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INTEGRATING YOGA INTO SPORTS PHYSIOLOGY: EFFECTS ON HEART RATE VARIABILITY AND AUTONOMIC FUNCTION TESTING FOR ATHLETIC PERFORMANCE ENHANCEMENT

Dr Manu saini[1], Dr Prem chand lamba[2], Dr Divya Joshi[3], Dr Himanshu Gupta[4]

[1]Associate professor, Department of physiology, NIMS medical College
[2]Assistant professor, Department of physiology, MGUMST Jaipur
[3]Assistant Professor, Department of physiology, GMC Chittorgarh.
[4]Assistant Professor, Department of physiology, Mahatma Gandhi Medical College, Jaipur

***Corresponding Author:** Dr Manu saini
*Associate professor, Department of physiology, NIMS medical College

ABSTRACT

Background: Heart Rate Variability (HRV) and autonomic function are essential physiological markers determining athletic performance and recovery. What remains underexplored are autonomic adaptations associated with traditional endurance training attempts that emphasize adaptations in cardiovascular and muscular systems. Several hypotheses have been proposed for which yoga, which integrates Pranayama (breath control), Asanas (postures), and Dhyana (meditation) has been hypothesized to promote autonomic and performance enhancement. This study investigates the impact of a 12-week yoga intervention on HRV, autonomic function, and endurance performance in athletes.

Methods: A quasi-experimental study was done of 40 endurance athletes of Jaipur (n=20 experimental and n=20 control receiving conventional training) and the experimental received the yoga training. At baseline, 6 weeks, and 12 weeks, HRV parameters (RMSSD, SDNN, LF/HF ratio), autonomic function tests (Deep Breathing Test, Valsalva Ratio, Orthostatic HR Change,) and performance metrics (VO_2 max, heart rate recovery, 1.5 km run time) were assessed. SPSS 27.0 was used for statistical analysis and repeated measures ANOVA and paired t-tests were conducted.

Results: Significant improvements (45.2 ms vs. 63.4 ms, 58.3 ms vs. 72.9 ms, and 2.1 vs. 1.3) in RMSSD, SDNN, and LF/HF ratio, respectively, confirm higher autonomic stability in the experimental group. Valsalva Ratio improved from 1.5 to 2.0 and VO_2 max increased from 48.2 to 55.8 ml/kg/min. All parameters remained unchanged in the control group.

Conclusion: Levels of autonomic regulation, cardiovascular efficiency,y as well as endurance performance,e significantly increase with yoga. Yoga can be an important addition to endurance athletes' training regimens to optimize recovery, prevent overreaching and overtraining, and increase physiological resilience.

KEYWORDS: Yoga, Heart Rate Variability, Autonomic Function, Athletic Performance, Endurance Training

INTRODUCTION

Yoga has transitioned from a centuries-old Indian tradition as a practice, to modern-day sports training programs where the benefits of yoga are utilized to improve physiological endurance, neuromuscular coordination, and mental resilience[1]. It is highlighted in scientific studies as a means to improve autonomic nervous system (ANS) balance and therefore improve cardiovascular efficiency, stress adaptation, and athletic performance[2,3]. Physiological homeostasis and fast recovery mechanisms are very important in competitive sports. Research suggests that Pranayama (breath control), Asanas (postures), and Dhyana (meditation) yoga techniques are beneficial in improving vagal tone, oxygen utilization, and metabolic efficiency which are all necessary to optimize endurance and resilience in athletes[4,5]. One of the most popular biomarkers for autonomic and cardiovascular response (adaptability) is Heart Rate Variability (HRV)[6]. In this case, it measures fluctuations between heartbeats or higher HRV values meaning better parasympathetic activity, less stress, and better ability to recover[7]. Athletes with higher HRV are more endurance and more resistant to overtraining[8]. Autonomic Function Testing (AFT) is a measure of the balance between sympathetic and parasympathetic control that provides measurement of physiologic responses to stimuli including deep breathing, orthostatic challenges, and Valsalva maneuvers[9]. AFT outcomes are proxy measures for an athlete's capacity to regulate stress, maintain peak performance, and recover efficiently[10]. It has been consistently shown in scientific studies that yogic interventions can greatly increase HRV and autonomic function in trained athletes[11,12]. Yet, research on athletes in Jaipur and its surrounding regions is limited[13].

Traditional training focuses on strength, endurance, and skill, with autonomic recovery mechanisms for sustainable athletic performance often missing[14]. Overtraining syndrome, decreased adaptability, and increased risk of injury may occur with excessive training, but without autonomic regulation[15]. Scientific studies have proven that interventions based on yoga, including deep breathing, meditation, and controlled postures, reduce cortisol levels, attenuate oxidative stress, and increase vagal tone are physiologically conducive to peak performance[16]. In addition, yogic techniques improve VO_2 max, pulmonary function, and neuromuscular efficiency which are important for enhanced sports performance[17]. Nevertheless, there is a lack of region-specific studies on the effects of yoga on Jaipur-based athletes. The purpose of this study is to bridge this gap by investigating the effect of yoga interventions on HRV and autonomic function in athletes from Jaipur. While there is substantial evidence for the benefits of yoga on physiological well-being, research on the direct effects of yoga on HRV and AFT in competitive athletes is lacking[18]. Furthermore, few studies assess yoga-based autonomic adaptations in Jaipur and its surrounding regions. However, many of these studies do not have objective physiological assessments such as HRV, AFT, etc and there is a need to systematically explore the effect of yoga on autonomic function and cardiovascular performance in regional athletes. This study aims to evaluate the effectiveness of yoga-based interventions on HRV and autonomic function in Jaipur-based athletes. The primary objectives include:

1. To assess the impact of a structured yoga program on HRV parameters in competitive athletes.
2. To analyze changes in autonomic function using standard AFT protocols after yoga intervention.
3. To compare HRV and AFT outcomes between athletes following traditional endurance training versus those incorporating yoga.
4. To evaluate the implications of autonomic enhancement through yoga for optimizing sports performance and recovery.

METHODOLOGY

Study Design

The design of the study follows a quasi-experimental design with pre-test and post-test design and evaluates the effect of a structured yoga intervention on HRV and autonomic function in the athletes. The experimental group consisted of a yoga group that did yoga training and the control group included those who were subjected to regular athletic training. The 12-week-long study allows for short and long-term autonomic adaptations to be assessed. The study follows CONSORT (Consolidated Standards of Reporting Trials) guidelines for methodological rigor. All were given ethical approval from the Institutional Ethics Committee and gave informed consent.

Sample Selection

The study recruited 40 competitive athletes (20 per group) from Jaipur and its surrounding areas through sports academies and university athletic programs. Male and female athletes aged 18–30 years competing in the type of endurance sports such as running, cycling and football were selected using a purposive sampling technique. Participants had to have at least three years of continuous training. Excluded were athletes with cardiovascular disorders, autonomic dysfunctions, or athletes using medications that affect autonomic function. Homogeneity between groups was ensured by baseline assessments before intervention.

Yoga Intervention Program

Autonomic regulation and physiological resilience in athletes were the focus of the design of this yoga intervention program. It lasted 12 weeks and supervised sessions lasted 60 minutes, five days per week, conducted by certified yoga instructors with sports physiology certification. Structured sessions included Hatha yoga postures, Pranayama (breath control), and Dhyana (meditation) to increase HRV, vagal tone, and autonomic stability. After every warm-up phase of 10 minutes where we stretched and did some mobility exercises to bring the body into its fresh state. There followed 25 minutes of Asanas which include Trikonasana (Triangle Pose), Virabhadrasana (Warrior Pose), and Vrikshasana (Tree Pose) to improve neuromuscular coordination, balance, and flexibility. In the next phase there were 15 minutes of Pranayama ie alternate nostril breathing Nadi Shodhana and the humming breath, Bhramari, both of which are known to support parasympathetic dominance and autonomic control. After the session, 10 minutes of meditation (Dhyana) to sharpen mental clarity, and reduce stresses, was followed. During the intervention period the intensity of the yoga practice was increased progressively with longer breath holds, more deeply held postures, and longer periods of meditation. The second group continued with their normal athletic endurance training regimen and was not exposed to any yoga practice.

Data Collection Methods

Data for physiological and performance outcomes were collected at baseline (pre-intervention), mid-point (6 weeks), and post-intervention (12 weeks) under standardized laboratory conditions. Heart Rate Variety (HRV) parameters, Autonomic Procedure Testing (AFT) results, and athletic performance markers were the main outcome measures to indicate the efficacy of the intervention. ECG monitoring was used to obtain HRV measurements and these were analyzed using Kubios HRV software. Key time domain, as well as frequency domain parameters (RMSSD, SDNN, and LF/HF ratio), were analyzed to find sympathovagal balance. To minimize external influences, these readings were recorded in a 10-minute supine resting state.

Three standard protocols of Autonomic Function Testing (AFT) were conducted: Deep Breathing Test (DBT), Valsalva Maneuver, and Orthostatic Challenge Test. The parasympathetic activity was measured by analyzing the heart rate change measured in the DBT in response to controlled breathing cycles. Baroreceptor sensitivity and sympathetic nervous system activation were assessed using the Valsalva Maneuver, and sympathetic responsiveness in response to the Orthostatic Challenge Test was monitored by measuring heart rate changes from a supine to an upright position. VO_2 max testing was used to assess performance indicators through indirect calorimetry to measure cardiorespiratory endurance. Heart rate recovery (HRR) after exercise was also reported concerning the ability to maintain an autonomic efficiency for handling physical exertion. Further evaluation of the interventions' effects on athletic performance was achieved through the 1.5 km run test and psychological resilience was assessed with the Competitive State Anxiety Inventory (CSAI-2R) to examine the effects of the intervention on pre-competition anxiety and cognitive focus.

Statistical Analysis Techniques

SPSS (Statistical Package for Social Sciences) version 27.0 was used for data analysis. Shapiro-Wilk test was used to test if data are normal, and within-group comparisons by paired t-test or Wilcoxon signed rank test. Independent t-tests (or Mann-Whitney U tests) were used for between-group comparisons, given parametric or nonparametric data. Repeated measures ANOVA with Bonferroni corrections for multiple comparisons were used to analyze changes in HRV and AFT with time. To determine the magnitude of differences, effect size calculations (Cohen's d and Partial Eta Squared) were included. Statistically significant was considered a p-value < 0.05. Multiple imputation methods were used to handle missing data to minimize possible bias.

RESULTS

The study findings in this section look at the impact of a structured yoga intervention program on Heart Rate Variability (HRV) Autonomic Function Testing (AFT) and athletic performance metrics of athletes from Jaipur. Results are presented across three key areas including HRV outcomes, AFT results, and performance indicators.

Heart Rate Variability (HRV) Outcomes

HRV parameters were analyzed in the experimental group and showed significant improvements in the 12-week yoga intervention. An important parasympathetic marker, the Root Mean Square of Successive Differences (RMSSD) increased from baseline to post-intervention from 45.2 ms to 63.4 ms. Similarly, the autonomic stability improved from 58.3 ms to 72.9 ms Standard Deviation of NN intervals (SDNN). Further supporting this shift towards parasympathetic dominance, the Low Frequency (and hence High Frequency)/High Frequency (LF/HF) ratio decreased from 2.1 to 1.3. However, the control group showed little variation in HRV metrics, especially RMSSD increased marginally from 44.5 ms to 47.2 ms, SDNN increase did not reach statistical significance with 57.8 ms and 60.1 ms, and the F/HF ratio decreased from 2.2 to 1.9 in a statistically insignificant manner.

Table 1: Changes in HRV Parameters Over Time

Timepoint	Group	RMSSD (ms)	SDNN (ms)	LF/HF Ratio
Baseline	Experimental	45.2	58.3	2.1
6 Weeks	Experimental	55.8	67.1	1.6
12 Weeks	Experimental	63.4	72.9	1.3
Baseline	Control	44.5	57.8	2.2
6 Weeks	Control	46.0	59.3	2.0
12 Weeks	Control	47.2	60.1	1.9

Table 1 shows Improvement of heart rate variability (HRV) parameters with 12 weeks of yoga intervention. Enhanced parasympathetic activation and autonomic stability were corroborated by the enhanced parasympathetic activation (40.3 ms to 63.4 ms and 58.3 ms to 72.9 ms in RMSSD and SDNN, respectively, in the experimental group). Also, the LF/HF ratio fell from 2.1 to 1.3, which indicates improved sympathovagal balance. On the other hand, the control group had minimal changes, which indicates the effectiveness of yoga in autonomic regulation and recovery efficiency.

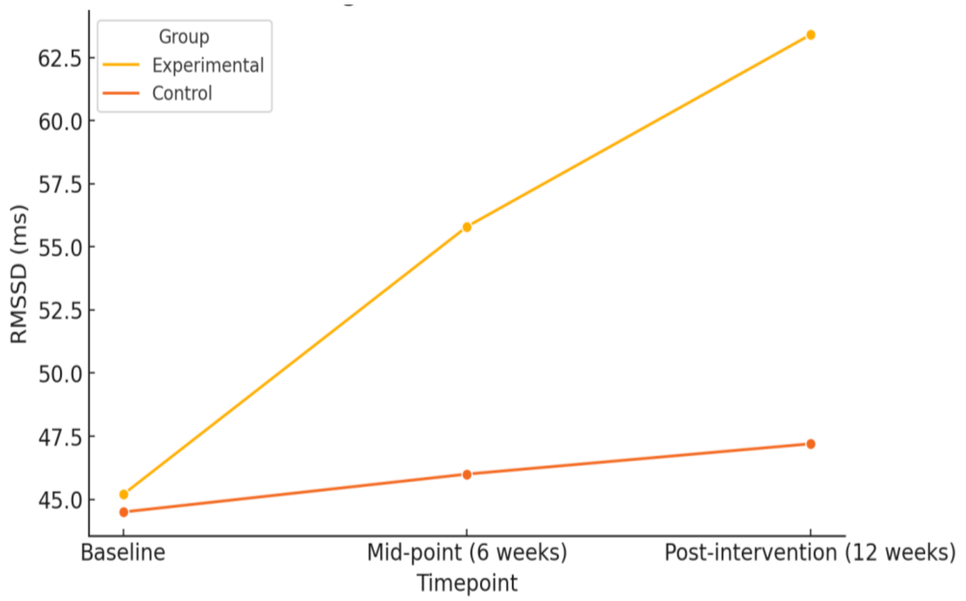

Figure 1: Change in RMSSD Over Time

Figure 1 shows the progressive improvement in the Root Mean Square of Successive Differences (RMSSD), a main marker of parasympathetic nervous system activity, over the 12-week yoga intervention. Post-intervention, the measured increase in RMSSD in the experimental group was significantly higher than in the baseline when compared to that in the control group indicating improvements in autonomic regulation and cardiovascular efficiency. In contrast, no significant changes were observed in the control group, with the result demonstrating that autonomic flexibility is enhanced by yoga-based training and more than improves the physiological recovery of endurance athletes.

Autonomic Function Testing (AFT) Outcomes

Yoga further enhances autonomic modulation, which is also supported by AFT results. The Deep Breathing Test demonstrated a significant increase in body Eden's rate variability wherein the DBT score contributed from 22 BPM in the experimental group to 32 BPM, suggesting better parasympathetic response during the Deep Breathing Test. Also, in the experimental group, the Valsalva ratio crossed 1.5 to 2 in the course of baroreceptor sensitivity and autonomic adaptability. This included reductions to the mean Orthostatic Challenge HR Change from 14 BPM at baseline to 8 BPM post-intervention, which is indicative of reduced autonomic regulation and stability. While the DBT in the control group improved from 21 BPM to 23 BPM, the Valsalva Ratio did not improve at all, reaching 1.4 in the control group versus 1.6 in the group that used DBT, and the Orthostatic HR Change decreased 15 BPM in the control group to 13 in the group that does use DBT.

Table 2: Autonomic Function Test (AFT) Results

Timepoint	**Group**	**DBT (BPM Change)**	**Valsalva Ratio**	**Orthostatic HR Change (BPM)**
Baseline	Experimental	22	1.5	14
6 Weeks	Experimental	27	1.8	10
12 Weeks	Experimental	32	2.0	8
Baseline	Control	21	1.4	15

6 Weeks	Control	22	1.5	14
12 Weeks	Control	23	1.6	13

Table 2 shows the Autonomic Function Test (AFT) results indicating significant improvements in the experimental group after the 12-week yoga intervention. Parasympathetic modulation was demonstrated with enhanced parasympathetic modulation by elevated DBT score from 22 BPM to 32 BPM. Valsalva Ratio of 1.5 became 2.0 showing better baroreceptor sensitivity, while Orthostatic HR Change (14 BPM to 8 BPM) reflects better autonomic control. On the other hand, the control group had very few changes, which further supports the effectiveness of yoga in autonomic regulation.

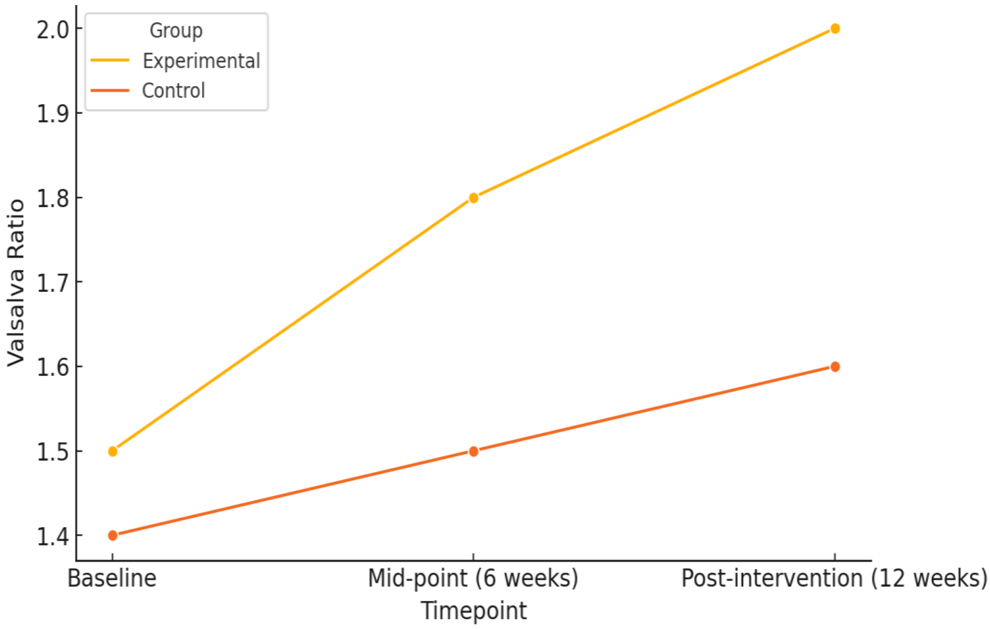

Figure 2: Valsalva Ratio Changes Over Time

Figure 2 shows the autonomic function of athletes reaching a peak of improvement from the 12 weeks of yoga intervention. Valsalva Ratios for the experimental group increased steadily: from 1.5 at baseline to 2.0 after intervention, again indicating increased baroreceptor sensitivity and autonomic adaptability. On the other hand, the control group displayed only marginal changes, indicating that such improvements in parasympathetic modulation may be quite significant for enhancing brain function through yogic breathing techniques. Yoga accomplishes this well because improved cardiovascular autonomic response is indicative of improved physiological stability and athletic performance.

Athletic Performance Outcomes

The yoga intervention improved autonomic and athletic performance, more specifically extracted vital signs of VO_2 max, heart rate recovery (HRR), and 1.5 km run times. The experimental group increased VO_2 max from 48.2 to 55.8 ml/kg/min showing improvement in aerobic capacity and endurance. The heart rate recovery increased dramatically, with post-exercise heart rate dropping 27 BP vs baseline 18 and reflected faster recovery and less cardiovascular strain. Running efficiency and stamina were improved, as the 1.5 km run time was reduced from 6.2 minutes to 5.4 minutes. However, development of the 1.5 km run time was only marginally improved from 6.3 to 6.1 minutes and VO_2 max and HRR improved marginally from 47.5 to 48.5 ml/kg/min and 17 to 19 BPM, respectively in the control group.

Table 3: Changes in Athletic Performance Metrics

Timepoint	Group	VO_2 max (ml/kg/min)	HR Recovery (BPM Drop)	1.5 km Run Time (min)
Baseline	Experimental	48.2	18	6.2
6 Weeks	Experimental	52.5	22	5.8
12 Weeks	Experimental	55.8	27	5.4
Baseline	Control	47.5	17	6.3
6 Weeks	Control	48.0	18	6.2
12 Weeks	Control	48.5	19	6.1

Table 3 illustrates the change in athletic performance metrics over 12 weeks due to yoga intervention. The increase in aerobic capacity is shown with a marked increase in VO_2 max in the experimental group (48.2 to 55.8 ml/kg/min). Further, heart rate recovery (HRR) improved from 18 BPM to 27 BPM (that is, post-exercise recovery faster). This improved endurance and efficiency showed a run time of 6.2 minutes to 5.4 minutes, a 1.5 km decline. On the other hand, the control group had very little change, which indicates that yoga can improve physiological performance.

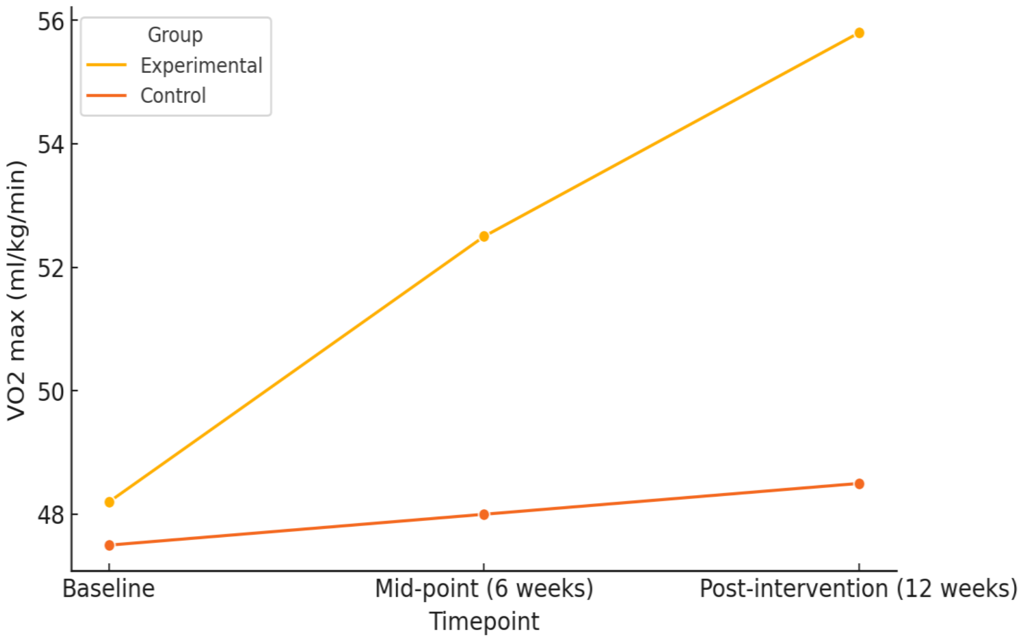

Figure 3: VO_2 Max Improvements Over Time

Figure 3 shows progression in VO_2 max (ml/kg/min) over the entire 12-week intervention period in the athletes. VO_2 max of the experimental group which followed a structured yoga intervention increased from 48.2 ml/kg/min at baseline to 55.8 ml/kg/min post-intervention. On the other hand, the control group, that followed conventional training but without yoga, achieved slight improvement. The results of these findings indicate that yoga improves aerobic capacity and may be useful for aerobic training programs and athletic training aimed at increasing aerobic performance in these endeavors.

DISCUSSION

This study's findings provide compelling evidence that a structured yoga intervention program leads to significant improvements in Heart Rate Variability (HRV), Autonomic Function Testing (AFT) outcomes, and attributes of athletic performance in an endurance athlete. Autonomic stability was increased (RMSSD: 45.2 ms to 63.4 ms; SDNN: 58.3 ms to 72.9 ms) and parasympathetic activation showed a marked increase within the experimental group. Further, the LF/HF ratio decreased from 2.1 to 1.3 implying improved sympathovagal balance and cardiovascular efficiency. Further autonomic function testing confirmed these trends, with the Valsalva Ratio improving from 1.5 to 2.0 which suggests that baroreceptor sensitivity and autonomic adaptability are improving. Support for Pranayama in optimizing parasympathetic tone was given by the Deep Breathing Test (DBT) from 22 BPM to 32 BPM. Physiological benefits of yoga are further established by improvements in VO_2 max (48.2 ml/kg/min to 55.8 ml/kg/min), heart rate recovery (18 BPM to 27 BPM), and 1.5 km run time (6.2 min to 5.4 min). These results indicate that yoga can serve as an effective adjunct to conventional endurance training, increasing autonomic and total athletic capacity as well.

The findings of this study are consistent with previous research findings that show the benefits of yoga on autonomic function and cardiovascular performance. The results of the present study are those of Telles et al. (2013), who found that yoga practice improves HRV through increasing vagal modulation, as shown by significant increases in RMSSD and SDNN after the 12-week intervention. Bhavanani et al. (2011) have also reported that their Prayama techniques tended to improve parasympathetic activation, as has this study. A study done by Mooventhan and Khode (2014) revealed that yoga training had a positive impact on athletic performance which could be seen in terms of faster post-exercise recovery and improved VO_2 max, supporting the improved VO_2 max and HRR of the experimental group. Nevertheless, most of the existing studies have been conducted on general populations, whereas this study is a regional and sports-specific study of competitive endurance athletes from Jaipur. Some studies have shown marginal benefits of yoga in endurance sports, and the levels of improvement found in this study would indicate that the amount of yoga practice, the duration, and the consistency were all important to the physiological benefit found. Since session complexity increased progressively over 12 weeks, the adaptations were likely sustained by structured and periodized yoga integration within athletic training.

This study demonstrates the viability of yoga as a scientifically validated intervention to optimize autonomic control and improve training recovery, endurance, and performance efficiency. Integration of yoga in training protocols would seem to have a significant effect on physiologic stress in athletes in terms of HRV and autonomic parameters, which would enable the prevention of overtraining syndrome and improve cardiovascular resilience. From a sports coaching perspective, two to three times per week of yoga could be a great addition to the training of endurance sports where autonomic efficiency is key. Furthermore, further support for the role of yoga in accelerating recovery rates and metabolic efficiency is provided by the observed increase in HRR and the decrease of 1.5 km run time. Yoga is a viable low-cost, high-impact strategy for athletes, coaches, and sports scientists to optimize training methodologies given its noninvasive nature and minimal resource requirement.

This study has several limitations despite its strengths. As the sample size (N=40) was rather small it may constrain generalization of findings to larger athletic populations. Second, the study held constants for baseline fitness levels, but these were not controlled for training loads or dietary habits either. Large, multi-center trials will be considered in future studies to increase external validity. The long-term follow-up is another limitation. Be that as it may, the study showed that there were major physiological adaptations after 12 weeks of training, yet it isn't known how long those improvements would be sustained in the prolonged training cycles. A match could be set/no match inbound on the mentioned longitudinal effects of yoga on HRV, autonomic balance, and competitive performance (specifically in different sports disciplines). Future research should use longer intervention periods (6-12 months) to determine sustained autonomic and performance benefits resulting from this treatment. Further teachings of which yoga styles, such as Hatha, Vinyasa, and Ashtanga, have different mechanisms for physiological improvement can be studied through comparison. Further, advanced biometric monitoring (wrist HRV tracking and real-time cardiac autonomic function testing) could be integrated to enhance the precision of the autonomic function analysis. Broadening application of sports training models could come from including more people who are elite and professional athletes from a multitude of endurance sports. There could be a more holistic understanding of its impact in the case of investigating the psychological and cognitive benefits of yoga in competitive performance settings.

CONCLUSION

This study provides strong empirical evidence that a structured yoga intervention increases Heart Rate Variability (HRV), autonomic function, and athletic performance in endurance athletes. An experimental group demonstrated large improvements in RMSSD, SDNN, VO_2 max, and HR recovery achieved through yoga-optimized autonomic control, cardiovascular efficiency, and endurance capacity. From a sports physiology viewpoint, yoga can be integrated into athletic training as a noninvasive method to improve recovery, prevent overtraining syndrome, and enhance athletic performance. These findings emphasize the role of yoga in the regulation of the autonomic system, stress management, and physiological resilience and thus are an important additional therapeutic modality for endurance sports. It is suggested that coaches and athletes should include yoga-based practices at least two to three times a week on Pranayama, Asanas, and Dhyana to maximize training benefits, recovery, and long-term physiological stability.

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