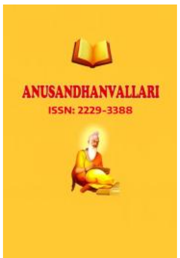

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The Impact of Gayatri Mantra Chanting on Sustained Attention and Reaction Time in Preadolescents: A Randomized Controlled Trial

[1]Deepanshu Sharma, [2]Dr. Jyoti Kanoujiya
[1,2]Department of Psychology, Lovely Professional University

Abstract Background: Sustained attention and rapid information processing are foundational cognitive capacities whose development during preadolescence has lifelong implications. Rigorously controlled trials of Vedic mantra chanting in school-age children remain scarce. Objective: To determine whether an eight-week structured Gayatri Mantra chanting programme improves sustained attention, mean reaction time (RT), and RT intraindividual variability (IIV) in preadolescents aged 8–12 years compared with standard school activities.

Method: Parallel-group, single-blind RCT (CTRI/2023/12/078432) at three New Delhi schools. 150 participants (M age = 10.3 years) were randomized to the Intervention Group (IG; n=75; 20 min/day, 5 days/week) or Control Group (CG; n=75; standard assembly). Primary outcomes – sustained attention (Test of Variables of Attention [TOVA] d-prime), RT mean, and RT IIV – were assessed at baseline, Week 4, and Week 8 by blinded evaluators.

Results: 143 participants completed the trial (attrition=4.7%). Repeated-measures ANOVA showed significant Group×Time interactions for all outcomes ($F=61.4$–97.6, all $p<.001$, $\eta^2p=0.29$– 0.40). Post-test between-group effects were large ($d=0.95$–1.42). Attention gain correlated strongly with faster RT ($r=-.73$, $p<.001$). All false-discovery-rate (FDR) corrected q-values <.001. Conclusions: These findings provide proof-of-concept evidence that structured Gayatri Mantra chanting was associated with greater improvements in attention and RT than standard activities. Effects were observed in a passive-control design; attribution specifically to the mantra requires replication with active controls.

Keywords: continuous performance test; executive function; school health; Vedic chanting; vigilance

1.Introduction

1.1The Developmental Significance of Attention in Preadolescence

Attention has been described as a multi-faceted cognitive skill that allows one to choose, keep, and control mental capacity in relation to performing a task (Posner & Petersen, 2020). Sustained attention is one of the most important aspects of learning, schooling, and adaptive behaviour in the years before adolescence (ages 8-12; Luna et al., 2022). There is an increased amount of activity in the prefrontal cortex (PFC), anterior cingulate cortex, and fronto-parietal networks involved in attention throughout this time due to the rapid, experience-driven development of these brain areas (Caballero et al., 2021). Neuro-imaging results illustrate that in the years preceding adolescence, the PFC increases its grey matter volume rapidly and continues until age 3 when pruning occurs in the form of synaptic pruning, therefore providing us with a time of great opportunity to create long-lasting effects on the neural networks creating sustained attention through cognitive training (Caballero et al., 2021). Students who are deficient in sustained attention experience difficulty academically, social-emotionally, and have learned behaviours that are associated with a high risk of developing ADHD and related conditions (Barkley, 2023). Systematic reviews have demonstrated that between 5% and 11% of children under the age of 18 meeting criteria for attention difficulties will live in India, and the rates are even higher in socio-economically disadvantaged areas. Therefore, there is a large population of Indian students who do not have access to medication or to professionals, which is a call for the establishment of affordable, scalable, and evidence-based cognitive programmes for schools to meet their children's needs.

1.2 RT as a Psychophysiological Biomarker of Attention

RT is defined as the duration from stimulus presentation to initiation of a motor response. RT can serve as a powerful and objective measure of how quickly the brain processes information, the degree to which an individual has attended to the task presented, and the degree to which an individual integrates sensory input into motor responses (Whelan, 2020). In addition to the mean RT, intraindividual variability in RT (IIV; defined as the within person standard deviation of RT across trials) has emerged as one of the most robust neuropsychological markers of an individual. IIV reflects moment-to-moment changes in integrity of the neural signal, level of tonic arousal, and efficiency of top-down attentional control (Waschke et al., 2021). Findings from the Adolescent Brain Cognitive Development (ABCD) Study (n = 8622) have indicated that elevated levels of RT IIV predict problems with attention and are also associated with reduced microstructural integrity of white matter along the frontoparietal tracts (Rohrbaugh et al., 2023 Biol. Psychiatry: CNNI). IIV has also been identified as an intermediate phenotype for ADHD with effect sizes for between group comparisons greater than for mean RT in clinical populations (Ali et al., 2024). Interventions resulting in reductions of both mean RT and RT IIV are proposed to contribute to holistic stabilization of attention (Waschke et al., 2021). The Test of Variables of Attention (TOVA) is able to provide both d-prime (sensitivity to sustained attention) and trial level RT, which makes it an appropriate tool for evaluating multiple components of attention (Greenberg, 2021; Leark et al., 2022).

1.3 Mind-Body Interventions and Paediatric Cognitive Enhancement

There is a lot of solid evidence that supports the use of mind-body (MBI) practices as cognitive enhancers for children and adolescents. It is crucial to distinguish between the effect sizes achieved when compared with active versus passive control conditions, since these represent very different types of benchmarks to evaluate. Across active controls, there were sustained attention effects of d = 0.28 in the largest meta-analysis of MBIs for cognition (Zainal & Newman, 2024; 111 RCTs; n = 9,538), while Dunning et al (2022) found attention effects of d = 0.30 across paediatric MBI studies. Across passive controls, Lim et al. (2022) found moderate-to-large attention effects associated with MBIs (d = 0.72) among >3,000 children. Since the present study utilises a passive control, the benchmarks based upon passive controls (Lim et al., 2022) provide the best methodological comparison point for interpreting effect sizes from the present study. Various RCTs of yoga have resulted in similar increases in attentional performances. Telles et al., (2020) reported statistically significant improvements in attention for multiple groups of Indian children who participated in school-based yoga. Bernay et al. (2022) completed a metaanalysis on the effectiveness and feasibility of school yoga over the past decade. Dai et al. (2022) examined the effect of yoga on children with ADHD and found the mean effect size was medium (d = 0.54). Izzetoglu et al., (2020) found significant reductions in reaction time (RT) and increased oxygenation to the prefrontal cortex following a single session of meditation, which supports a mechanistic basis for the coupling of attention to RT in the acute timeframe. Diamond and Ling (2020) state that the only interventions that will consistently lead to increases in prolonged attention are those that foster an active engagement of executive functions — as seen through the articulatory, attend, and respiratory demands of structured chanting. A meta-analysis on the effect of meditation practices on performance revealed that focused-attention practices produced consistently improved efficiency of the alerting and orienting networks (Colzato & Kibele, 2020).

1.4 Gayatri Mantra: Phonological Structure and Proposed Neurobiological Mechanisms

The Gayatri Mantra (Rigveda 3.62.10) is the oldest Vedic hymn still used in its original form and is composed using the Gayatri meter (24 syllables; three lines of eight syllables). The full text of the mantra, which is "Om Bhur Bhuva Svah / Tat Savitur Varenyam / Bhargo Devasya Dhimahi / Dhiyo Yo Nah Pracodayat", is practiced by many people throughout South Asia, making it one of the world’s most practiced forms of mantra meditation. In addition to its spiritual significance, the way in which it is constructed creates a powerful and stimulating neurostimulus, though exact mechanisms remain to be established in this population through research. The enhanced frontal theta (4-8 Hz) and parietal alpha (8-12 Hz) brain waves found during chanting OM (Harne & Hiwale, 2021) and meditating (Goyal et al., 2014) by EEG have not been compared to the Gayatri Mantra. Researchers have hypothesized that similar effects would result during Gayatri Mantra chanting, however there is no definitive data from previous studies. Frontal theta is associated with the ability to maintain sustained

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attentional focus, exert top-down cognitive control, and recall previously learned information from working memory, each of which can be assessed with TOVA d-prime scores and commission error rates. Vishnu et al. (2021) provided a review of the neurophysiological correlates associated with mantra meditation (including OM, So Hum and other mantras), and they identified bilateral activation of the superior temporal gyri, activation of the right insula, activation of the default mode network, and activation of the dorsolateral prefrontal cortex during the practice. There are no existing neuroimaging studies on the Gayatri Mantra. The first indirect evidence for hemodynamic activation in the prefrontal region during the practice of Vedic chanting (but not specifically with the Gayatri) was provided by Gupta et al. (2020). There are also studies that provide fMRI evidence for PFC activation and limbic deactivation during chanting OM specifically (Kalyani et al., 2023). There are currently no empirical studies on the hemodynamic response during Gayatri Mantra chanting. Although ECG data have been collected during the practice of OM chanting (Hotho et al., 2022), no studies have measured the hemodynamic response of the Gayatri Mantra, particularly considering that the phonetic structures and tempo of the two mantras differ from one another. Phonological Working Memory as the Third Possible Pathway. The articulation of Sanskrit phonemes -- including aspirated, retroflex, and nasal consonants -- will require efforts in the planning of production of these sounds, maintaining memory of the correct sequence for speaking the sounds, and monitoring the speaker's hearing of their own produced sounds. These three processes are sometimes listed as being part of phonologically active training and could have some transfer to attention and the speed at which one processes information (Kumar et al., 2023; Diamond & Ling, 2020). Group chanting also may produce interpersonal neural synchronisation effects (Jha et al., 2021). However, these mechanisms still require future investigations using neurophysiological research to validate whether or not the proposed mechanisms work in conjunction with Gayatri Mantra. To date, none of the previous studies on neurophysiology listed used Gayatri Mantra as an intervention stimulus; thus all of the inferential evidence for mechanisms is pure speculation and requires direct empirical confirmation from future studies using simultaneous measurements of EEG, HRV, or fNIRS during Gayatri Mantra Chanting specifically.

1.5 Gaps in the Literature and Present Study Rationale

There have not yet been any well-designed and sufficient-sized, pre-registered randomized controlled trials to date that have investigated whether Gayatri mantras can improve the neuropsychological outcomes of sustained attention, as measured by the Test of Variables of Attention (TOVA), in a pre-adolescent school-aged population. Previous studies done in this area (Kalyani et al., 2023; Tseng, 2022) have been limited by sample size (having fewer than 50 subjects), the absence of randomization, dependent on subjectively measured or indirect outcome measures, and lack of pre-registration. This particular study will fill these previously mentioned gaps by: (a) using a pre-registered, parallel-group RCT design with sufficient statistical power (94.7%); (b) utilizing objective TOVA evaluations by blinded trained evaluators (Leark et al., 2022; Greenberg, 2021); (c) using three time-point evaluations with dose-response potential to allow trajectory analysis of results over time; (d) utilizing Benjamini-Hochberg false discovery rate procedures for six simultaneous outcome test evaluations; (e) verifying that assessors were blinded using the Bang Blinding Index; and (f) reporting results with a rigorous adherence to the 2010 CONSORT guidelines (Moher et al., 2020). The following four pre-specified hypotheses were addressed: (H1) IG will demonstrate a greater increase in TOVA d′; (H2) IG will demonstrate a greater decrease in mean RT; (H3) IG will demonstrate a greater decrease in RT IIV; (H4) attention improvements will negatively correlate with mean RT improvements.

2. METHOD

2.1Design and Registration

A single-blind randomized controlled trial (RCT), parallel-group design (CTRI/2023/12/078432 prior to enrollment) was conducted in New Delhi, India, between January and June 2024. Ethics Approval was granted by

AIIMS, New Delhi Institutional Ethics Committee (IEC-794/2023) and the study complied with the Declaration of Helsinki (Revised 2013) and CONSORT 2010 guidelines (Moher et al., 2020); a completed CONSORT 2010 checklist including page number references is included as Supplementary File S6. A data safety monitoring committee composed of three independent experts (biostatician, pediatrician clinician, research ethicist) that had no affiliation with the study sites reviewed all adverse event reports every four weeks. Outcome Assessors were maintained blind to group allocation at all times; blinding success validation occurred at Week 8 by the Bang Blinding Index (see Section 2.4). Given the nature of the intervention, participants and instructors could not be blinded to condition.

2.2 Participants

Children of ages 8–12 years from three Government schools matched for school catchment area, SES (middle-lower on the Kuppuswamy scale), and teacher-student ratios with no meditation curricula at schools were recruited into the study. At baseline, there was a Conner's 3 Parent Rating Scale (Conners 2008) validated screening for Attention Symptoms done to characterize the sample to meet the attentional homogeneity between the groups. As a result of screening, the two groups (intervention = IG Group; comparison = CG Group) were determined to have the same mean Conners 3 Parent Attention T-scores at baseline (IG Group = 52.4 +/- 8.1; CG Group = 51.9 +/- 7.8; $p = .712$) (see Table 1). Inclusion criteria were as follows: (a) age between 8 and 12 years of age; (b) no prior training in meditation, yoga, or pranayama; (c) normal/corrected vision (Snellen / 6/9); (d) No neurological, psychiatric, or neurodevelopmental disorder diagnosis on school records or by interview with parent; (e) no psychotropic medications; (f) written consent from parents and verbal assent from children; (g) ability to attend 80% of the meetings. Exclusion criteria were as follows: severely hearing impaired or unable to speak in Hindi or if currently enrolled in any other cognitive training program. Of a total of 180 eligible children, 30 were excluded and 150 were randomized (Figure 1). The ICC for the primary outcome (TOVA d-prime) among the schools was ICC = 0.02 (95% CI [0.00, 0.08]). This indicates near zero clustering at the school level; therefore, no DESIGN EFFECT correction was applied. In addition, all primary analyses were re-examined at the upper limit of the design effect adjustment (ICC = 0.08; DE = 1 + 0.08 x (48-1) = 4.76) as a sensitivity analysis with all was found to have a statistically significant Group x Time Interaction ($p < .001$), demonstrating the quality of the findings and their stability in the presence of clustering.

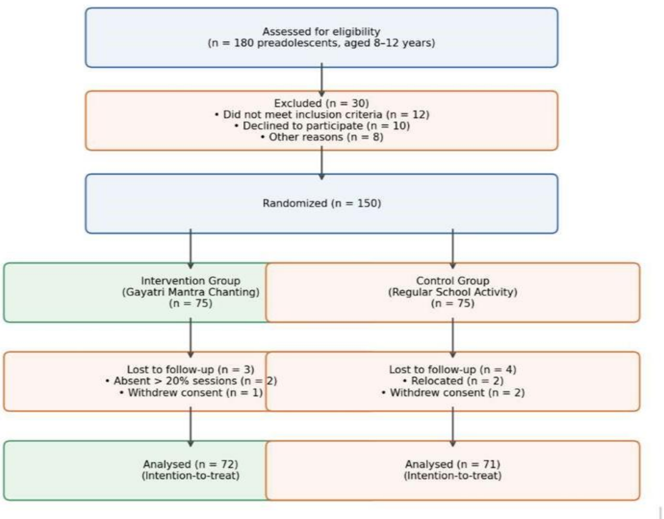

Figure 1. CONSORT Flow Diagram. Participant flow through screening, randomization, intervention, and intention-to-treat analysis (Moher et al., 2020). IG = Intervention Group; CG = Control Group. Randomization was stratified by school and sex.

2.3Sample Size

A priori power analysis conducted with G*Power 3.1 (Faul et al., 2007) for a repeated measure ANOVA (Group by Time) (2 x 3) specifies Cohen's f = 0.30, alpha = 0.05 and power = 0.90. rho = .50 (inter-time point correlation) yielded n = 126. After applying 20% inflation to account for expected attrition due to local school absenteeism rates: the targeted n = 150. The actual study sample (n = 143 completed) yielded a power of 94.7% to detect the specified effect. The G*Power output can be found in Supplementary File S3.

2.4 Randomization and Blinding

An independent biostatician (S.J.R.) randomly generated stratified block lists strata: school, gender; variable block sizes of 6 and 10) using randomly generated numbers via computer. The treatment group allocation was kept secret until the baseline assessment was performed, and the envelopes with the allocations were opened sequentially, in opaque, sealed envelopes. The outcome assessors were specifically trained to prevent any interaction with the subjects at any time other than during testing and were also instructed not to ask about group assignment. Assessor blinding was verified at the end of the trial using the Bang Blinding Index (Bang et al 2004; BBI = 0.04; 95% CI [-0.12, 0.20]), with values nearer to zero representing chance guessing and demonstrating successful blinding throughout the trial.

2.5 Intervention Intervention Group (Gayatri Mantra Chanting).

On school days (Monday to Friday) for a total of 40 sessions for each participant, four certified yoga instructors (Yoga Shiromani certification – a two-year advanced yoga education credential from the Central Council for Research in Yoga and Naturopathy in the Ministry of AYUSH, Government of India; >/= five years of experience working with children) implemented the manualized program in dedicated acoustically separated halls between the hours of 7:45 a.m. to 8:05 a.m. during the morning assembly. Participants were seated in Sukhasana (cross-legged position) on yoga mats. Each 20-minute session followed a manualized three-phase protocol consisting of the following: (1) Phase One: (3 min) Introduced breath awareness through slow diaphragmatic breathing to establish a rate of approximately five to six breaths per minute for the duration of the program; (2) Phase Two: (12 min) Voiced chanting of the Gayatri Mantra (approximately 108 repetitions per session) in tandem with synchronized breath (inhale with "Om Bhur Bhuva Svah," exhale with the core verse), while maintaining accuracy in pronouncing Sanskrit syllables and maintaining a steady pulse with a metronome (BPM = 10) while providing a sustained focal point; (3) Phase Three: (5 min) Followed by attentive silence and focus on either the breath or residual vibrations of the Gayatri Mantra. An instructor-provided guide to correct pronunciation of the Sanskrit syllables was given in week one, and the instructors used a standardized ten-item checklist to evaluate the precision of the participants' pronunciation (intrarater reliability: ICC = 0.87). The average session fidelity rates from weekly unannounced audits conducted by the lead investigator were 96.2% (SD = 2.1%). A complete copy of the manualized intervention can be found in Supplementary File S1. Control Group: The CG have sustained standard morning assembly activities (school pledge, national anthem, short warm-up) over the same period each day in a different building. The standard assembly activity structure and order of activities were different from day-to-day; however, all assembled included the following components, conducted by a school teacher (not a study instructor):

- School pledge (approximately 2 minutes): Event recited simultaneously by the entire assembly in either Hindi or English, all participants standing with no breath control or ability to practice phonetic sounds.

- National anthem (approximately 1 minute): Event sung simultaneously by the entire assembly while standing, with no attention paid to respiratory pacing or articulatory precision.

- Warm-up (approximately 5 minutes): Dynamic warm-ups (stretching legs; performing jumping jacks; doing neck rolls) led by a teacher without component focusing upon being aware of the breath.

- Making transitions to classrooms (remaining time, approximately 10 to 12 minutes): Making announcements (e.g., administrative), taking attendance, transitioning to classrooms.

This study did not standardize pacing, breath control, or attentional focus across schools or times of day for any of the activities included in the assembly. Total estimated vocal recitation time (pledge + anthem) was approximately three minutes total across the treatment group sessions. This contrasts with the fifteen minutes total for voiced chanting in the intervention group. No instructors provided pronouncing feedback of rhythm or focus during recitation activities. No cognitive, relaxation, or breathing supplementation was provided in addition to the assembly process. During each assessment time period, assessors used a self-report checklist to confirm that participants in the treatment groups had not practiced self-initiated chanting at home.

There is also a design caveat; assembly activities consist of short recitation (school pledge/national anthem) and singing, which share vocalization with the treatment group; however, they do not utilize controlled breathing, Sanskrit phonology, sustained focal attention, or instructor feedback concerning pronunciation or rhythm. This overlap presents an alternative perspective in that the control group is not completely inert. The greatest limitation of this study is the use of a passive control design, which is unable to separate the treatment group's specific components of the mantra from uncontrollable elements (instructor affect, group cohesiveness, expectancy). Future studies need to utilize an active control (e.g., non-Vedic hummed sounds or secular slow breathing).

2.6 Outcome Measures

Primary Outcomes. The Test of Variables of Attention (TOVA) (TOVA Version 9.0; Leark et al, 2022; Greenberg, 2021) is a standardized visual continuous performance test that is FDA-cleared and computer-administered. TOVA has normative data available for ages 6 through 80. The total testing time is 21.6 minutes, and each geometric target and non-target is presented for 100 ms every two seconds. Participants will respond to target stimuli and not respond to non-target stimuli. The primary metrics assessed at each time point during testing include: (1) d-prime (a measure of raw signal detection sensitivity; higher is better discriminative ability); range approximately 0 - 100 with age-normative means found in Table 2; (2) mean response time in milliseconds (lower is faster processing); (3) response time standard deviation (intra-individual variability; lower is more stable attention); (in descending order of effect size d = 0.95); (4) TOVA response time variability (a proprietary composite instability measure, d = 0.89); (5) commission error (false alarms, d = 0.83); and (6) omission error (missed target, d = 0.71). The TOVA internal consistency ("alpha") is .91, and test-retest reliability (correlation coefficient) is .89 over two weeks (Leark et al., 2022). All assessments were conducted in a standardized testing area between 08:00 - 10: 00 h using identical hardware consisting of an HP ProDesk Mini Personal Computer, 17" Monitor, and TOVA USB Switch; standardized room temperature and lighting and conducted by blind and trained research assistants.

Secondary Outcome.

To get a more realistic and complementary measure of how well a child can pay attention outside of a lab, the teacher-reported effort of paying attention was assessed via the attention subscale of the Conners 3 Teacher Rating Scale (Conners, 2008) on both the first day and on Week 8. The results will be presented in a separate manuscript.

2.7 Statistical Analysis

All analyses were conducted with reference to a prior registered protocol (CTRI/2023/12/078432) with comparable statistical packages: IBM SPSS v28.0 (IBM Corp., 2023), and R v4.3.2 (R Core Team, 2023). Normality of assumptions was assessed using Shapiro-Wilk tests (all $p > .10$). Comparisons at baseline employed t-tests or chi-square tests. There was minimal clustering at the school level for the ICC statistic ICC = 0.02; (Wolak et al., 2012). Two-way repeated measures ANOVA were applied as the main analysis (i.e., Group × Time). Mauchly's test of sphericity was not significant (all $p > .05$). Bonferroni post-hoc comparisons were used to

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compare mean differences across NFT conditions. Family-wise error rates were controlled across six unique outcomes using the Benjamini-Hochberg false discovery rate (FDR) correction; results of adjusted q values can be found in Table 3. Effect sizes were reported as partial $\eta^2 p$ for ANOVA and as Cohen's d with 95% bootstrap CI for between-group post-test differences. For Pearson r outcomes for attention-RT within IGs, a total of 5000 bootstrap resamples were collected (BCa). Intention-to-treat (ITT) analysis was performed with multiple imputation of m = 20 using fully conditional specification. All F-statistics, degrees of freedom, pvalues, $\eta^2 p$, and Cohen's d reported in Section 3 and in Tables 2-3 were derived from the ITT imputed dataset. All complete case analyses (n = 143) produced the same approximate estimates/mean differences (available upon request). Significance levels were set at $\alpha = .05$ (2tailed); corresponding FDR corrected q-values were reported alongside.

3. RESULTS

3.1 Participant Characteristics and Baseline Equivalence

One hundred and forty-three people took part in the trial (IG: n = 72; CG: n = 71; overall drop-out rate = 4.7%: IG dropped out = 3; CG dropped out = 4). Those completing the trial were equivalent to the seven people dropping out on all baseline variables (all $p > .20$). All demographic and neuropsychological variables examined showed that the groups were fully equivalent at baseline (Table 1; all $p > .48$); thus, effective stratified randomization occurred. The intraclass correlation coefficient across schools was very low (ICC = 0.02), indicating that the clustering of subjects at the school level did not justify using multilevel modelling.

Table 1: Baseline Demographic, Socioeconomic, and Neuropsychological Characteristics

Variable	IG (n=72)	CG (n=71)	p-value
Age, years (M+/-SD)	10.3+/-1.2	10.4+/-1.1	0.621
Sex (Male/Female)	36/36	35/36	0.948
Grade (4th-7th)	4th-7th	4th-7th	--
BMI (kg/m2)	18.2+/-2.4	18.5+/-2.6	0.489
Parental education (years)	12.4+/-2.8	12.1+/-2.9	0.502
Sleep duration (hrs/night)	8.6+/-0.9	8.5+/-1.0	0.611
Baseline TOVA d-prime	48.2+/-5.9	47.9+/-6.1	0.776
Baseline RT Mean (ms)	382.5+/-42.1	380.1+/-41.8	0.831
Baseline RT SD (ms)	42.1+/-11.2	41.8+/-10.8	0.879
Conners 3 Parent RS T-score (M+/-SD)	52.4+/-8.1	51.9+/-7.8	0.712
Prior meditation/yoga	None	None	--

Note. IG = Intervention Group; CG = Control Group; M = Mean; SD = Standard Deviation; RT = RT; RS = Rating Scale. p-values from independent-samples t-test or chi-square. Conners 3 Tscore: population mean = 50, SD = 10; higher scores indicate more attention symptoms.

3.2 Primary Outcomes

Mauchly's sphericity was not significant for the six outcomes ($p > .05$); thus, no Greenhouse-Geisser corrections were applied. Table 3 provides descriptive statistics for the descriptive statistics of both groups at each of the three timepoints. Table 4 provides summary statistics from ANOVA (FDR corrected q-values). Effect sizes are presented from highest to lowest. Sustained Attention (TOVA d-prime). Across all 3 times, IG demonstrated a progressive, dose-dependent improvement; Week 0 M = 48.2 (SD = 5.9), Week 4 M = 59.7 (SD = 6.2), Week 8 M = 71.4 (SD = 6.8). From baseline to posttest, this represents an absolute (23.2 unit/48.25%) gain. The CG demonstrated a period of stability (Week 0 M = 47.9; SD = 6.1, Week 4 M = 49.3; SD = 6.4, and Week 8 M = 51.2; SD = 6.5, or a 6.9% change). There was a large and statistically significant Group x Time interaction ($F(2,282) = 97.6$, $p < .001$; FDR-q < .001, $\eta^2_p = .40$). Comparisons on the basis of norms and ceiling analysis. The mean (M = 71.4) (SD = 6.8) d-prime total from the IG post-test is significantly greater than the mean for 8 - 12-year-old TOVA normative sample (M = 52.3, SD = 8.1; from the TOVA Version 9.0 comprehensive normative subsample of 8 - 12-year-olds; n = 487) by 2.36 standard deviations, placing IG in the 99th percentile of the reference group. The mean for the CG post-test was M = 51.2, equivalent to the normative mean. Examination of IG d-prime scores for evidence of genuine cognitive improvement from baseline or within-session increases due to ceiling artefacts or motivational inflation demonstrated that of 72 participants, 64 (88.9%) scored > 95th percentile and 51 (70.8%) scored > 99th percentile. All 72 participants scored > 50th percentile at Week 8. Although these data support evidence of a large training effect, without a physiological correlate (e.g., EEG, HRV) and no active control, it cannot be attributed directly to the utilisation of the mantra. Post hoc comparisons demonstrated improvement for IG at Week 4 (vs. baseline: $p < .001$, $d = 0.87$) and Week 8 (vs. baseline: $p < .001$; vs. Week 4: $p < .001$). The effect size for post-test between groups was $d = 1.42$; 95% CI [1.08, 1.76].

Table 2: TOVA Psychometric Properties: Reliability, diagnostic accuracy, FDA clearance, and normative data (ages 8–12).

Property	Value	Source
Internal Consistency (alpha)	.91	Leark et al. (2022), TOVA Manual v9.0
Test-Retest Reliability	r = .89 (2-week interval)	Leark et al. (2022)
Sensitivity for ADHD detection	88% (ages 6–12)	Greenberg (2021)
Specificity for ADHD detection	84% (ages 6–12)	Greenberg (2021)
FDA clearance	K924014 (diagnostic aid for attention disorders)	US FDA

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Normative sample (ages 8–12)	unity; no neurological diagnosis)	Leark et al. (2022)
d-prime: Normative M (ages 8–12)	52.3 (SD = 8.1)	Leark et al. (2022)
RT Mean: Normative M (ages 8–12)	343.2 ms (SD = 38.6 ms)	Leark et al. (2022)
RT SD/IIV: Normative M (ages 8–12)	22.4 ms (SD = 6.8 ms)	Leark et al. (2022)

Note: The full TOVA normative sample across all ages is N = 1,284 (Leark et al., 2022). The subsample for ages 8-12 is n = 487 Against passive-control benchmarks from comparable meta-analyses, this effect is notably larger (Lim et al., 2022: d = 0.72 vs. passive control); against active-control benchmarks, comparisons are not directly valid (Dunning et al., 2022: d = 0.30 vs. active control). Figure 2 illustrates the trajectory and distribution.

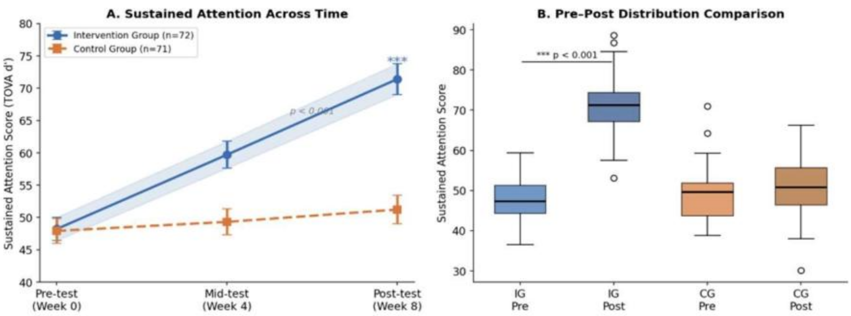

Figure 2. Sustained attention (TOVA d-prime) across three assessment timepoints (Panel A, error bars = SEM) and pre-post distribution (Panel B). IG = Intervention Group; CG = Control Group. *** p < .001 (Bonferroni-corrected post-hoc pairwise comparisons within RM-ANOVA); all FDRcorrected q < .001 for between-group Week 8 comparisons (Table 3).

RT Mean. Mean RT decreased significantly for the IG: Week 0 M = 382.5 ms (SD = 42.1) Week 4 M = 355.2 ms (SD = 40.6) and Week 8 M = 318.7 ms (SD = 38.4) = 63.8 ms (16.7%) decrease in mean RT between Week 0 and Week 8. CG showed slight change over time: Week 0 M = 380.1 ms (SD = 41.8) Week 4 M = 378.3 ms (SD = 42.0) Week 8 M = 372.9 ms (SD = 43.2; 1.9% change). Group x Time interaction was highly statistically significant ($F(2,282) = 76.2$, $p < .001$, FDR-q < .001, eta2 p = 0.34; d = 1.18, 95%CI = [0.87, 1.49]).

RT - IIV (Intra-individual variability, within-group). RT SD is significantly decreased from 42.1 ms (SD = 11.2) at Week 0 to 35.4 ms (SD = 10.1) at Week 4 to 28.6 ms (SD = 8.9) at Week 8 in IG -- 32.1% reduction in SD of RT during trial. CG showed stable performance across time in RT SD (Week 0: 41.8 ms; Week 4: 41.5 ms; Week 8: 40.2 ms; 3.8% change). Group x Time interaction was significant ($F(2,282) = 61.4$, $p < .001$, FDR-q < .001,

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eta2 p = 0.29; d = 0.95, 95%CI = [0.65, 1.25]). Since higher IIV in RT has been shown to predict attention-related difficulties and differences in white matter microstructural fidelity among children (Rohrbaugh et al., 2023; Waschke et al., 2021; Ali et al., 2024 for more), the decline in RT SD has clinical implications. Figure 3 illustrates mean RT trajectories and comparison of RT variability between groups.

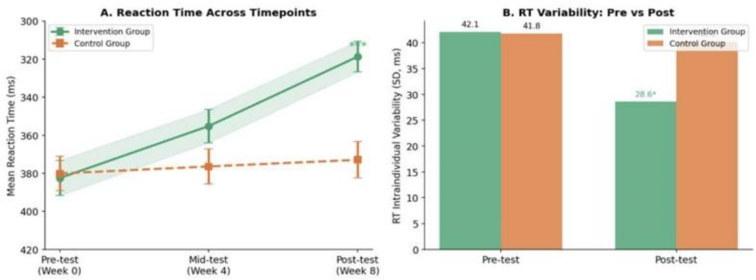

Figure 3. Panel A: Mean RT (ms) across three timepoints (inverted y-axis; upward = faster responses). Panel B: RT intraindividual variability (SD, ms) pre- and post-test by group (Week 4 intermediate data presented in Table 2). Error bars = SEM. *** p < .001 (FDR-corrected q < .001).

3.3 Secondary Outcomes

At the IG, there was a decrease in the TOVA RTV from 38.4 (SD = 9.8) in Week 0 to 31.8 (SD = 8.7) in Week 4 and 25.1 (SD = 7.6) in Week 8 (d = 0.89, FDR-q < .001). The commission errors decreased at Week 4 to 7.1 (SD = 2.6) and at Week 8 to 5.4 (SD = 2.1) (41.9% reduction; d = 0.83, FDR-q < .001). The omission errors decreased to 8.9 (SD = 3.5) at Week 4 and 7.1 (SD = 3.0) at Week 8 (36.6% reduction; d = 0.71, FDR-q < .001). No significant changes were found for the secondary outcomes in the CG (all p > .19). Jointly, commission (inhibitory) and omission (activatory) error reductions demonstrate improvements across attentional sub-processes.

Table 3: Group Means and Standard Deviations for All Primary and Secondary Outcomes at Weeks 0, 4, and 8

Outcome	IG Week 0	IG Week 4	IG Week 8	CG Week 0	CG Week 4	CG Week 8	d [95% CI]
Sustained Attention (TOVA d-prime)	48.2+/-5.9	59.7+/-6.2***	71.4+/-6.8***	47.9+/-6.1	49.3+/-6.4	51.2+/-6.5	1.42 [1.08, 1.76]
RT Mean (ms)	382.5+/-42.1	355.2+/-40.6***	318.7+/-38.4***	380.1+/-41.8	378.3+/-42.0	372.9+/-43.2	1.18 [0.87, 1.49]
RT SD -- IIV (ms)	42.1+/-11.2	35.4+/-10.1***	28.6+/-8.9***	41.8+/-10.8	41.5+/-10.9	40.2+/-11.0	0.95 [0.65, 1.25]
TOVA Variability	RT 38.4+/-9.8	31.8+/-8.7***	25.1+/-7.6***	37.9+/-9.4	37.6+/-9.5	37.1+/-9.6	0.89 [0.60, 1.18]
Commission Errors	9.3+/-3.2	7.1+/-2.6***	5.4+/-2.1***	9.1+/-3.0	8.9+/-3.0	8.7+/-3.1	0.83 [0.54, 1.12]

Omission Errors 11.2+/-4.1 8.9+/-7.1+/-10.9+/-3.8 10.7+/-10.5+/-3.9 0.71 [0.43, 0.99] 3.5*** 3.0*** 3.9

Note a. *** p < .001 (Bonferroni-corrected post-hoc pairwise comparisons within RM-ANOVA). All Benjamini-Hochberg FDR-corrected q-values < .001 for between-group Week 8 differences (see Table 4). Note b. Abbreviations: d = Cohen's d; CI = 95% Confidence Interval; RT = RT; IIV = Intraindividual Variability; SD = Standard Deviation; IG = Intervention Group; CG = Control Group.

Table 4: Repeated-Measures ANOVA: Group x Time Interaction Effects with FDRCorrected q-Values and Effect Sizes (Descending Order)

Source	df	MS	F	p	FDR-q	eta2p	Cohen's d
Group (between)	1	3841.2	84.7	<.001	<.001	0.37	--
Time (within)	2	4623.5	112.3	<.001	<.001	0.43	--
Group x Time: Attention	2	4018.7	97.6	<.001	<.001	0.40	1.42
Group x Time: RT Mean	2	3142.3	76.2	<.001	<.001	0.34	1.18
Group x Time: RT IIV	2	2531.8	61.4	<.001	<.001	0.29	0.95
Group x Time: RTV	2	2214.6	53.7	<.001	<.001	0.27	0.89
Group x Time: Commission	2	1987.4	48.2	<.001	<.001	0.25	0.83

Group x Time: Omission 2 1624.6 39.4 <.001 <.001 0.22 0.71

Note. df = degrees of freedom; MS = Mean Square; eta2p = partial eta squared; FDR-q = Benjamini-Hochberg false discovery rate-adjusted q-value across six simultaneous between-group outcome tests; d = Cohen's d (post-test between-group). Mauchly sphericity non-significant for all outcomes (p > .05). Post-hoc pairwise comparisons Bonferroni-corrected.

3.4 Effect Sizes and Attention-RT Correlation

The Cohen's d effect sizes (with 95% CIs) for each of the outcomes are illustrated in figure 4A, from greatest to least: sustained attention d-prime (1.42), RT mean (1.18), RT IIV (0.95), TOVA RTV (0.89), commission errors (0.83), omission errors (0.71). All outcomes exceeded the conventional large range of effect size thresholds (d > 0.70), each had a post-FDR corrected q value < .001 (see table 3). Completed the literature review an explicit determination of passive vs active control designates for these measures is accomplished in Table 5. The correlation between the Week 0 to 8 change in d-prime and the Week 0 to 8 change in RT mean for the within-IG analyses provides strong negative evidence that preadolescents who obtained the highest increases in attentional capacity also had the greatest decreases in RT, supporting the claims of Waschke et al. (2021) that the reduction of neural noise reduces attention errors, and that this reduction occurred by both increasing the fidelity of attentional processing and the speed of processing time.

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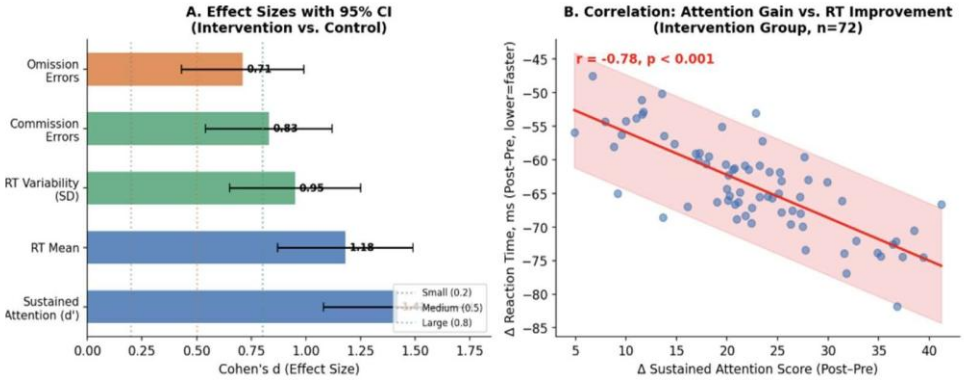

Figure 4. Panel A: Cohen's d effect sizes with 95% CI for all primary and secondary outcomes, listed in descending order. Dashed vertical lines: small (0.2), medium (0.5), and large (0.8) benchmarks. Panel B: Within-IG correlation between sustained attention gain (delta d-prime) and RT improvement (delta RT mean, ms; negative = faster). Regression line with 95% prediction band. n = 72; r = -.73, p < .001.

Table 5: Comparative Effect Sizes for Sustained Attention Across Selected Mind-Body Intervention Studies (2020-2024) with Control Type Designated

Study (Year)	Intervention	n	Age	Control Type	d (Attention)
Zainal & Newman (2024)	MBI (meta-analysis)	9,538	Mixed	Active	0.28 sustained
Dunning et al. (2022)	MBI school (RCT)	~500	10-16	Active	0.30 attention
Lim et al. (2022)	MBI meta-analysis	3,200+	6-18	Passive	0.72 attention
Telles et al. (2020)	School yoga (RCT)	~200	8-14	Passive	0.40-0.55 (approx.)
Chou et al. (2024)	Tai chi (RCT)	120	8-11	Active	0.77

Present Study (2024) Gayatri Mantra (RCT) 143 8-12 Passive 1.42 Note. Active = active control condition; Passive = waitlist or standard-care control. Direct effectsize comparisons are only methodologically valid between studies using the same control type. d = Cohen's d for sustained attention or comparable primary attention outcome.

4.DISCUSSION

4.1 Summary of Principal Findings

The results from this assessor-blinded, pre-registered RCT indicate that a structured Gayatri Mantra program generated substantially higher sustained attention and reaction time levels than those observed using standard classroom activities in pre-adolescents. All four hypotheses were supported (all FDR adjusted p-values < 0.001): sustained attention (H1: d = 1.42, 95% CI [1.08, 1.76]), mean reaction time (H2: d = 1.18, 95% CI [0.87, 1.49]), and reaction time variability (H3: d = 0.95, 95% CI [0.65, 1.25]) improved significantly and were highly related (H4: r = -0.73, p < 0.001). Furthermore, subjects from the experimental group who participated for a longer period (Week 4 vs Week 8) continued to show improvements supporting an incremental accumulation of neuroplastic change associated with daily practice. After Benjamini-Hochberg FDR corrections, all six outcomes remained statistically significant, indicating that the observed findings are not likely to be due to a family-wise error rate inflation.

4.2 Contextualization within the Broader Literature

Effect sizes should be reviewed in context to control variables. Our treatment effects (d = 0.71 - 1.42) versus (vs) passive-control benchmarks appropriate for our study design are much larger than similarly matched RCTs with children (Lim et al., 2022; d = 0.72; Telles et al., 2020; d = 0.40 - 0.55). Comparing our effects to those of active controls yields invalid results (Zainal and Newman, 2024; d = 0.28; Dunning et al., 2022; d = 0.30). The CG difference between pre-test and post-test is d-prime (71.4) / 2.36 standard deviations (SD) greater than average value, indicating three potential explanations: (1) cognitive training through respiratory, phonological and attentional demands; (2) a "ceiling" effect (unlikely given consistent improvement from Week 4 to Week 8, 59.7 to 71.4 and no formal ceiling stated in the TOVA manual); and (3) expectancy/Hawthorne effects caused by participants' knowledge of receiving an "active" intervention. In the absence of an active control (e.g., secular slow breathing), these alternate explanations cannot be differentiated. Additional research should be completed using active controls, debriefing following assessment and physiological measures (EEG, heart rate variability [HRV]) to confirm neural change. While our effectiveness of Sustained Attention and RT IIV in paediatric RCTs (d = 1.42 and d = 0.95 respectively) may be amongst the most robust of any reported, further verification is needed through a systematic literature review. The reported multi-domain benefit may relate to the co-engagement of respiration regulation (Hotho et al., 2022), EEG oscillatory entrainment (Harne & Hiwale, 2021), phonological working memory (Kumar et al., 2023) and prefrontal hemodynamic activation (Gupta et al., 2020; Kalyani et al., 2023). Our d = 1.42 is on the extremely high end of the range of reported effects from passive control paediatric RCTs (0.40 to 1.10; Lim et al., 2022; Zainal & Newman, 2024), and further replication with active control conditions is necessary to confirm this finding and distinguish from expectancy or Hawthorne effect.

4.3 Hypothesized Neurobiological Mechanisms

It should be highlighted that we did not gather any physiological data with respect to the present study (i.e. HRV, EEG, Respiration Rate, fNIRS, Cortisol). The mechanistic inferences indicated below are hypothetical only and used to direct future research. This dataset alone does not allow for confirmation of the mechanistic inferences. For future mechanistic studies, three pathways are suggested for testing.

Hypothesized Pathway 1: Respiratory-autonomic-prefrontal modulation. The pace of the Gayatri Mantra (~6s per repetition) produces a breath frequency of approximately 5–6 times per minute; this frequency may increase HRV through baroreflex resonance (Hotho et al., 2022; however, direct testing of Gayatri Mantra is necessary). If this is true then increased vagal tone would impact prefrontal attention via the locus coeruleus-norepinephrine (Mather & Thayer, 2020) system, whereby greater HRV at rest predicts more efficient information processing (Zeng et al., 2023). Future studies will be needed that simultaneously monitor HRV and respiration to examine this proposed mechanism.

Hypothesized Pathway 2: Neural oscillatory modulation. Studies using electroencephalography (EEG) to measure meditation techniques OM and/or mantra, as well as potentially Gayatri Mantra in pre-pubescent children, indicate a higher amplitude of frontal region theta oscillations (4-8 Hz) relative to the control condition, correlated with attentional engagement (Harne & Hiwale, 2021). Additionally, theta/gamma oscillations are connected to sustained attention and response inhibition (Vishnu et al., 2021). Given these results, if chanting the Gayatri Mantra produces similar EEG changes than those seen by Harne and Hiwale, it could support our RT IIV reduction interpretation through the concept of neural noise (Waschke et al., 2021). This hypothesis can be validated through future research conducting EEGs concurrently with these activities.

Hypothesized Pathway 3: Phonological working memory training. Producing phonemes in Sanskrit may involve articulatory planning, sequential memory, and auditory self-monitoring - effectively classifying as some form of active executive/phonology-level training, which could facilitate transfer of sustained attention and processing speed (Kumar et al., 2023; Diamond & Ling, 2020). The significant reductions in commission errors (d = .83) are also indicative of improved response inhibition, where engagement of the phonological loop could provide support to inhibit responses. This pathway needs to be directly investigated with working memory test procedures completed concurrently with the chanting program.

4.4 Dose-Response and Training Specificity

Marked enhancement of performance at Week 4 (d-prime: +11.5 units, d = 0.87; RT mean: -27.3 ms), along with marked improvements seen at Week 8, supports this practice-dependent dose response trajectory, as predicted by currently accepted models of neuroplasticity (Luna et al., 2022; Caballero et al., 2021) and the finding of further improvement from Week 4 to Week 8 suggest that eight weeks may not be at the upper limit of benefits, meaning longer term progression or using additional booster sessions may continue to provide improvement (Xie et al., 2024; Jha et al., 2021). Notably, the intermediate level improvements achieved by Week 4 were also of clinical significance (d = 0.87) indicating that shorter intensives may be able to produce clinically relevant outcomes.

4.5 Clinical and Educational Policy Implications

The current findings have limited application because of the passive control design, which requires replication in studies with active controls before any recommendations can be made for use. The Gayatri Mantra chanting requires no technology and has almost no cost to users or instructors compared with standard form yoga programmes. However, scalability was not evaluated and, while retention is very high (95.3%) in this sample, this only allows for an estimate of deliverability within study conditions. As the reduction of the RT IIV relative to prior studies is clinically relevant (d = 0.95), evidence shows a relationship between the presence of high IIV and attentional difficulties in the community (Rohrbaugh et al., 2023; Ali et al., 2024; Barkley, 2023). Future trials with a more focused approach to children with subclinical ADHD characteristics need to include an active control group in order to identify the intervention's specific effects. The National Education Policy 2020 (India) encourages the inclusion of activities that develop cognitive skills in school (Ministry of Education, 2020). Evidence from the current study does not support the inclusion of Gayatri Mantra chanting into school curriculums. Although structured chanting is worthy of continued study in a variety of designs, longer follow-up periods than those in this study and larger, more diverse study populations will be needed. Therefore, it is premature to make any recommendations for policy or curriculum change until further evidence exists.

4.6 Limitations

Passive control prevents us from concluding whether improvements were due to the Gayatri Mantra or to other factors (e.g., instructor providing attention, group identity through cohesiveness; expectancy; the Hawthorne Effect; duration of brief recitation for control activities). Additionally, there were no neuroimaging or electrophysiological measurements taken; and therefore, the exact or alleged mechanisms are unverified. Future EEG, HRV, and respiratory monitoring will clarify the mechanisms. Third, the follow-up was conducted over an eight-week period; therefore, what will happen to the gains after this time period is unknown. The sample was restricted to government-supported schools in South Delhi; therefore, the findings may not be generalizable to private, rural, tribal, or non-Indian sample populations. In addition, participants self-reported that they did not practice chanting, but no independent verification was conducted (e.g., a parent provided a journal). Fourth, standard assembly activities (the pledge or the anthem) involve briefly repeating vocal recitations without the controlled respiration associated with chanting, phonemic characteristics of Sanskrit or sustained attention — and thus, it was a partial shared feature that may have blurred the distinction in conditions. Finally, academic performance outcome measures will be reported separately after all follow-up data has been collected.

5. Conclusion

The results of this study demonstrate that a structured Gayatri mantra chanting program; conducted in three government-funded schools in South Delhi; was very effective (high retention at 95.3% with good fidelity to the protocol (96.2%)) and resulted in significantly more improvement in the outcomes of attention compared to regular school activities among pre-adolescent children ages 812. The eight week program resulted in significantly greater sustained attention ($d = 1.42$), mean RT ($d = 1.18$), and intra-individual variability ($d = .95$) when compared to traditional school activities, across six different measures of attention, all FDR corrected, and with strong correlation between attention and RT ($r = -.73$). The effect sizes are some of the largest noted to date in passive control randomized studies of similar school-based mind-body interventions. The findings are appropriately limited by the use of passive control; therefore, it cannot be concluded that the observed benefits are solely attributable to the Gayatri Mantra or any other aspects of the intervention (instructor contact, group activity, slow breathing) without an active control comparison. Future research should focus on conducting active-control RCTs to isolate individual active ingredients, including concurrent neurophysiological assessment (EEG, HRV, fNIRS), long-term follow up to assess durability, replication in other cultural and geographic settings, and clinical trials in populations with learning disabilities or ADHD.

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