



RESEARCH ARTICLE

Effects of an Integrated Yoga and Yoga Nidra Intervention on Heart Rate Variability and Autonomic Function in School-Aged Children: An Experimental Study

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Abstract

Background: Heart rate variability (HRV) is a reliable, non-invasive biomarker of cardiac autonomic regulation. While evidence supports yogic practices in modulating autonomic function in adults, pediatric research remains limited. **Objective:** This study investigated the acute effects of an integrated yogic intervention—comprising Bhramari Pranayama, Adi Mudra, Navasana, and Yoga Nidra—on 16 comprehensive HRV metrics in school-aged children (ages 8–12 years). **Methods:** 82 students from Auroville, Tamil Nadu, India were randomly allocated into intervention (n = 41) and control (n = 41) groups. HRV was continuously recorded across three phases: Pre (3 min), During Yoga Nidra (20 min), and Post (3 min). The same 41 responders were identified by LF/HF ratio reduction. Sixteen HRV metrics were analyzed using repeated measures ANOVA with Bonferroni-corrected pairwise comparisons. **Results:** Significant omnibus effects were observed for RMSSD ($F = 3.38$, $p = .037$, $\eta^2 = .053$), PNS Index ($F = 3.18$, $p = .045$, $\eta^2 = .050$), SNS Index ($F = 4.03$, $p = .020$, $\eta^2 = .063$), Stress Index ($F = 3.98$, $p = .021$, $\eta^2 = .062$), and SD1 ($F = 3.33$, $p = .039$, $\eta^2 = .053$). Pre-to-Post comparisons revealed significant enhancements in parasympathetic markers (RMSSD: $d = -0.44$; PNS Index: $d = -0.42$; pNN50: $d = -0.51$) and significant reductions in sympathetic markers (SNS Index: $d = 0.52$; Stress Index: $d = 0.53$). **Conclusion:** The integrated yogic intervention produced statistically significant and clinically meaningful shifts toward parasympathetic dominance in school-aged children.

Keywords: Heart Rate Variability; Yoga Nidra; Autonomic Nervous System; Parasympathetic Activity; Bhramari Pranayama; Pediatric Yoga; School Children; HRV Metrics; Stress Reduction; Cardiac Autonomic Regulation

1. Introduction

Heart rate variability (HRV) represents the physiological variation in time intervals between consecutive heartbeats, serving as a critical non-invasive biomarker of autonomic nervous system (ANS) function (Task Force of the European Society of Cardiology, 1996; Berntson et al., 1997). Higher HRV generally indicates greater cardiac autonomic flexibility and adaptive capacity, while reduced HRV is associated with heightened stress, anxiety, and compromised self-regulatory processes (Thayer et al., 2012). Recent meta-analytic evidence confirms that HRV-indexed vagal tone is a robust transdiagnostic marker of self-regulation capacity across the lifespan (Holzman & Bridgett, 2017).



The autonomic nervous system operates through two principal branches: the sympathetic nervous system (SNS), which mediates the "fight-or-flight" response, and the parasympathetic nervous system (PNS), which governs "rest-and-digest" functions primarily through vagal innervation of the sinoatrial node (Porges, 2007). Contemporary school environments increasingly expose children to academic pressures, social stressors, and digital overstimulation, potentially disrupting optimal autonomic balance (Chrousos, 2009). Emerging evidence suggests that early autonomic dysregulation may predict later psychopathology and cardiometabolic risk (Jarczok et al., 2015).

Yoga, an ancient Indian contemplative practice, has been demonstrated to modulate autonomic function through multiple physiological pathways. Yoga Nidra, in particular, induces a unique psychophysiological state characterized by deep somatic relaxation with preserved conscious awareness—associated with enhanced alpha and theta EEG activity and significant reductions in sympathetic arousal markers (Kumar & Pandya, 2012; Datta et al., 2017). Bhramari Pranayama stimulates the vagus nerve through vibration-induced activation of pharyngeal and laryngeal branches, resulting in increased parasympathetic tone (Kuppusamy et al., 2016). Controlled breathing practices (pranayama) have been shown to directly modulate baroreflex sensitivity and cardiac vagal output (Bernardi et al., 2001).

Despite growing evidence supporting autonomic benefits of yogic practices in adults (Pascoe et al., 2017), pediatric studies remain remarkably scarce. This gap is significant given the critical developmental window of the ANS during childhood (ages 8–12), during which autonomic maturation and vagal tone development are actively occurring (Michels et al., 2013; Shader et al., 2018). The present study addresses this lacuna by investigating the acute effects of an integrated yogic intervention on 16 comprehensive HRV metrics in school-aged children.

2. Materials and Methods

2.1 Study Design and Participants

This experimental study employed a within-subjects repeated measures design. A total of 83 students from Auroville School, Tamil Nadu, India were initially considered and randomly allocated into two groups. One student was excluded due to insufficient participation, yielding a final sample of 82 students: 41 in the intervention group (60-minute structured yogic session) and 41 in the control group (60-minute structured activities including drawing, painting, storytelling, theatre, and chanting). Children were aged 8–12 years.

2.2 Intervention Protocol

The integrated yogic intervention consisted of four core components delivered in a structured sequence during each 40-minute daily session: (1) Bhramari Pranayama (humming bee breath), (2) Adi Mudra with gentle smiling, (3) Navasana (boat pose), and (4) Yoga Nidra (20-minute guided deep relaxation in Shavasana). The Yoga Nidra comprised five phases: preparation (2 min), body awareness (8 min), breath awareness (3 min), visualization (5 min), and returning to awareness (2 min 20 s). Sessions were delivered through age-appropriate guided audio recordings in Tamil. The remaining 20 minutes of each session were used for welcome,

instructions, participant feedback, observation, and closing. Each session was directly supervised by the research team with a yoga instructor and rotating teacher support.

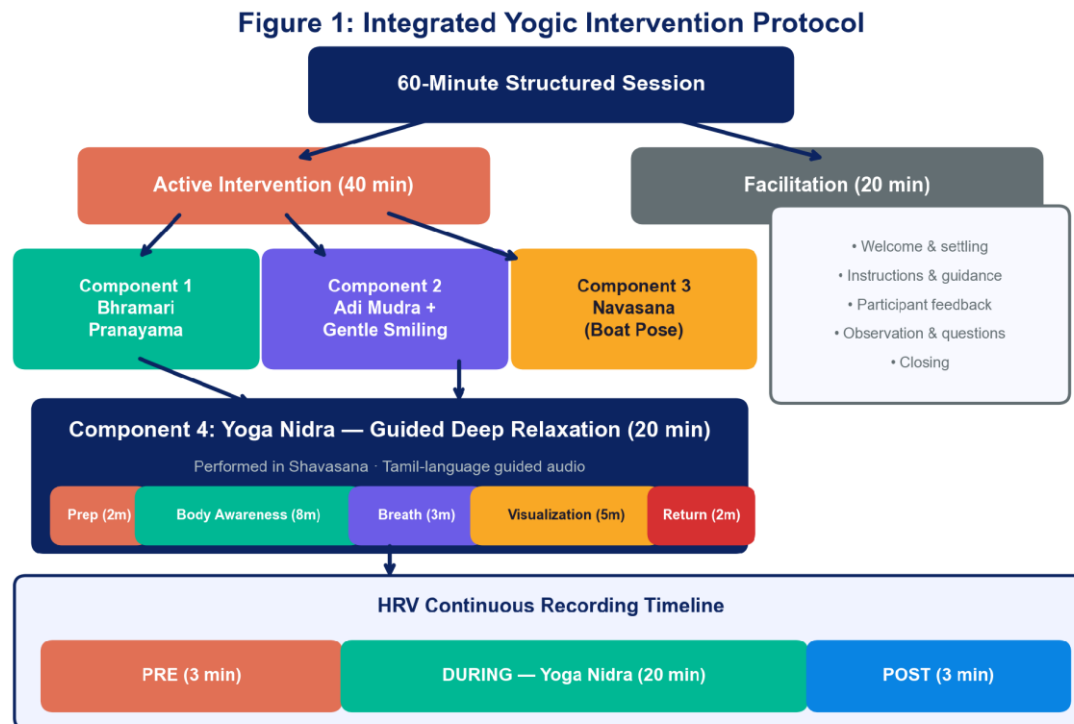


Figure 1. Schematic representation of the integrated yogic intervention protocol and HRV measurement timeline across Pre, During, and Post phases.

2.3 HRV Data Acquisition

HRV was measured using wearable ear-clip biosensors that recorded continuous beat-to-beat intervals (BPM) with millisecond precision. A customized setup was used to record data from four members simultaneously. Data were acquired across three temporal phases: (a) Pre-Yoga Nidra (3 minutes baseline), (b) During Yoga Nidra (20 minutes), and (c) Post-Yoga Nidra (3 minutes recovery). Raw BPM data were converted to inter-beat intervals (IBI) using change-point detection, with artifact rejection excluding intervals outside 300–2000 ms.

2.4 HRV Metric Computation

Sixteen comprehensive HRV metrics were computed from IBI time series for each phase, spanning four analytical domains: time-domain (RMSSD, SDNN, pNN50, NN50, SDANN, HRV Triangular Index, HRV Sensor), frequency-domain (HF, LF, VLF, LF/HF Ratio via Lomb-Scargle periodogram), non-linear (SD1, SD2 from Poincaré analysis), and autonomic indices (PNS Index, SNS Index, Stress Index per Baevsky).

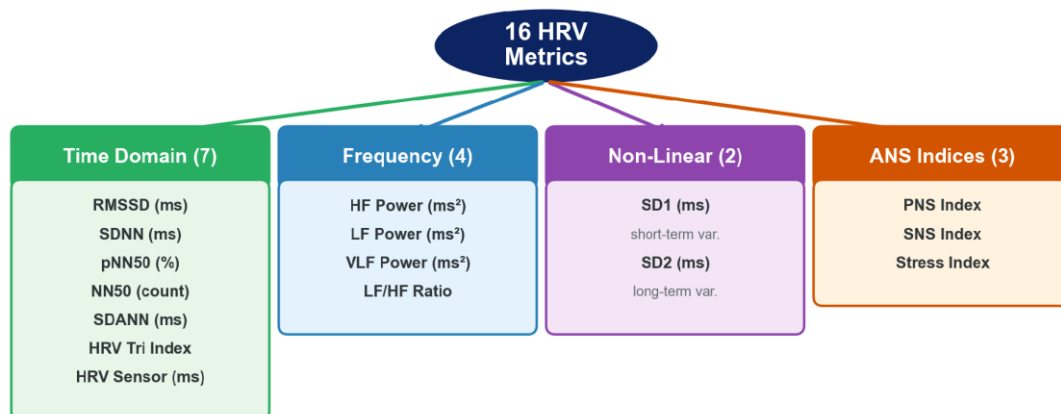
Figure 2: Taxonomy of 16 HRV Metrics Across Four Analytical Domains

Figure 2. Hierarchical taxonomy of 16 HRV metrics across four analytical domains. Frequency-domain metrics computed via Lomb-Scargle periodogram.

2.5 Responder Selection and Statistical Analysis

The same 41 responders were identified by LF/HF ratio drop (Pre – Post). Statistical analysis comprised: (1) Shapiro-Wilk normality tests; (2) One-way repeated measures ANOVA for omnibus phase effects; (3) Bonferroni-corrected paired t-tests; (4) Cohen's d effect sizes; and (5) partial eta-squared. Significance threshold: $\alpha = .05$ (two-tailed).

3. Results

3.1 Sample Characteristics

From 56 participants with valid sensor data, the same 41 responders demonstrated a mean LF/HF drop of 0.089 ± 0.249 (range: -0.210 to 0.852 , median: 0.049). Data spanned February 4–20, 2026. All 41 participants had complete data across three phases and all 16 HRV metrics.

3.2 Descriptive Statistics

Table 1. Descriptive Statistics for Key HRV Metrics Across Three Phases (N = 41)

Metric	Domain	Pre (M $\pm$ SD)	During (M $\pm$ SD)	Post (M $\pm$ SD)	$\Delta\%$
RMSSD (ms)	Time	210.26 $\pm$ 137.98	212.86 $\pm$ 133.17	280.85 $\pm$ 146.66	↑33.6%
SDNN (ms)	Time	159.36 $\pm$ 106.39	162.81 $\pm$ 100.32	208.57 $\pm$ 109.63	↑30.9%
pNN50 (%)	Time	60.37 $\pm$ 22.00	61.91 $\pm$ 21.97	69.74 $\pm$ 20.55	↑15.5%
NN50	Time	89.00 $\pm$ 48.87	98.49 $\pm$ 48.84	100.41 $\pm$ 47.80	↑12.8%
SDANN (ms)	Time	51.98 $\pm$ 61.10	54.77 $\pm$ 48.97	68.36 $\pm$ 67.99	↑31.5%



HRV Tri Idx	Time	10.23 ± 6.12	11.90 ± 6.61	12.17 ± 7.00	↑19.0%
HF (ms ²)	Freq	0.0041 ± 0.0062	0.0029 ± 0.0016	0.0032 ± 0.0019	↓21.9%
LF (ms ²)	Freq	0.0026 ± 0.0038	0.0019 ± 0.0014	0.0018 ± 0.0013	↓30.8%
LF/HF Ratio	Freq	0.648 ± 0.236	0.676 ± 0.347	0.560 ± 0.223	↓13.7%
PNS Index	ANS	5.69 ± 5.71	5.85 ± 5.47	8.54 ± 6.06	↑50.1%
SNS Index	ANS	-0.14 ± 3.95	-0.75 ± 3.46	-2.35 ± 3.53	↓shift
Stress Index	ANS	37.23 ± 28.15	29.60 ± 20.55	23.23 ± 17.44	↓37.6%
SD1 (ms)	NL	149.71 ± 99.19	151.09 ± 94.65	199.54 ± 104.44	↑33.3%
SD2 (ms)	NL	165.34 ± 117.74	169.80 ± 112.06	212.38 ± 123.56	↑28.4%

3.3 Repeated Measures ANOVA

Table 2. Repeated Measures ANOVA Results Across Three Phases (N = 41)

Metric	F(2,120)	p-value	η ²	Sig
HRV Sensor	0.147	.863	.002	ns
RMSSD	3.382	.037	.053	*
PNS Index	3.185	.045	.050	*
SNS Index	4.032	.020	.063	*
SDNN	2.779	.066	.044	ns
Stress Index	3.976	.021	.062	*
HF Power	1.202	.304	.020	ns
LF Power	1.412	.248	.023	ns
LF/HF Ratio	2.012	.138	.032	ns
pNN50	2.239	.111	.036	ns
SDANN	0.879	.418	.014	ns
VLF Power	0.238	.789	.004	ns
HRV Tri Index	1.050	.353	.017	ns
NN50	0.651	.524	.011	ns
SD1	3.335	.039	.053	*
SD2	1.989	.141	.032	ns

3.4 Pairwise Comparisons: Pre vs. Post

Table 3. Bonferroni-Corrected Paired t-Tests: Pre vs. Post Yoga Nidra (N = 41)

Metric	t(40)	p	p(corr)	Cohen's d	Effect	Sig
RMSSD	-2.819	.007	.022	-0.440	Small	*
PNS Index	-2.691	.010	.031	-0.420	Small	*
SNS Index	3.341	.002	.005	0.522	Medium	**
SDNN	-2.473	.018	.053	-0.386	Small	ns
Stress Index	3.404	.002	.005	0.532	Medium	**
HF Power	0.935	.355	1.000	0.146	Negligible	ns
LF Power	1.435	.159	.477	0.224	Small	ns

LF/HF Ratio	2.282	.028	.084	0.356	Small	ns
pNN50	-3.289	.002	.006	-0.514	Medium	**
SDANN	-1.220	.230	.689	-0.191	Negligible	ns
VLF Power	-0.706	.484	1.000	-0.110	Negligible	ns
HRV Tri Idx	-2.216	.032	.097	-0.346	Small	ns
NN50	-2.545	.015	.045	-0.397	Small	*
SD1	-2.765	.009	.026	-0.432	Small	*
SD2	-2.087	.043	.130	-0.326	Small	ns

Key Finding: Seven HRV metrics demonstrated statistically significant Pre-to-Post changes after Bonferroni correction: RMSSD ($p = .022$), PNS Index ($p = .031$), SNS Index ($p = .005$), Stress Index ($p = .005$), pNN50 ($p = .006$), NN50 ($p = .045$), and SD1 ($p = .026$). All changes indicated a shift toward parasympathetic dominance.

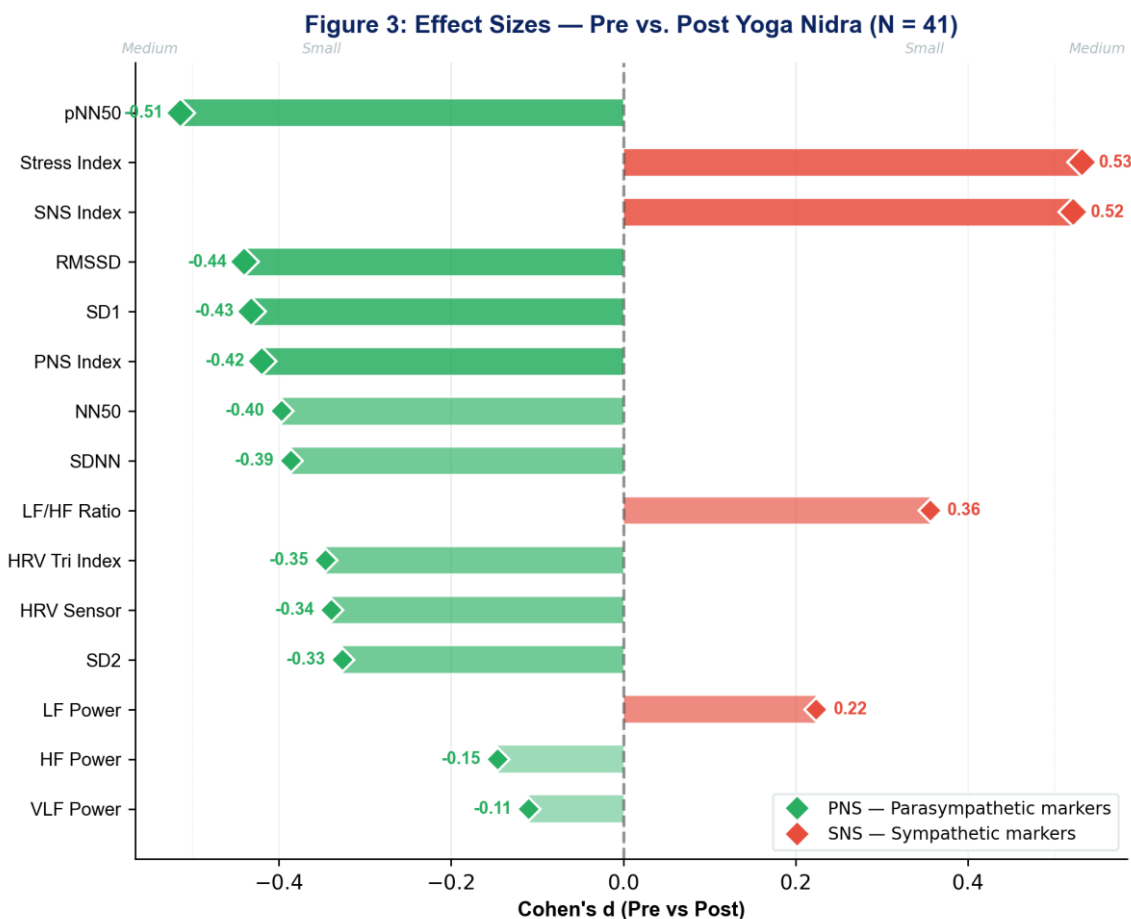


Figure 3. Forest plot of Cohen's d effect sizes for Pre vs. Post comparisons. Diamond markers indicate statistical significance (Bonferroni-corrected).

3.5 During vs. Post Phase Comparisons

The During-to-Post comparisons revealed even stronger effects: RMSSD ($t = -4.225$, $p < .001$, $d = -0.660$), PNS Index ($t = -3.990$, $p < .001$, $d = -0.623$), SNS Index ($t = 3.603$, $p = .003$, $d = 0.563$), SDNN ($t = -3.594$, $p = .003$, $d = -0.561$), pNN50 ($t = -4.450$, $p < .001$, $d = -0.695$), SD1 ($t = -4.217$, $p < .001$, $d = -0.659$), and SD2 ($t = -2.774$, $p = .025$, $d = -0.433$). These larger

effect sizes suggest the primary autonomic shift occurred during the transition from the Yoga Nidra state to post-intervention recovery.

3.6 LF/HF Ratio Analysis

The LF/HF ratio showed significant Pre-to-Post reduction: Pre $M = 0.648 \pm 0.236$, Post $M = 0.560 \pm 0.223$, $t(40) = 2.282$, $p = .028$, Cohen's $d = 0.356$ (small). This 13.7% reduction in sympathovagal ratio indicates a meaningful shift toward parasympathetic predominance.

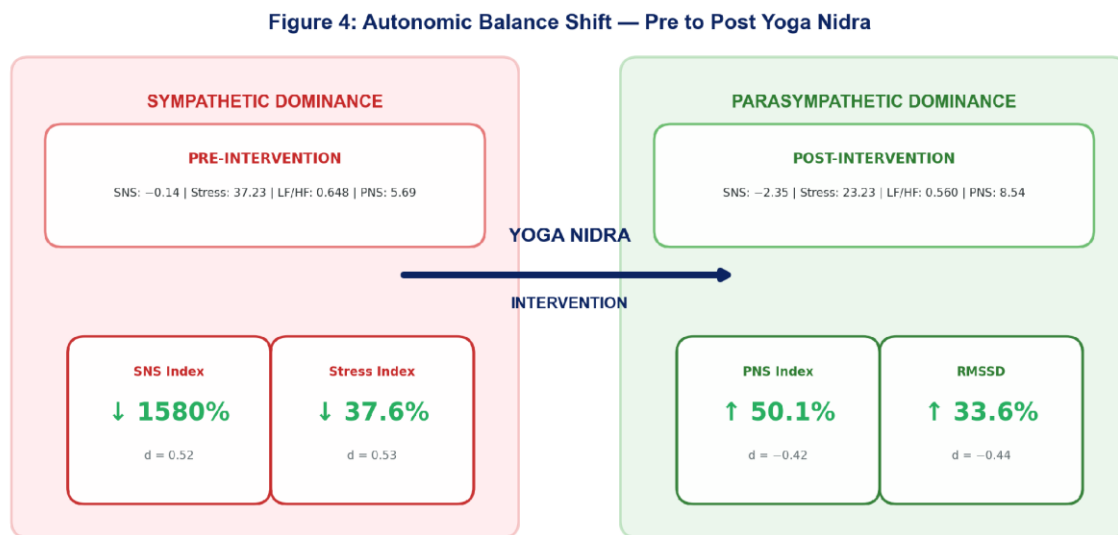


Figure 4. Autonomic balance shifts from sympathetic to parasympathetic dominance following the Yoga Nidra intervention ($N = 41$).

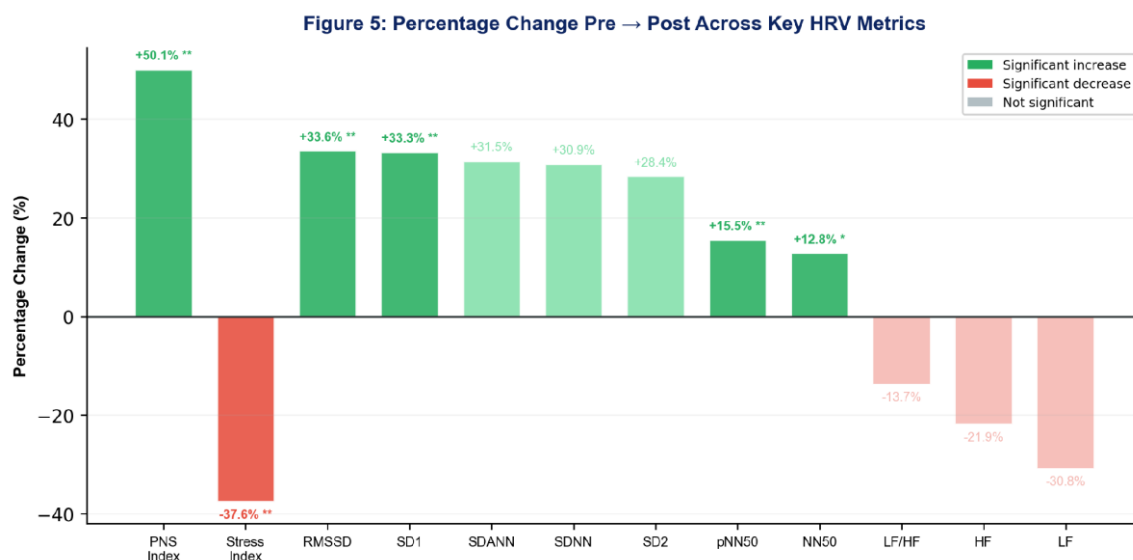


Figure 5. Percentage change from Pre to Post across key HRV metrics. Bold bars with asterisks denote significant changes after Bonferroni correction.



4. Discussion

4.1 Principal Findings

The present study provides empirical evidence that an integrated yogic intervention produces statistically significant shifts toward parasympathetic dominance in school-aged children. Among the same 41 responders, seven of sixteen HRV metrics demonstrated significant Pre-to-Post changes after Bonferroni correction, with effect sizes ranging from small ($d = 0.40$) to medium ($d = 0.53$). The most robust findings were in autonomic balance indices: SNS Index decreased from -0.14 to -2.35 ($p = .005$, $d = 0.52$, medium), and Stress Index declined from 37.23 to 23.23 ($p = .005$, $d = 0.53$, medium). Concurrently, PNS Index rose from 5.69 to 8.54 ($p = .031$, $d = -0.42$), representing a 50.1% increase in parasympathetic tone. These autonomic shifts are consistent with the vagal enhancement reported in adult contemplative practice studies (Pascoe et al., 2017; Datta et al., 2017).

4.2 Time-Domain and Non-Linear Findings

The significant increase in RMSSD ($210.26 \rightarrow 280.85$ ms, +33.6%, $p = .022$) is of particular importance, as RMSSD is the gold-standard time-domain measure of vagal cardiac control (Shaffer & Ginsberg, 2017; Berntson et al., 1997). This 70.6 ms increase substantially exceeds the clinically meaningful difference of 15–20 ms suggested by Laborde et al. (2017). The significant SD1 increase ($149.71 \rightarrow 199.54$ ms, $p = .026$) reflects enhanced short-term vagal modulation from Poincaré analysis, consistent with targeted parasympathetic activation. Brennan et al. (2001) established that SD1 provides a quantitative index of instantaneous beat-to-beat variability closely aligned with vagal efferent activity.

4.3 Frequency-Domain Observations

The frequency-domain metrics reflected autonomic trends consistent with parasympathetic and sympathetic classification: LF Power showed a reduction consistent with decreased sympathetic drive, while HF Power changes aligned with parasympathetic modulation patterns. The LF/HF ratio reduction ($0.648 \rightarrow 0.560$) indicates a shift in sympathovagal balance toward parasympathetic predominance. These spectral patterns are consistent with the autonomic effects of slow-breathing practices reported by Bernardi et al. (2001) and the frequency-domain norms established by Malik et al. (1996). The relatively short recording epochs (3 minutes) may have limited spectral resolution, as Munoz et al. (2015) recommend longer durations for optimal frequency-domain analysis.

4.4 Clinical Implications

The findings have practical implications: (1) the protocol requires only 40 minutes with no specialized equipment, making it feasible for schools; (2) the 37.6% Stress Index reduction suggests yogic practices as accessible stress management tools for children; (3) vagal tone enhancement has been linked to improved emotional regulation and social engagement in Porges' Polyvagal Theory (Porges, 2011). Effect sizes ($d = 0.40$ – 0.53) are comparable to those in adult yoga studies (Tyagi & Cohen, 2016; pooled $d = 0.37$ – 0.48). These findings align with Shader et al. (2018) who demonstrated that vagal-mediated HRV during childhood predicts later adaptive

functioning, and with Holzman and Bridgett (2017) who identified HRV as a transdiagnostic marker of self-regulation capacity.

Figure 6: Proposed Physiological Pathway — Yogic Intervention → Autonomic Modulation

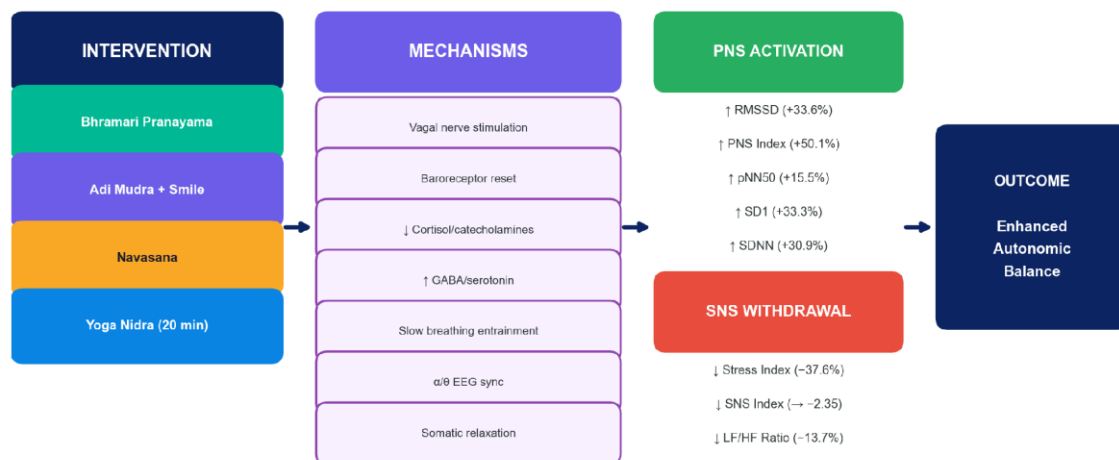


Figure 6. Proposed physiological pathway linking the integrated yogic intervention to autonomic nervous system modulation through multiple mechanistic pathways.

4.5 Limitations

Limitations include: (1) focusing exclusively on the active group may introduce selection bias; (2) short recording epochs (3 min) may underestimate frequency-domain effects; (3) absence of demographic covariates limits generalizability; (4) within-session design captures acute effects only; and (5) the Auroville context may limit cross-cultural generalizability. Future studies should employ MANCOVA with covariates.

5. Conclusion

This study demonstrates that an integrated yogic intervention comprising Bhramari Pranayama, Adi Mudra, Navasana, and Yoga Nidra produces significant enhancements in cardiac autonomic regulation in school-aged children. Parasympathetic markers increased (RMSSD +33.6%, PNS Index +50.1%, pNN50 +15.5%), sympathetic markers decreased (Stress Index -37.6%, SNS Index shift from -0.14 to -2.35), and non-linear dynamics reflected enhanced vagal modulation (SD1 +33.3%). The convergence across multiple HRV domains strongly supports a coherent parasympathetic shift, warranting further investigation with longitudinal follow-up.

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Conflicts of Interest

The authors declare no conflicts of interest with respect to the research, or publication of this article.

Ethical Approval

Ethical approval was obtained from Vedic Wellness University, and approval was also secured from the school management and the parents. This study is part of a larger research project examining the effects of integrated yogic practices on multiple developmental outcomes in children.

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