitations that should be addressed in future work. CAM researchers not only need to focus on establishing the link between yoga and cognition, but also examine its effectiveness in comparison to traditional forms of exercise such as walking, cycling and strength training that have been extensively investigated for their cognitive benefits. It would be ideal to ascertain post yoga performance on cognitive tasks used in the physical activity literature and compare these traditional and non-traditional modalities. At the same time, researchers need to design adequate control groups that control for potential confounders such as social support and attention from research staff and yoga instructors. It is also possible that individuals practicing yoga may have unique outcome expectations that might influence their performance on cognitive tests. Future studies need to account for these factors and design appropriate attentional control groups.

Our findings are preliminary and should be confirmed through higher-quality randomized controlled trials and well-designed acute yoga studies. Research examining the benefits of physical activity has progressed to a point where neuroimaging techniques such as functional magnetic resonance imaging are employed to study cognition during task performance (83). In comparison to such state of art methodologies, much needs to be done in the field of yoga and cognition to thoroughly assess the generality or specificity of the cognitive benefits and investigate underlying mechanisms of this holistic mind-body practice. We hope that this meta-analysis will serve as a significant platform for researchers to review the past limitations, estimate sample sizes, design and implement sound yoga protocols and use established cognitive measures in future studies.

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Table 1.

Study characteristics of the Randomized Controlled Trials (RCTs) included in the meta-analysis

First Author (year)	Sample N (mean age ± sd)	Groups	Type of Yoga	Duration of Intervention	Cognitive Tests	Effect Size
Madden (1989)	Older adults N=85 (66.98 ± 4.5)	Aerobic n=25 Yoga n=28, Waitlist n=26	Not described	4 months, 2days/week, 60minutes/class	Letter search, Word comparison	APS: .15
Blumenthal (1989)	Older adults N=101 (67 ± 4.9)	Aerobic n=34 Yoga and Flexibility n=34 Waitlist n=34	Not described	4 months, 2days/week, 60minutes/class	Stroop, Verbal nonverbal fluency, Trail making B, WAIS - Digit Symbol, WAIS - Digit Span, Benton Visual Retention, Selective Reminding, Randt Memory, 2+7 Digits and Letters	APS: .25 EF: .07 MEM: .08
Manjunath (2001)	School girls N=20 (age range 10 -13 yrs.)	Yoga n=10 Physical Training n=10	Hatha Yoga	1 month, 7days/week, 75 minutes/class	Tower of London	EF: 1.17**
Oken (2004)	Multiple Sclerosis Patients N=69 (49 ± 9.2)	Yoga n=26 Stationary Bike n=21 Waitlist n=22	Iyengar Yoga	6 months, 1day/week, 90 min/week	Stroop, CERAD, Letter Number Sequencing, Simple and Choice RT, WCST, Useful Field of View, WAIS-similarities	APS: .06 EF: .10 MEM: .34
Oken (2006)	Healthy Seniors N=135 (72.1 ± 4.8)	Yoga n=44 Walking n=47 Waitlist n=44	Iyengar Yoga	6 months, 1day/week, 90 min/week	Stroop, CERAD, Letter Number Sequencing, Useful Vield of View, Covert Orienting, Simple and Choice RT, WCST	APS: .23 EF: .15 MEM: .06
Sharma (2006)	Adults with depression N=30 (31.77 ± 8.62)	Sahaj yoga n=15 Standard anti-depressant n=15	Sahaj Yoga	8 weeks, 3days/week, 30 minutes/class	Letter Cancellation, Trail making A & B, Ruff Figural Fluency, WAIS - Digit Span	APS: .21 EF: .04
Chattha (2008)	Peri-menopausal Women N=108 (48.5 ± 3.8)	Yoga n=59 Control n=61	Integrated Approach of Yoga Therapy	8 weeks, 5days/week, 60minutes/class	Six letter cancellation	APS: .77**
Velinkonja (2010)	Multiple Sclerosis Patients N=20 (age range 26-50	Yoga n=10 Sports Climbing n=10	Hatha Yoga	10 weeks, 1day/week Duration per class not	Neuropsychological assessment battery – Mazes test, Tower of London, Brickenkamp d2 test	APS: 1.14* EF: .07

	yrs.)			reported		
Chaya (2010)	School children N=200 (7.69 ± 0.88)	Yoga n=100 Physical Activity n=100	Hatha Yoga	3 months, 6days/week, 45 minutes/class	Malin's Intelligence Scale for Indian Children, Indian adaptation of WISC-II	APS: .098 EF: .05 MEM: .14
Bowden (2012)	Healthy adults N=35 (age not reported)	Iyengar Yoga n=9 Brain Wave Vibration n=12 Mindfulness n=12	Iyengar Yoga	5 weeks, 2days/week, 75 minutes/class	2-back	EF: .66
Bilderbeck (2013)	Prisoners N=167 (36.08± 12.14	Yoga n=45 Control n=55	Hatha Yoga	10 weeks, 1day/week, 120 minutes/class	Go/No-Go	EF: .39
Hariprasad (2013)	Older adults from resident homes (75.62 ± 6.91)	Yoga n=68 Waitlist n=58	Hatha Yoga	6 months total Month 1: supervised 60 minutes daily Month 2-3: supervised 60 minutes weekly Month 4-6: Unsupervised, home practice	Rey's Auditory Verbal Learning, Rey's complex figure, Digit and spatial span, Controlled Oral Word Association, Stroop, Trail Making A & B	APS: .48* EF: .47* MEM: .39
Telles (2013)	School children N=98 (10.5 ± 1.3)	Yoga n=49 Physical Exercise n=49	Hatha Yoga	3 months, 5days/week, 45 minutes/class	Stroop	APS: .07 EF: .11*
Gothe+ (2013)	Older adults N=118 (62.0 ± 5.6)	Yoga n=61 Stretching & Strengthening n=57	Hatha Yoga	8 weeks, 3days/week, 60 minutes/class	Attention Network, Trail Making A & B, Pattern Comparison	APS: .299 EF: .47
Gothe (2014)	Older adults N=118 (62.0 ± 5.6)	Yoga n=61 Stretching & Strengthening n=57	Hatha Yoga	8 weeks, 3days/week, 60 minutes/class	Task switching, N-back, Running Memory Span	EF: .31

Note: + Published abstract, *p<.05, **p<.001

WAIS = Wechsler's Adult Intelligence Scale, CERAD = Consortium to Establish a Registry for Alzheimer's Disease, RT = Reaction Time, WCST = Wisconsin Card Sorting Test, WISC = Wechsler's Intelligence Scale for Children, APS = Attention and Processing Speed, EF = Executive Function, MEM = Memory

Table 2.

Study characteristics of the acute yoga studies included in the meta-analysis

First Author (year)	Sample N (mean age ± sd)	Study design	Yoga Condition	Other Conditions	Duration of Yoga session	Cognitive Tests	Effect Size
Bhavanani (2003)	Male school children N=22 (14.5 ± 1.25)	Pre-post	Mukh Bhastrika (yogic breathing)	None	9 rounds of breathing	Auditory and Visual reaction time	APS: .63*
Telles (2008)	Young adults N=11 (20.9 ±2.3), Middle age N=48 (30-59), Older adults N=16 (60+)	Repeated Measures counterbalanced	Kapalabhati (yogic breathing)	Breathing Awareness	Duration not reported	Six Letter Cancellation	APS: .64*
Subramanya (2009)	Male adults N=57 (26.5 ± 4.6)	Repeated Measures counterbalanced	Cyclic Meditation	Supine Rest, Control	22.5 minutes	Digit-letter Substitution, Letter-copying, Circle-dotting	APS: 1.04*
Pradhan (2010)	School children N=208 (13.84±0.98)	Repeated Measures counterbalanced	Cyclic Meditation+ Hatha Yoga	Supine Rest	22.5 minutes	Six letter cancellation	APS: .05
Telles (2012)	Male army recruits N=160 (32.0 ± 6.35)	3 independent groups	Hatha Yoga	Meditation Music Control, Breathing Awareness	45 minutes	Digit-letter Substitution	APS: .06
Gothe+ (2012)	Female college students N=30 (20.07±1.95)	Repeated Measures counterbalanced	Hatha Yoga	Aerobic Exercise, Control	20 minutes	Word Memory	MEM: .78*
Gothe (2013)	Female college students N=30 (20.07±1.95)	Repeated Measures counterbalanced	Hatha Yoga	Aerobic Exercise, Control	20 minutes	Erikson's Flanker, N-back	APS: .17 EF: .39*

Note: +Published abstract, *p<.001

APS = Attention and Processing Speed, EF = Executive Function, MEM = Memory

Table 3.

Classification of the neurocognitive tests used in acute yoga studies and RCTs by cognitive domain

	Attention and Processing Speed	**Executive Function**	**Memory**
RCTs			
	Simple reaction time (2)	Stroop interference (3)	CERAD delayed recall (2)
	Choice reaction time (2)	WAIS letter number sequencing (2)	15-concrete noun word list easy/difficult (2)
	Six letter cancellation (3)	Wisconsin card sorting task (2)	Long term word recognition easy/difficult (2)
	WAIS digit symbol substitution (1)	WAIS similarities (1)	Benton visual retention test (1)
	Ruff 2 and 7 letters and digits (1)	Useful field of view (2)	Immediate story recall (1)
	Trail making – part A (2)	Attention network task - incongruent (1)	Selective reminding (2)
	Covert orienting spatial attention (1)	Verbal fluency (1)	Word comparison (1)
	Attention network task – congruent (1)	Non-verbal fluency (1)	Sternberg's memory search task (1)
	Pattern comparison (1)	Trail making – part B (3)	Rey's complex figure test (1)
	Brickenkamp d2 test (1)	WAIS forward/backward digit span (3)	
		N-back – 1 and 2 back AC (1)	
		Running memory span (1)	
		Task switching (1)	
		Ruff figural fluency (1)	
		Go/No-Go task (1)	
		Tower of London (1)	
		Controlled oral word association (1)	
		Mazes test (1)	
Acute studies			
	Erickson's Flanker – congruent (1)	Erikson's Flanker – incongruent (1)	Word Memory (1)
	N-back – 0 back reaction time (1)	N-back – 1 and 2 back reaction time (1)	
	Six letter cancellation (2)		
	Digit letter substitution (1)		
	Letter-copying (1)		
	Circle-dotting (1)		
	Auditory and visual RT (1)		

Note: The number in the parentheses indicates the number of studies that used the test, WAIS = Wechsler's Adult Intelligence Scale, CERAD = Consortium to Establish a Registry for Alzheimer's Disease, Malin's Intelligence Scale for Indian Children, an adaptation of WISC –II which spans attention and processing speed as well as executive function was also used in one study (Chaya 2010)

Table 4.

Study quality assessment for the RCTs

Study	Random Sampling	Appropriate Randomization	Blinding of Assessors	Withdrawals and Dropouts reported	Total Jadad score
Madden (1989)	Yes	Yes	NR	Yes	3/4
Blumenthal (1989)	Yes	Yes	NR	Yes	3/4
Manjunath (2001)	Yes	Yes	NR	NR	2/4
Oken (2004)	Yes	Yes	Yes*	Yes	4/4
Oken (2006)	Yes	Yes	Yes*	Yes	4/4
Sharma (2006)	No	Yes	NR	NR	1/4
Chattha (2008)	Yes	Yes	Yes^	Yes	4/4
Velinkonja (2010)	NR	Yes	Yes	NR	2/4
Chaya (2010)	Yes	Yes	Yes	Yes	4/4
Bowden (2012)	Yes	Yes	NR	Yes	3/4
Bilderbeck (2013)	Yes	Yes	NR	Yes	3/4
Hariprasad (2013)	Yes	No[#]	Yes	Yes	3/4
Telles (2013)	Yes	Yes	NR	No°	2/4
Gothe[+] (2013)	Yes	Yes	No	Yes	3/4
Gothe (2014)	Yes	Yes	No	Yes	3/4
				Mean (± SD)	**2.93** (±.88)

Note: NR=Not Reported

[+] Published abstract

[#] Limitation acknowledged by the authors: block randomization without accounting for baseline characteristics

*In spite of precautions, authors reported rare instances of un-blinding

^Assessor blinded only at baseline, pre-randomization

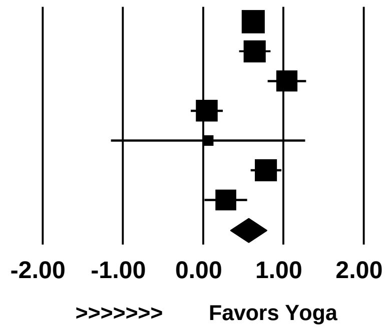
°Authors report the number of participants who ‘could not complete assessments’, withdrawals/dropouts not reported

Fig.1.
Overall effect of yoga on cognition for the 7 acute yoga studies.

Overall Effect Size (Acute studies)

Study name	Statistics for each study: Hedges's g	Standard error	p-Value
Bhavnani 2003	0.626	0.036	<.001
Telles 2008	0.644	0.101	<.001
Subramanya 2009	1.043	0.124	<.001
Pradhan 2010	0.045	0.104	0.665
Telles 2012	0.060	0.619	0.923
Gothe 2012*	0.782	0.100	<.001
Gothe 2013	0.283	0.137	0.039
	0.557	**0.114**	**<.001**

Hedges's g and 95% CI



Note: *Published Abstract

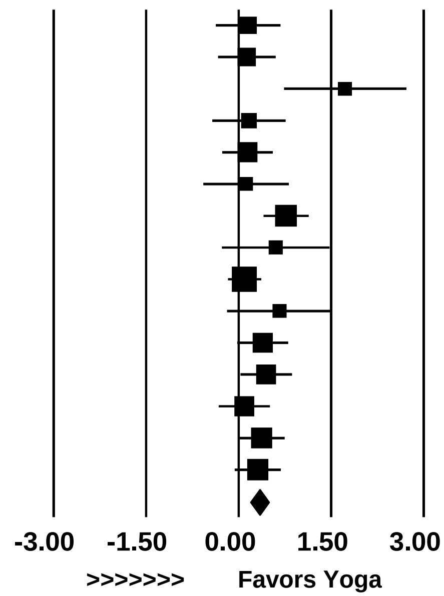
Fig. 2.
Overall effect size for the 15 RCTs.

Overall Effect Size (RCTs)

Study name	Hedges's g	Standard error	p-Value
Madden 1989	0.154	0.269	0.566
Blumenthal 1989	0.134	0.240	0.577
Manjunath 2001	1.724	0.508	0.001
Oken 2004	0.167	0.304	0.584
Oken 2006	0.143	0.212	0.500
Sharma 2006	0.121	0.356	0.734
Chattha 2008	0.769	0.188	<.001
Velinkonja 2010	0.603	0.447	0.177
Chaya 2010	0.096	0.141	0.498
Bowden 2012	0.664	0.436	0.127
Bilderbeck 2013	0.390	0.213	0.067
Hariprasad 2013	0.448	0.215	0.037
Telles 2013	0.093	0.214	0.663
Gothe 2013*	0.374	0.193	0.053
Gothe 2014	0.312	0.193	0.106
	0.329	**0.076**	**<.001**

Statistics for each study

Hedges's g and 95% CI



Note: *Published Abstract

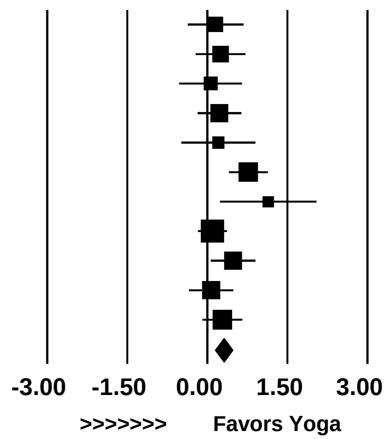
Fig. 3.

Effect of yoga on attention and processing speed (n =11). Individuals randomized to yoga group exhibited improved attention and processing speed relative to controls g=.299. Each study is denoted with a square, with larger sample sizes corresponding to larger marks.

Attention and Processing Speed

Study name	Hedges's g	Standard error	p-Value
Madden 1989	0.154	0.269	0.566
Blumenthal 1989	0.250	0.241	0.298
Oken 2004	0.063	0.303	0.835
Oken 2006	0.227	0.212	0.285
Sharma 2006	0.206	0.356	0.562
Chattha 2008	0.769	0.188	<.001
Velinkonja 2010	1.141	0.465	0.014
Chaya 2010	0.098	0.141	0.489
Hariprasad 2013	0.484	0.216	0.025
Telles 2013	0.072	0.214	0.737
Gothe 2013*	0.281	0.193	0.144
	0.299	**0.083**	**<.001**

Hedges's g and 95% CI



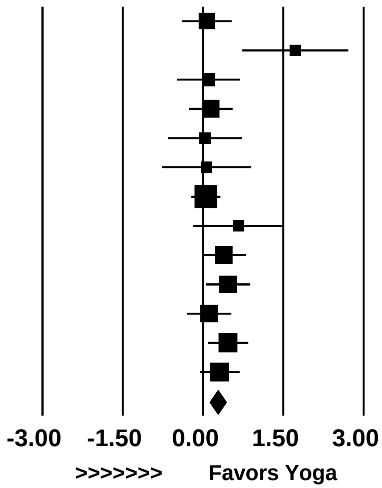
Note: *Published Abstract

Fig. 4.
Effect of yoga on executive function (n =13). Individuals randomized to yoga group exhibited improved executive function performance g=.267. Each study is denoted with a square, with larger sample sizes corresponding to larger marks.

Executive Function

Study name	Hedges's g	Standard error	p-Value
Blumenthal 1989	0.073	0.240	0.762
Manjunath 2001	1.724	0.508	0.001
Oken 2004	0.101	0.303	0.739
Oken 2006	0.145	0.212	0.494
Sharma 2006	0.035	0.355	0.921
Velinkonja 2010	0.065	0.428	0.880
Chaya 2010	0.053	0.141	0.706
Bowden 2012	0.664	0.436	0.127
Bilderbeck 2013	0.390	0.213	0.067
Hariprasad 2013	0.465	0.215	0.031
Telles 2013	0.114	0.214	0.593
Gothe 2013*	0.467	0.194	0.016
Gothe 2014	0.312	0.193	0.106
	0.267	**0.078**	**0.001**

Hedges's g and 95% CI



Note: *Published Abstract

Fig. 5.
Effect of yoga on memory (n =5). Individuals randomized to yoga group showed marginally significant improvements in memory performance g=.18. Each study is denoted with a square, with larger sample sizes corresponding to larger marks.

Memory

Study name	Statistics for each study		
	Hedges's g	Standard error	p-Value
Blumenthal 1989	0.078	0.240	0.744
Oken 2004	0.335	0.305	0.272
Oken 2006	0.057	0.211	0.787
Chaya 2010	0.136	0.141	0.335
Hariprasad 2013	0.394	0.215	0.066
	0.177	**0.090**	**0.051**

Hedges's g and 95% CI