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A Randomized Controlled Trial Examining the Effect of Mindfulness Meditation on Working Memory Capacity in Adolescents

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A B S T R A C T

Purpose: To investigate the effectiveness of a mindfulness meditation intervention on working memory capacity (WMC) in adolescents via a randomized controlled trial comparing mindfulness meditation to hatha yoga and a waitlist control group.
Methods: Participants (N = 198 adolescents) were recruited from a large public middle school in southwest United States and randomly assigned to mindfulness meditation, hatha yoga, or a waitlist control condition. Participants completed a computerized measure of WMC (Automated Operational Span Task) and self-report measures of perceived stress (Perceived Stress Scale) and anxiety (Screen for Childhood Anxiety Related Emotional Disorders) at preintervention and postintervention/waitlist. A series of mixed-design analyses of variance were used to examine changes in WMC, stress, and anxiety at preintervention and postintervention.
Results: Participants in the mindfulness meditation condition showed significant improvements in WMC, whereas those in the hatha yoga and waitlist control groups did not. No statistically significant between-group differences were found for stress or anxiety.
Conclusions: This is the first study to provide support for the benefits of short-term mindfulness practice, specifically mindfulness meditation, in improving WMC in adolescents. Results highlight the importance of investigating the components of mindfulness-based interventions among adolescents given that such interventions may improve cognitive function. More broadly, mindfulness interventions may be delivered in an abridged format, thus increasing their potential for integration into school settings and into existing treatment protocols.

IMPLICATIONS AND CONTRIBUTION

This study demonstrates a significant effect of mindfulness meditation on working memory capacity in adolescents. Mindfulness interventions may be feasibly abridged, while still delivering important benefits.

In the last decade, mindfulness research in youth has grown rapidly. Mindfulness involves directing attention to the present-moment experience in a nonjudgmental and accepting way [1]. Mindfulness is often recognized as a "practice" or "training," requiring a constant shift from an "automatic pilot" mindset to one that comprises attention and awareness [2].

The term *mindfulness* has been applied to numerous interventions, including multicomponent interventions such as Mindfulness-Based Stress Reduction (MBSR) [1], and to particular forms of mindfulness practice (e.g., mindfulness meditation). In general, mindfulness-based interventions have been shown to be effective in producing beneficial effects on physical and psychological functioning, particularly in adults. Although the methodological rigor of many treatment studies with youth

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remains questionable [2–4], the existing body of research suggests that mindfulness training may be feasibly adapted for use with adolescents in medical and community-based samples. Furthermore, mindfulness interventions have demonstrated beneficial effects on general well-being and physical health among adolescents [4–10].

Although the global benefits of mindfulness on physical and psychological functioning are encouraging, as researchers emphasize the positive outcomes of mindfulness interventions, it is imperative to begin identifying whether *specific* benefits may be uniquely associated with particular forms of mindfulness practice. One specific benefit of mindfulness training that has been explored exclusively in adult samples is the effect of mindfulness meditation on working memory. A growing number of neurologic studies have documented that mindfulness practices have been associated with changes in neural pathways [11–13]. Neurologic changes in the structure of the brain may affect specific cognitive functions such as attention and memory. Research has shown that mindfulness exercises, specifically mindfulness meditation, have a direct effect on higher-order cognitive processes, such as executive functioning [14,15]. There has been particular interest in the impact of mindfulness on working memory because both constructs require moment-to-moment awareness [16]. Working memory is a mental workbench that allows an individual to hold information in awareness long enough for reasoning and comprehension to occur [16]. This cognitive function helps the brain shift information from short-term memory to long-term memory. Working memory also impacts performance on other higher-level cognitive tasks such as reasoning, comprehension, and executive functioning [16].

The adult literature suggests that mindfulness meditation may be used as a tool to enhance working memory capacity (WMC) [17–20]. WMC is implicated in processes such as reasoning ability, mathematical problem solving, language, and reading comprehension, and many other aspects of learning [21,22]. Recent studies suggest that even brief mindfulness meditation training may improve WMC, mind wandering, and standardized test scores in nonclinical and college student samples [19,20]. To date, however, the effectiveness of mindfulness training in improving WMC among adolescents has not been examined, although it would follow that strengthening WMC would be especially valuable during the developmental stage of adolescence, where the majority of the day is spent in an educational setting. Although school-based mindfulness interventions have been conducted [23,24], the incorporation of mindfulness practice in schools is inextricably linked to the availability of adequate resources. Briefly, low-cost programs integrated into existing curricula are likely to be the most feasible, particularly in schools with limited resources. [23].

The present study

The primary objective of this randomized controlled trial was to examine the impact of mindfulness meditation on WMC in adolescents. Based on previous research, we hypothesized that mindfulness meditation would result in significantly greater improvement in WMC compared to a hatha yoga intervention or a waitlist control condition. We chose to compare mindfulness meditation to hatha yoga given that both are formal mindfulness practices used in mindfulness-based interventions (e.g., MBSR [1]). Although theoretically similar in terms of their ability to enhance awareness of the present-moment, theoretical and experimental research suggests that mindfulness meditation may be particularly effective in promoting executive functioning [17,20]. By comparing mindfulness meditation to hatha yoga, a potentially important *unique* benefit of mindfulness meditation may be revealed. Given the proposed broad psychological benefits of mindfulness practice, our secondary aim was to examine the effectiveness of mindfulness meditation and hatha yoga on perceived stress [25] and anxiety [26]. We hypothesized that adolescents in both the mindfulness meditation and hatha yoga groups would report significantly lower levels of stress and anxiety and greater mindfulness at postintervention compared to the waitlist control group.

Methods

Participants

The clinical trial was approved by the Alliant International University institutional review board and was conducted at a large public junior high school in southern California between March 2013 and July 2013. The school consisted of students who were predominately from low-income minority households. About 80 percent of students were eligible for a free or reduced lunch. All parents or legal guardians provided written informed consent and youth provided assent. Inclusion criteria were (1) current school enrollment, (2) current age between 12 and 17 years, (3) English speaking, and (4) ability to attend weekly study sessions. Exclusion criteria were (1) hearing impairments, (2) injuries, or (3) physical disabilities that would hinder full participation in either intervention.

Study design and interventions

Participants completed a baseline assessment that included all study measures (see *Measures*). Participants were then randomly assigned to mindfulness meditation, hatha yoga, or a waitlist control condition. Participants in both intervention groups (mindfulness meditation and hatha yoga) met a total of eight times: twice weekly for 4 weeks. Each intervention session lasted 45 minutes, resulting in a total of approximately 6 hours of intervention time. Daily home practice was monitored through a written home practice log that was collected once a week during the intervention. Each intervention group comprised 10–13 participants. Both intervention arms were delivered during participants' physical education (PE) class periods. The sitting meditation intervention was held in the school's library, whereas the hatha yoga intervention was held in the school's gym. The waitlist control group attended regular PE classes. After the 4-week intervention period, all participants completed post-intervention/postwaitlist measures. Waitlist control participants were then randomly assigned to receive the mindfulness meditation or hatha yoga intervention.

Mindfulness meditation intervention. Two female instructors with extensive training in mindfulness meditation facilitated the mindfulness meditation groups. Both instructors completed mindfulness-based training programs (i.e., Mindfulness Based Cognitive Therapy, MBSR) at various workshops and retreats, while maintaining their own personal practice. The instructors each had between 5 and 10 years of meditation experience. The curriculum was based on the MBSR program developed by

Jon Kabat-Zinn [1]. Developmentally appropriate modifications included minor wording changes, shortening the session timeframe to fit the academic school schedule, and incorporating incentives for participation. To ensure intervention fidelity, instructors followed a mindfulness meditation curriculum and schedule. A researcher periodically attended sessions to verify that the intervention was being implemented with minimal variability.

Each mindfulness meditation session consisted of (1) breathing techniques, (2) formal meditation, and (3) discussion. Participants learned new types of mindfulness meditation each week (Week 1, Breathing; Week 2, Being in the Body and Feelings; Week 3, Awareness and Leaves on a Stream; Week 4, Silent and Loving Kindness). Instructors were provided written scripts to help guide each of the weekly mindfulness themes (e.g., Being in the Body Meditation). Instructions on sitting posture, breathing, and wandering thoughts were repeated during each session. Each intervention session concluded with an instructor-led group discussion. Participants received a CD of meditation audio recordings to enable home practice. Participants were encouraged to practice meditation daily for 15–30 minutes and to record details of their practice in home practice logs.

Hatha yoga intervention. Two female yoga instructors trained in teaching child and adolescent yoga facilitated the hatha yoga groups. Both instructors were 200-hour yoga teacher training certified. The instructors each had practiced yoga for 6–10 years and maintained their own yoga practice while also teaching in private studios in the community. The hatha yoga curriculum was used with permission from Shanti Generation Yoga (2009). Hatha yoga sessions consisted of (1) breathing techniques, (2) yoga poses, and (3) discussion. Participants learned a series of new yoga poses each week and reviewed old poses (Week 1, Creating Happiness: Forward bends for flexibility; Week 2, Energy Amplified: Balancing and core strengthening postures; Week 3, Choosing Peace: Standing poses, backbends, and forward bends; Week 4, Being Sound: Twist, bend, and relax; and Voice Choice Possibility: Breathe, visualize, and move). Yoga poses included a series of mindful movements that required bending, stretching, and holding to increase muscle tone and flexibility. Yoga poses were used as tools to elicit moment-to-moment awareness. With each pose, adolescents practiced noticing without judgment the different sensations that arose in their mind and body. They were instructed to observe their thoughts, feelings, and mood as they transitioned into different postures. Instructors also encouraged participants to pay attention to their body language, facial expressions, and attitude to help them tune-in to their daily reactions. Participants received a DVD containing yoga lessons corresponding to the poses taught in the intervention. Participants were encouraged to practice yoga daily for 15–30 minutes and to record their practice in home practice logs.

Measures

Demographic data. Brief demographic questionnaires were completed by participants and their parents to obtain background information including age, gender, grade level, race/ethnicity, socioeconomic status, and extracurricular activities.

Automated Operation Span Task. The Automated Operation Span Task (AOSPAN) [27] is a computerized task used to measure WMC that comprises 15 sets of trials, each containing two simultaneous tasks: performing a memory task while answering math equations. In the memory section, participants were presented a series of letters appearing one at a time for 800 ms. Participants were asked to recall letters in the same order they were presented by clicking the box next to the appropriate letters in correct order. In the math portion of the task, math equations were presented in sets of simple questions such as "$(1 \times 2) + 1 = ?$)." After solving the problem, participants were then asked to click to the next screen where a potential answer, such as "3" was presented. Participants clicked on the "true" or "false" box. There were 75 letters to recall and 75 math equations to solve. Although five scores were calculated, the OSPAN score was used as it is the most commonly used index of WMC [28]. It is the sum of all recalled letters from letter sets that were recalled completely in the correct order. OSPAN scores have shown acceptable internal consistency ($\alpha = .78$) and good test–retest reliability in nonclinical samples. This task has been used extensively in working memory research, and it has been shown to be appropriate for use with children and adolescents. [29].

Perceived Stress Scale 10. The Perceived Stress Scale 10 (PSS-10) [30] is a 10-item measure that examines perceived stressful situations that may occur in daily life. All questions are rated on a five-point Likert scale, ranging from 0 (never) to 4 (very often) to assess how respondents felt during the past month. Overall scores range from 0 to 40, with higher scores indicating greater perceived stress. The PSS-10 has been used with diverse adolescent samples to examine perceptions of stress and has exhibited good internal consistency [31] ($\alpha = .82$). In the present study, internal consistency ($\alpha = .63$) was lower than what has been previously reported. After omitting scores for 23 participants who endorsed the same response option for all items[1], scores from the remaining participants ($n = 149$) showed acceptable internal consistency ($\alpha = .71$).

Screen for Child Anxiety and Related Emotional Disorders. The Screen for Child Anxiety and Related Emotional Disorders (SCARED) [32] is a 41-item self-report anxiety measure designed for youth ages 8–18 years. The SCARED parallels the five types of anxiety disorders described in the DSM-IV: generalized anxiety, social phobia, separation anxiety, panic disorder, and school phobia. Higher total scores indicate higher levels of anxiety and worry. Respondents use a three-point Likert scale: 0 (not true), 1 (sometimes true), or 2 (often true) after reading statements such as "I worry about other people liking me." The SCARED has shown good psychometric properties in clinical and nonclinical youth samples. [33] In the present study, the SCARED Cronbach $\alpha = .93$.[2]

[1] The 23 participants demonstrating an invalid response pattern (i.e., the same response option was chosen for every item) on the PSS-10 were excluded from analyses involving the PSS-10. However, these participants were not excluded from analyses involving the AOSPAN as it was not subject to self-report response biases. An independent t test found no significant differences in OSPAN scores between those with an invalid PSS-10 and the remaining participants ($p = .86$), suggesting that those with invalid PSS-10 scores did not score differently than other participants on the AOSPAN task.

[2] Less than 5% of cases were missing data on the SCARED. Missing data were examined using listwise deletion methods in SPSS to determine if data were missing at random (MAR) or not missing at random (NMAR). The data was MAR; therefore, mean imputation was used to replace single missing item values. Scale means were computed for each participant using the mean of all other available item scores for that participant.

Child Acceptance and Mindfulness Measure. The Child Acceptance and Mindfulness Measure (CAMM) [34] is a 25-item self-report measure that assesses the degree to which respondents observe internal experiences, act with awareness, and accept internal experiences in a nonjudgmental manner. A five-point Likert scale ranging from 0 (never true) to 4 (always true) is used in response to items such as "I try only to think about things that makes me feel happy." Total scores range from 0 to 100. Higher scores indicate greater levels of acceptance and mindfulness. The CAMM has demonstrated good internal consistency previously [34]; however, in the present study, it was extremely low ($\alpha = .33$). Nineteen participants endorsed the same response option throughout the entire measure. Despite excluding these scores, the scores from the remaining participants (n = 150) yielded unacceptably low internal consistency ($\alpha = .41$).

Data analysis

Analyses were completed using SPSS Statistics for Windows Version 20.0 (IBM Corp., Armonk, NY). A mixed-design analysis of variance was used to examine changes in WMC, as measured by OSPAN scores, between three conditions (mindfulness meditation, hatha yoga, waitlist control) from preintervention to postintervention. Mixed-design analyses of variance were also used to compare PSS-10 and SCARED scores among the three groups from pre intervention to postintervention. The CAMM was eliminated from further statistical analyses because of poor reliability ($\alpha = .41$). A Bonferroni correction was applied to reduce the chance of a type 1 error. The number of hypothesized comparisons was 3; thus, α was adjusted to .016 (α/n). A power analysis (using G*Power) indicated that an estimated total sample size of 120 participants was needed to achieve 80% power and a medium effect size of .05.

Results

Participant characteristics

One hundred ninety-eight adolescents completed the study. Figure 1 illustrates the flow of participants through the trial. Four hundred and twenty students received information about the study. However, because of space and study personnel limitations, only the first 30 to 35 students in each of the PE class periods who turned in their assent/consent forms were able to participate. Twelve participants (4.7%) dropped out after completing baseline measures, resulting in 186 participants being randomly assigned to mindfulness meditation, hatha yoga, or waitlist control. Participants who (1) completed both baseline and postintervention measures and (2) attended six or more mindfulness sessions (75% of the intervention) were deemed study completers and included in statistical analyses (N = 172). At baseline, no significant differences were found between those who dropped out after completing baseline measures, those who attended fewer than six sessions, and those who completed six or more sessions (OSPAN, $F(2,197) = 2.7$, $p = .07$; PSS, $F(2,192) = .4$, $p = .70$; SCARED, $F(2,185) = 2.39$, $p = .10$).

Demographic characteristics for the 198 participants appear in Table 1. Participants were primarily female (62%) ranging in age from 12 to 15 years (mean age = 13.18, SD = .72). Most participants were Hispanic and had little or no experience with any mindfulness practices.

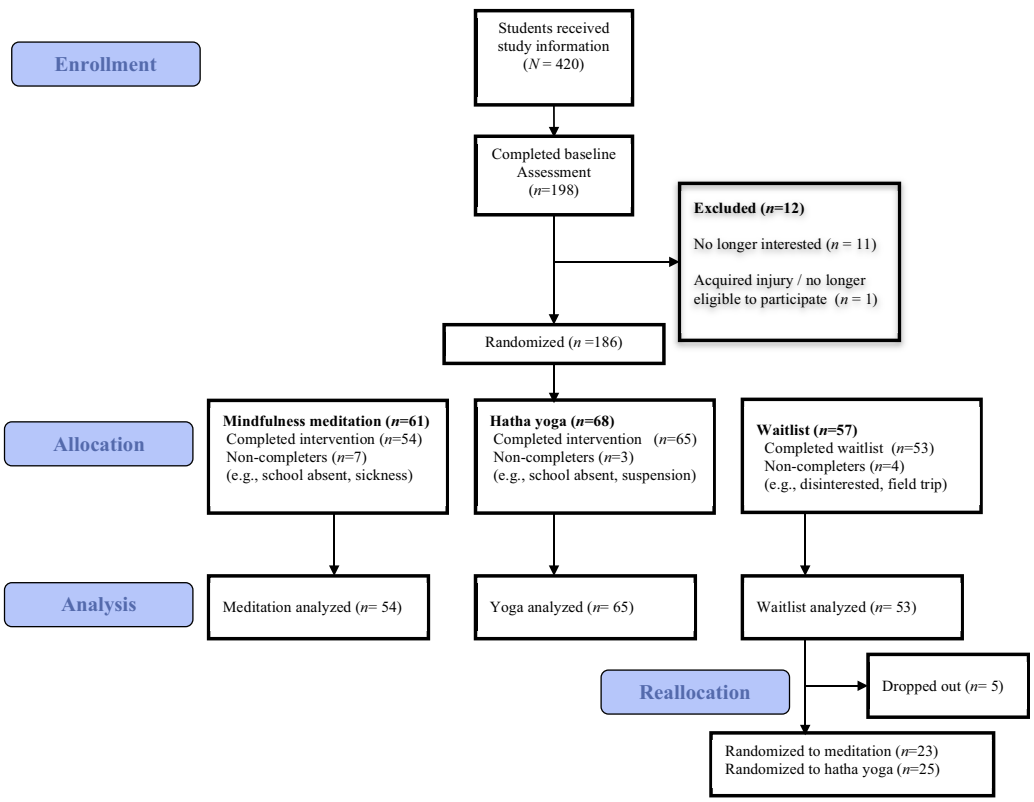

Figure 1. Participant flowchart.

Table 1
Demographic characteristics of the study sample

Characteristic	Meditation group (n = 54)	Hatha yoga group (n = 65)	Waitlist group (n = 53)
Gender			
Female	83.3 (n =45)	63.1 (n = 41)	52.8 (n = 28)
Male	16.7 (n = 9)	36.9 (n = 24)	47.2 (n = 25)
Race/ethnicity			
Spanish/Hispanic/Latino	72.2 (n = 39)	67.7 (n = 44)	56.5 (n = 30)
Asian or Pacific Islander	14.8 (n = 8)	21.5 (n = 14)	24.5 (n = 13)
Biracial	3.7 (n = 2)	7.7 (n = 5)	11.3 (n = 6)
Caucasian	0 (n = 0)	1.5 (n = 1)	1.9 (n = 1)
African-American	1.9 (n = 1)	1.5 (n = 1)	0 (n = 0)
Native American	5.6 (n = 3)	0 (n = 0)	3.8 (n = 2)
Other	1.9 (n = 1)	0 (n = 0)	1.9 (n = 1)
Grade			
Seventh grade	38.9 (n = 21)	44.6 (n = 29)	49.1 (n = 26)
Eighth grade	61.1 (n = 33)	53.8 (n = 35)	50.9 (n = 27)
Ninth grade	0 (n = 0)	1.5 (n = 1)	0 (n = 0)
Period			
Second period	11.1 (n = 6)	23.1 (n = 15)	0 (n = 0)
Third period	16.7 (n = 9)	12.3 (n = 8)	28.3 (n = 15)
Fourth period	14.8 (n = 8)	13.8 (n = 9)	26.4 (n = 14)
Fifth period	13.0 (n = 7)	20.0 (n = 13)	20.8 (n = 11)
Sixth period	22.2 (n = 12)	9.2 (n = 6)	24.5 (n = 13)
Seventh period	22.2 (n = 12)	21.5 (n = 14)	0 (n = 0)
Previous meditation experience			
Never tried	44.4 (n = 24)	49.2 (n = 32)	34.0 (n = 18)
Tried once or twice	44.4 (n = 24)	38.5 (n = 25)	52.8 (n = 28)
Practice a few times a year	5.6 (n = 3)	4.6 (n = 3)	7.5 (n = 4)
Practice a few times a month	1.9 (n = 1)	1.5 (n = 1)	0 (n = 0)
Practice once a week	1.9 (n = 1)	1.5 (n = 1)	3.8 (n = 2)
Practice few times a week	1.9 (n = 1)	3.1 (n = 2)	1.9 (n = 1)
Practice daily	0 (n = 0)	1.5 (n = 1)	0 (n = 0)
Previous yoga experience			
Never tried	55.6 (n = 30)	53.8 (n = 35)	47.2 (n = 25)
Tried once or twice	40.7 (n = 22)	36.9 (n = 24)	45.3 (n = 24)
Practice a few times a year	1.9 (n = 1)	4.6 (n = 3)	3.8 (n = 2)
Practice a few times a month	1.9 (n = 1)	3.1 (n = 2)	1.9 (n = 1)
Practice once a week	0 (n = 0)	0 (n = 0)	1.9 (n = 1)
Practice a few times a week	0 (n = 0)	1.5 (n = 1)	0 (n = 0)
Practice daily	0 (n = 0)	0 (n = 0)	0 (n = 0)
Extracurricular activities			
No activities	57.4 (n = 31)	33.8 (n =22)	30.2 (n = 16)
1–2 Activities	40.8 (n = 22)	53.9 (n = 35)	56.6 (n = 30)
3–4 Activities	1.9 (n = 1)	12.3 (n = 8)	13.2 (n = 7)

Data is reported as percentages. One-way analyses of variance (ANOVAs) and chi-square analyses were conducted to determine if randomization produced three equivalent groups with regard to demographic information. There were no significant between-group differences in age, $F(2,171) = .81$, $p = .45$; grade $F(2,171) = .54$, $p = .59$; class period, $F(2,171) = .30$, $p = .29$; or race, $F(2,171) = 2.0$, $p = .15$. Similarly, no significant between-group differences were found with regard to previous yoga experience ($p = .54$) or previous mindfulness meditation experience ($p = .79$). There was a significant between-group difference in the number of reported extracurricular activities, $F(2,171) = 4.40$, $p = .02$. The mindfulness meditation group reported less participation in extracurricular activities compared to the hatha yoga and waitlist control groups. No statistically significant differences were found on any outcome variables when using a series of ANOVAs, suggesting that involvement in extracurricular activities was unlikely to be a confound. There was also a significant between-group difference in gender ($p = .003$). There were significantly fewer male participants in the mindfulness meditation group (n = 9 of 54, 16.7%) compared to the hatha yoga group (n = 24 of 65, 36.9%). Independent samples *t* tests were conducted to see if there were statistically significant gender differences on the dependent variables. No statistically significant differences were found on the PSS-10 or SCARED, suggesting that gender was unlikely to be a confound.

Outcomes

The primary study hypothesis was that the mindfulness meditation group would show significantly greater improvement in WMC compared to the hatha yoga and waitlist control conditions at postintervention. There was a significant time by group interaction, $F(2,160) = 4.77$, $p = .01$, $\eta_p^2 = .04$. A simple effects procedure was then conducted to determine the specific interaction effect and test the separate group conditions for significance. Results indicated that the mindfulness meditation group reported significant pre–post improvements in WMC, $F(1,50) = 15.71$, $p < .001$, $\eta_p^2 = .24$, whereas participants in the hatha yoga and waitlist control groups did not [hatha yoga: $F(1,59) = 3.85$, $p = .11$, $\eta_p^2 = .04$, waitlist: $F(1, 51) = .50$, $p = .46$, $\eta_p^2 = .01$; Figure 2]. Hypothesis 1 was supported, suggesting that mindfulness meditation was more effective in improving WMC than hatha yoga.

The secondary hypothesis was that the mindfulness meditation and hatha yoga groups would report significantly lower levels of stress and anxiety at postintervention compared to the waitlist control group. Differences in PSS-10 scores among the three groups preintervention to postintervention did not show a significant condition by time interaction effect, $F(2,143) = 1.53$, $p = .22$, $\eta_p^2 = .02$. There was a significant main effect for time, $F(1,143) = 7.10$, $p = .01$, $\eta_p^2 = .05$, with all three groups showing a reduction in perceived stress from preintervention to postintervention. The main effect of group was not significant, $F(2,143) = .01$, $p = .99$, $\eta_p^2 = .00$.

Similarly, differences in SCARED scores among the three groups from preintervention to postintervention did not show a significant condition by time interaction effect, $F(2,159) = .22$, $p = .80$, $\eta_p^2 = .00$. There was a significant main effect for time, $F(1,159) = 15.73$, $p < .001$, $\eta_p^2 = .09$, with all three groups showing a reduction in anxiety from preintervention to postintervention. The main effect of group was not significant, $F(2,159) = .18$, $p = .84$, $\eta_p^2 = .00$. Hypothesis 2 was not supported, suggesting that mindfulness meditation and hatha yoga were not significantly different in their ability to reduce stress or anxiety. Means, standard deviations, and within-group pre–post effect sizes are presented in Table 2.

Discussion

The primary purpose of this randomized controlled trial was to evaluate the effectiveness of mindfulness meditation on WMC in adolescents. The broader goal was to advance our understanding of the potential benefits of mindfulness practice among adolescents. We hypothesized that mindfulness meditation training would result in greater improvement in WMC compared to hatha yoga and a waitlist control condition. This hypothesis was supported. Results revealed a significant increase in WMC for participants in the meditation group, whereas those in the hatha yoga and waitlist control groups did not exhibit significant changes. These findings suggest that mindfulness meditation may be an effective approach for improving WMC in adolescents, which, to date, has only been investigated in adults [17–20]. These results are consistent with the notion that the practice of meditation—which requires *sustained attention* while simultaneously *redirecting* attention back to the current experience—is closely related to the function of working memory [35].

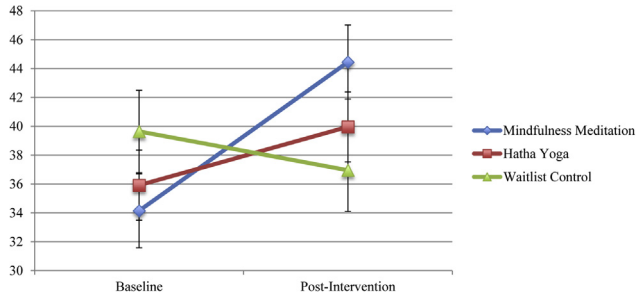

Figure 2. Changes in working memory capacity (Operational Span Task) by group (mindfulness meditation, hatha yoga, waitlist control) from baseline to postintervention. Error bars represent one standard error above and below the mean.

Although mindfulness invariably involves directing attention to the present moment, mindfulness is complex and can be practiced in myriad ways. Such complexity allows for the possibility that certain mindfulness practices may be uniquely associated with aspects of cognitive functioning and physical health [1,36]. Thus, although the present study's findings suggest that mindfulness meditation may be particularly effective in strengthening WMC, practices that cultivate mindfulness in other ways (e.g., through mindful movement) likely afford their own distinctive benefits. For example, hatha yoga requires different physical involvements than sitting meditation. Research suggests that regular hatha yoga practice is associated with improved musculoskeletal strength and flexibility [1,37]. However, to our knowledge, no studies have investigated the impact of hatha yoga on WMC specifically or cognitive functioning more broadly. Finally, although present findings suggest that mindfulness meditation more effectively promotes WMC, it is also conceivable that learning to practice yoga *mindfully* was challenging for adolescents, but if done so mindfully, yoga may confer similar benefits to WMC.

The secondary hypothesis was that adolescents receiving mindfulness training (either meditation or hatha yoga) would report lower levels of stress and anxiety at postintervention compared to waitlist controls. This hypothesis was not supported. Rather all three groups showed significantly reduced stress and anxiety postintervention. This challenges conclusions drawn in several uncontrolled studies reporting the benefits of mindfulness techniques to decrease stress and anxiety [38]. Because the present study included a waitlist control group, it is clear that such decreases in stress and anxiety cannot be solely attributed to the "active ingredients" of mindfulness interventions.

One potential explanation for the nonsignificant results pertaining to perceived stress may be the low internal consistency on the PSS-10. Although the PSS-10 has exhibited reliability in previous studies, the majority of research was conducted with adult samples. In the present study, participants were adolescents from primarily ethnic minority backgrounds. Patterns of inconsistent responding on the PSS-10 were mainly (74%) found among Hispanic participants. As approximately 25% of participants' parents preferred completing study forms in Spanish, language barriers may have influenced participants' completion of self-report measures. Although data from inconsistent responders were excluded from analyses, results from the PSS-10 should be interpreted with caution.

Another possible reason for the lack of group differences on stress and anxiety measures may be attributable to using a community, rather than clinical sample. Past research has found significant improvements in levels of perceived stress and anxiety with clinical samples [4,5]; these measures are likely not as sensitive in a community sample. The present study included adolescents who scored similarly on the PSS ($M = 19.28$) to other community samples [39]. Likewise, approximately half (53%) of participants in this study scored within the normal range on the SCARED. Thus, although it seems promising that moderate or high levels of stress and anxiety may be reduced through mindfulness training [5], individuals whose level of distress is within the normal range may show less improvement [10], which is consistent with the small (hatha yoga) to medium (mindfulness meditation) pre–post effect sizes found in the present study [9]. It may also be that more intervention sessions were needed to show greater benefit.

It was initially hypothesized that participants in the mindfulness meditation and hatha yoga groups would report greater levels of mindfulness postintervention compared to waitlist controls. This could not be tested due to the unacceptable internal consistency ($\alpha = .41$) of the CAMM. Problems with reliability may be partially explained by the inconsistent response patterns (e.g., acquiescence bias) evidenced by a subset of participants. Additionally, mindfulness is a complex,

Table 2
Descriptive statistics of dependent variables by group condition at baseline and postintervention

Group	Variable	Baseline					Post-intervention					*d*
		n	M	SD	Min	Max	n	M	SD	Min	Max	
Meditation	AOSPAN	54	34.15	18.74	.00	75.00	51	44.45	18.91	3.00	72.00	−.55
	PSS	48	20.13	5.30	9.00	33.00	46	17.41	5.05	5.00	30.00	.52
	SCARED	53	22.96	14.11	2.00	69.00	51	20.15	13.82	3.00	59.00	.20
Hatha yoga	AOSPAN	65	35.92	19.62	.00	75.00	60	39.96	21.05	.00	75.00	−.20
	PSS	58	19.22	5.36	10.00	31.00	57	18.19	5.82	5.00	33.00	.18
	SCARED	62	23.80	15.03	.00	53.00	61	21.10	13.14	.00	47.00	.19
Waitlist control	AOSPAN	53	39.64	20.77	.00	75.00	52	36.96	20.60	.00	75.00	.13
	PSS	43	18.88	6.35	7.00	33.00	43	18.47	6.15	2.00	32.00	.06
	SCARED	50	23.70	14.56	.00	64.00	50	20.60	13.10	.00	47.00	.22

AOSPAN = Automated Operational Span Task; *d* = Cohen's *d* for within-group pre-post effect sizes; M = mean; Min = minimum score; Max = maximum score; n = number; PSS = Perceived Stress Scale; SCARED = Screen for Childhood Anxiety Related Emotional Disorders; SD = standard deviation.
Some participants did not complete all study measures. Nine participants skipped the AOSPAN at postintervention. Three participants did not complete the SCARED at postintervention. In addressing measures that were not completed in their entirety (i.e., whole measure), sample size was sufficient to use case pairwise deletion. This option excluded cases only if they were missing the data required for the specific analysis. The cases were still included in the analysis for which they had the necessary information; thus, there are different sample sizes (n) among the various analyses.

abstract construct that may be challenging to capture in a self-report measure. Thus, adolescents may have had difficulty understanding and responding to CAMM items. Studies have generally found the CAMM to display adequate reliability, and it is considered a developmentally appropriate measure for adolescents [34]. However, research has been conducted with predominately Caucasian youth [34]. The present findings suggest that the crosscultural generalizability of the psychometric properties of the CAMM should be further investigated.

Limitations and directions for future research

The present study is the first to date to explore the effectiveness of mindfulness interventions on working memory in adolescents. As the present study was conducted with an adolescent sample attending a public school in a lower–socioeconomic status (SES) neighborhood, intervention effects may not generalize to samples in other settings. Research has shown that lower-SES students score significantly lower than their higher-SES counterparts on tests of language, working memory, and executive functioning [40]. Given the relationship between WMC and broader executive functioning, which is integral to learning, improvement in this area may benefit adolescents from disadvantaged backgrounds. In general, future work should examine mindfulness meditation with diverse populations in terms of ethnicity, age, SES, geographic location, and other demographic variables.

The timing of the intervention may have introduced a source of error. This study took place near the end of the academic school year. Students may have experienced a general decrease in stress and anxiety as they approached summer break. This may have contributed to the general reduction in stress and anxiety seen across all participants. Future studies need to examine whether differences in intervention effectiveness are seen at different times of the academic year.

It may be beneficial to further investigate whether enhancements in WMC are associated with improvements in overall academic performance to further evidence improvements in cognitive functioning. Investigations of a broader range of school-related outcomes would be helpful in understanding whether gains from sitting meditation translate into improvements in academic performance or school functioning more broadly. Similarly, future research may also benefit from administering additional performance-based tasks, such as the N-back or Stroop task, to more fully evaluate the impact of mindfulness interventions on WMC and other neuropsychological functions.

Despite the growing literature on mindfulness in adolescents, this is the first study to provide support for the benefits of short-term mindfulness practice, specifically mindfulness meditation, in improving WMC in adolescents. It is essential to continue the improvement, implementation, and empirical examination of mindfulness practices to improve our understanding of their usage and clinical utility.

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