

ORIGINAL ARTICLE

Heart Rate Variability Analysis in Young Badminton Players: Comparing Amateurs vs. Professionals With Gender Exploration – A Cross-Sectional Study

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ABSTRACT

Introduction: Heart Rate Variability (HRV) is a vital tool in sports science, reflecting autonomic nervous system balance and training adaptation. By assessing R-R intervals, HRV optimizes athletic performance across time and frequency domains. This study compares HRV parameters between professional and amateur badminton players and explores gender-specific differences within these groups. **Method:** A cross-sectional study was conducted among 127 badminton players (67 males, 60 females) aged 15–24 years in Chennai (September–December 2023). Participants were selected via simple random sampling. Data were collected through face-to-face interviews using a pretested structured questionnaire. Statistical analysis was performed using SPSS version 27, with significance set at P value <0.05. **Results:** The mean age was 17.68 ± 3.21 years for professionals and 18.23 ± 3.54 years for amateurs. Skill level significantly impacted heart rate, RMSSD, and SDNN. An interaction effect between gender and skill level was observed for RMSSD and SDNN, though not for heart rate. Additionally, male and female amateurs exhibited significant differences in HRV parameters (RMSSD and SDNN). **Conclusion:** This study established enhanced cardiovascular adaptability with intensified training and, also prompted to explore further interaction between gender and skill on HRV and influence of hormones.

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INTRODUCTION

Badminton is a dynamic and demanding racquet sport that requires a unique blend of cardiovascular fitness, agility, and strategic thinking making it imperative to understand the intricate physiological responses associated with this sport (1). As sports science continues to evolve, there is a growing interest in exploring innovative tools for assessing and optimizing athletic performance. One such tool that has gained prominence in recent years is heart rate variability (HRV).

HRV is an indicator that mirrors the delicate equilibrium between the sympathetic and parasympathetic divisions of the autonomic nervous system (ANS) (2). As a non-invasive measure of cardiac autonomic modulation, HRV assesses the fluctuation in time intervals between consecutive normal R-R intervals (2,3). It is expressed through various parameters in time and frequency domains. It is widely utilized to monitor training

adaptation and optimize sports performance. Studies have found that better HRV profiles, characterized by elevated normal-to-normal (NN) intervals, standard deviation of NN intervals (SDNN) (ms), and high-frequency (HF) (m2) power, are associated with improved aerobic capacity and endurance performance (4).

Research on sex differences in HRV indicates that women generally exhibit increased parasympathetic and decreased sympathetic control of heart rate compared to men(5,6), although both genders benefit from long-term endurance training with improvements in HRV parameters(4). As athletes navigate the complexities of badminton, understanding their physiological responses becomes paramount for coaches, trainers, and sports scientists seeking to tailor training regimens, monitor recovery (1).

In the context of badminton, where split-second decisions and explosive movements are the norm, the integration of HRV analysis provides a nuanced perspective on the athlete's adaptability to training loads. HRV is crucial in badminton because it can offer insights into the player's recovery status, stress levels, and overall cardiovascular

health, which are essential for maintaining peak performance. Additionally, by analysing HRV, coaches can personalize training programs to enhance performance and reduce the risk of overtraining. Despite the known benefits of HRV analysis, there is a paucity of literature specifically addressing HRV in badminton players. Many players experience issues related to overtraining, inadequate recovery, and suboptimal performance due to the sport's physical demands and the high frequency of competition. Understanding HRV can help mitigate these issues by providing detailed insights into the autonomic regulation of athletes, thereby informing better training and recovery strategies. Hence there is paucity of literature on this topic, we aimed at understanding the HRV among professional and amateur badminton players and to explore the gender differences within each group.

Heart rate variability serves as a vital indicator of autonomic nervous system balance and cardiovascular adaptability, particularly in athletic population. While HRV have been extensively studied as a tool for optimizing training and performance, there remains a limited understanding of how factors like skill level [profession vs amateur] and gender differences influence HRV among badminton players. Furthermore, the interaction effects of gender and skill level on HRV parameters such as RMSSD and SDNN, along with the underlying physiological mechanisms, are not well explored. This gap hinders the ability to design personalized training protocols and optimize performance based on specific athlete profiles. Addressing these gaps is crucial for enhancing training strategies and promoting evidence-based interventions tailored to the unique needs of professionals and amateur athletes across genders

MATERIALS AND METHODS

This cross-sectional study was conducted across various badminton academies in Chennai, Tamil Nadu, India, between September and December 2023, involving a final sample of 127 participants selected through simple random sampling from an initial pool of 141 interested individuals. The study included non-smoking and non-alcoholic males and females aged 15 to 24 years, while excluding those with a BMI under 25 kg/m², recent injuries, chronic pain, or diagnosed cardiovascular, endocrinological, or psychiatric disorders, as well as those on regular medication. Participants were operationally categorized by skill level, with professional players defined as those competing at district to international levels with 12 to 15 hours of weekly training, and amateur players defined as recreational participants training 4 to 6 hours per week for local tournaments. Data collection utilized a structured English questionnaire for demographics and the McLean’s Wellness questionnaire to assess baseline fatigue, muscle soreness, sleep quality, stress, and mood prior to heart rate variability (HRV) acquisition via the

Biosignalplux wireless explorer. Following informed written consent and face-to-face interviews, participants adhered to a strict pre-recording protocol involving overnight fasting, avoidance of stimulants for two hours, 7 to 8 hours of quality sleep, and no exhaustive exercise for 24 hours. Recordings were conducted between 7:00 AM and 9:00 AM in a semi-dark room at 20–22°C after a 10-minute supine relaxation period. HRV was recorded for 7 to 10 minutes, with a 5-minute standardized segment extracted to analyze time-domain parameters, specifically the standard deviation of NN intervals (SDNN) and the root mean square of successive RR interval differences (RMSSD).

Statistical analysis was performed using IBM SPSS Statistics version 27.0, expressing quantitative variables as Mean ± SD or Median (IQR) after assessing normality through histograms and skewness values (skewness between -0.5 to +0.5: normal distribution). A two-way ANOVA was employed to determine the mean differences in SDNN and RMSSD between professional and amateur players and their interaction with gender, while independent sample t-tests evaluated gender differences within each group separately, with significance set at p < 0.05. Ethical clearance for the study was provided by the Institutional Ethics Committee of Saveetha Medical College and Hospital under reference number 014/05/23/IEC/SMCH.

RESULTS

The study included 127 participants, comprising 62 professional and 65 amateur players, with a balanced gender distribution (Table I). The mean age was 17.68 ± 3.21 years for professional players and 18.23 ± 3.54 years for amateurs. Overall, the mean heart rate, RMSSD, and SDNN among all players were 70.43 ± 7.63 bpm, 63.86 ± 16.67 ms, and 63.53 ± 17.07 ms, respectively.

As shown in Table II, there was no significant main effect of sex on heart rate (p = 0.178). However, a significant main effect of skill level was observed, with amateurs demonstrating higher heart rates compared to professionals (p < 0.001). No significant interaction effect between sex and skill level was found for heart rate (p = 0.677).

Similarly, for HRV indices, no significant main effects of sex were observed for RMSSD (p = 0.356) and SDNN (p = 0.128). In contrast, significant main effects of skill level were found for both RMSSD and SDNN (p < 0.001), with professional players demonstrating higher HRV values compared to amateurs. Notably, significant

Table I: Distribution of Study Participants (n = 127)

Group	Male (n)	Female (n)	Total (n)
Professional players	33	29	62
Amateur players	34	31	65
Total	67	60	127

Table II: Two-way ANOVA Results for Heart Rate and HRV Indices Across Sex and Skill Level (n = 127)

Variable	Factor	Mean \pm SE	F value	p value
Heart Rate (bpm)	Sex (Male)	69.75 \pm 0.57	1.837	0.178
	Sex (Female)	70.88 \pm 0.61		
	Skill (Professional)	64.30 \pm 0.60	208.667	<0.001
	Skill (Amateur)	76.33 \pm 0.58		
	Sex x Skill	-	0.175	0.677
RMSSD (ms)	Sex (Male)	63.60 \pm 0.93	0.858	0.356
	Sex (Female)	64.85 \pm 0.98		
	Skill (Professional)	78.88 \pm 0.97	469.382	<0.001
	Skill (Amateur)	49.58 \pm 0.94		

interaction effects between sex and skill level were identified for RMSSD ($p = 0.022$) and SDNN ($p = 0.008$), indicating that the effect of skill level varied across sexes.

To further explore these interaction effects, subgroup analyses were conducted. Within the professional group, no significant gender differences were observed for heart rate, RMSSD, or SDNN ($p > 0.05$ for all variables). In contrast, within the amateur group, females demonstrated significantly higher RMSSD ($p = 0.010$) and SDNN ($p = 0.002$) compared to males, while no significant difference was observed for heart rate ($p = 0.333$).

DISCUSSION

One of the key strengths of this study is its focus on the physiological mechanisms that contribute to the observed differences in HRV across groups. Professional badminton players typically exhibit higher HRV indices, such as increased normal-to-normal (NN) intervals, SDNN, compared to amateur players. These elevated HRV metrics suggest a more balanced autonomic nervous system with a greater parasympathetic tone and reduced sympathetic activity. This balance is crucial for elite athletes, as it indicates superior cardiovascular fitness, enhanced recovery capacity, and greater adaptability to training loads.

This study was undertaken to compare HRV among professional and amateur badminton players and to explore gender differences within each group involving 127 participants in Chennai. Our study findings indicated that there were no significant differences in HRV parameters like HR, RMSSD and SDNN solely

based on gender among badminton players. This was consistent with previous studies by M-Abdullah Shafik et al. (7), and Sinnreich et al. (8), which also reported non-significant gender differences in HRV.

The higher HRV observed in professionals may be explained by their more rigorous and structured training regimens, which are designed to optimize both performance and recovery (9). Regular high-intensity training, combined with adequate recovery periods, enhances vagal tone and promotes efficient autonomic regulation (10). This allows professional athletes to recover more quickly between training sessions and maintain peak performance during competition. In contrast, amateur players may have less consistent training routines and possibly lower overall fitness levels, leading to lower HRV and reduced recovery efficiency. Similarly, a study by Ching-Chieh Tai et al., (2) on elite male and female badminton athletes also found no significant differences in HRV parameters between male and female players.

Our study found that there was an interaction effect between gender and skill level on RMSSD & SDNN, but not on heart rate. A study by Mellisa Paniccia et al. (11), found consistent sex differences across various HRV measures, where females showed decreased HRV when compared to males. Studies also found that male tend to exhibit higher HRV in measures reflecting parasympathetic activity such as SDNN, RMSSD, pNN50, and HF (12,13). This observation was consistent with the timing of puberty, as girls typically undergo puberty approximately two years earlier than boys. Pre-pubertal hormonal fluctuations, including oestrogen and progesterone, alongside significant changes during ovulation induction, contributed to alterations in HRV, particularly in lowering HRV.(14) Thus, the timing of pubertal development might coincide with the emergence and maturation of neural autonomic mechanisms regulating HRV (11).

Similarly, Koenig and Thayer et al. (15), in a meta-analysis on sex differences in heart rate variability, discovered that females typically exhibit a higher average heart rate, as indicated by a shorter mean RR interval, compared to males. Males demonstrated relative sympathetic dominance over their cardiovascular regulation, even with a lower average heart rate.

Table III: Gender Differences in Heart Rate and HRV Indices Within Skill Groups

Variable	Group	Male (Mean \pm SD)	Female (Mean \pm SD)	t value	p value
Heart Rate (bpm)	Professional	63.91 \pm 2.29	64.69 \pm 2.15	1.37	0.174
	Amateur	75.59 \pm 5.55	77.06 \pm 6.59	0.98	0.333
RMSSD (ms)	Professional	79.81 \pm 8.42	77.93 \pm 8.04	0.89	0.374
	Amateur	47.38 \pm 6.01	51.77 \pm 7.34	2.64	0.010
SDNN (ms)	Professional	79.67 \pm 9.20	78.03 \pm 6.70	0.79	0.431
	Amateur	46.06 \pm 6.21	51.94 \pm 8.18	3.28	0.002

The gender-related differences in HRV within the amateur group prompted an exploration of potential influencing factors, particularly the menstrual cycle. The base line data revealed that a considerable proportion of females in both Professional (34.48%) and Amateur (38.7%) groups were in their follicular phase, which was an Oestrogen dominant phase. Kunikullaya et al. demonstrated the influence of Menstrual cycle on HRV, providing a plausible explanation for the observed gender differences in the amateur group (14). Research comparing HRV in pre- and postmenopausal women revealed a significant decrease in HRV among postmenopausal women, which was attributed to reduced oestrogen levels. This decline in oestrogen levels led to a shift in autonomic balance towards sympathetic dominance (17). Studies also found that physiological levels of oestrogen were found to enhance vagal tone and inhibit sympathetic modulation of heart rate in females, supporting the observed differences in HRV between pre- and postmenopausal women (16,17). Interestingly, this gender discrepancy was not observed in the professional players. The absence of gender differences in HRV within the professional group, despite a considerable percentage of females in the follicular phase, suggested that the rigorous training regimen undertaken by professionals might mitigate the hormonal influence on HRV. This aligned with existing literature highlighting the ability of regular, intensive training to balance hormonal fluctuations and maintain cardiovascular stability (20).

Although this study provides valuable insights into heart rate variability (HRV) among badminton players, several limitations should be acknowledged. First, the relatively small sample size may limit the generalizability of the findings to a broader population of badminton players. Additionally, the use of convenience sampling and the restriction of participants to an age range of 15 to 24 years further constrain external validity, particularly across different age groups and competitive levels. Second, the observational design of the study precludes the establishment of causal relationships between HRV parameters and performance outcomes. While significant associations were identified, experimental or longitudinal designs are required to determine the direct effects of HRV-guided training interventions on performance.

Third, the study focused primarily on short-term HRV measurements using time-domain indices (SDNN and RMSSD). Although these indices are well-established indicators of overall HRV and parasympathetic activity, respectively, frequency-domain analysis was not included. This limits a more comprehensive assessment of autonomic regulation. However, it is acknowledged that short-term recordings may not provide reliable frequency-domain measures. Furthermore, potential physiological confounders such as hormonal influences were not assessed. The absence

of hormonal assays, particularly those related to estrogen, limits the interpretation of observed gender differences in HRV. Similarly, anthropometric variables such as height, weight, and body mass index (BMI) were not included, restricting the ability to evaluate the influence of body composition on HRV and performance outcomes. Finally, the study examined HRV within a relatively short time frame during training and competition phases. This limits the ability to understand long-term adaptations and the sustained effects of HRV-based monitoring on athletic performance.

Future studies should aim to recruit larger and more diverse samples to enhance the generalizability of findings across different populations, age groups, and competitive levels. Longitudinal and experimental designs are recommended to establish causal relationships and to evaluate the effectiveness of HRV-guided training interventions over time. In addition, future research should incorporate long-term HRV monitoring across different phases of training and competition to better understand temporal fluctuations and recovery patterns. Controlling for external factors such as sleep, hydration, and psychological stress would further improve the accuracy and interpretability of HRV measurements.

Expanding HRV analysis to include frequency-domain parameters, where methodologically appropriate, would provide a more comprehensive understanding of autonomic nervous system regulation. Moreover, incorporating hormonal assessments could help clarify gender-related differences in HRV. Future studies should also include anthropometric measures such as height, weight, and BMI to evaluate the role of body composition in autonomic regulation and athletic performance. Additionally, investigating the role of HRV in injury prediction and prevention, as well as leveraging wearable technologies for continuous monitoring, may offer practical applications in sports performance optimization.

CONCLUSION

This study illuminates that Heart Rate variability (RMSSD and SDNN) is higher among professional badminton players as compared to amateur players and there is a significant involvement of gender characteristics in Heart Rate variability (RMSSD and SDNN) among professional and amateur badminton players. Presence of significant HRV differences between male and female in amateurs..

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