

Analysis of Fast Fourier Transform Parameters for Heart Rate Variability in Indian Professional Competitive Swimmers During Short-Duration Assessments

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Abstract

Background: Heart rate variability (HRV) is a non-invasive marker of autonomic nervous system function and is widely used to assess training adaptation, recovery, and cardiovascular regulation in athletes. Limited data are available regarding frequency-domain HRV parameters among Indian professional competitive swimmers.

Aim: To analyse Fast Fourier Transform (FFT)-derived HRV parameters in Indian professional competitive swimmers during resting and post-workout conditions.

Materials and Methods: This observational study included 45 professional competitive swimmers aged 8–24 years who fulfilled predefined inclusion and exclusion criteria. Five-minute Lead II ECG recordings were obtained at rest and after a one-hour intensive swimming session followed by a 15-minute recovery period. Frequency-domain HRV parameters including Very Low Frequency (VLF), Low Frequency (LF), High Frequency (HF), LF and HF power, and LF/HF ratio were analysed using dedicated HRV analysis software.

Results: VLF and HF frequencies showed minimal reductions following exercise, whereas LF frequency demonstrated a slight increase. LF power increased modestly, while HF power decreased after exercise. The LF/HF ratio increased significantly from 4.44 ± 2.00 at rest to 6.23 ± 2.47 following exercise ($p < 0.001$), indicating a shift toward sympathetic predominance during the post-workout period.

Conclusion: Frequency-domain HRV analysis demonstrated sympathetic predominance in Indian professional competitive swimmers at rest and after intensive exercise. Elevated LF power and LF/HF ratio may serve as useful indicators of autonomic balance and could assist in identifying inadequate recovery or possible overtraining when interpreted alongside clinical assessment and training history. Larger longitudinal studies are recommended to establish normative values for Indian athletes.

Keywords: Heart Rate Variability; Competitive Swimmers; Frequency-Domain Analysis; Autonomic Nervous System.

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Introduction

Swimming is an Olympic sport and the second-largest sport in the Olympics as per the number of participants. Swimming includes both pool events as well as open-water events. Swimming is divided into four strokes: Breaststroke, Butterfly, Backstroke, and Freestyle. All Competitions, including national and international are controlled by the which was the former name of the governing body for aquatics sports, which is "Fédération Internationale de Natation". It was renamed to "World Aquatics" in 2022.^[1,2] HRV is a non-invasive technique that evaluates the cardiac tone of the heart to assist the sympathetic and Parasympathetic Systems' effect on the heart by assessing cardiac rhythm.^[3]

HRV is increasingly recognized as a vital metric in sports science, particularly for monitoring athlete health, performance, and recovery. Since the values of HRV serve as an indicator of autonomic nervous system function, it helps to assess the swimmer's training adaptations and readiness. HRV is also recognized as a significant indicator of

performance and recovery in swimming. Research indicates that HRV can predict endurance capabilities, with a strong correlation found between higher HRV and improved swimming endurance in elite swimmers.^[4] Most of the literature available for the current study was from studies carried out in the Western population and counties outside of India. Since swimming is significantly developing in India, we decided to carry out this study on the Indian professional Competitive Swimmers.

Materials & Method

The current study was carried out in the Swimming training academy approved for International and National Level Swimming training on Professional Competitive Swimmers (who are taking professional Swimming training and participating in International/National/State Level) who volunteered for the study. Total 45 Swimmers selected for study. Inclusion criteria include Swimmers who participated

in the International/ National level tournament by FINA and the Swimming Federation of India criteria. Swimmers who have been practicing for the last 5 years and have been regularly practicing for the last 3 months. Exclusion criteria include Swimmers with co-morbidities, or on any medication and Swimmers found to be doping and taking anabolic steroids. Swimmers are instructed to avoid food, coffee, tea, and any caffeinated drinks for a minimum of 3 hours before the test & avoid pre-workout warm-up. Test carried out in an air-conditioned room with ideal lighting as per HRV Standards. Participants are advised to take a 5-minute rest in the supine position before the test. 5-minute II lead ECG recorded by using Digital Physiograph Physio-pac, and HRV analysis carried out by using HRV analysis software. Post-workout recordings were recorded after a 1-hour intense workout. Participants were instructed to take a 15-minute rest before recording, and the same procedure as above was followed for recording. The history of daily physical activities and sleep was also noted during the study.

Parameters studied during study

- LF (component of the Low-Frequency range, 0.04-0.15 Hz), modulated by both sympathetic and parasympathetic nervous systems and also associated with baroreceptor activity, mostly used to assess activity of Sympathetic nervous system
- HF component (component of the High-Frequency range, 0.15-0.14 Hz), modulated by the parasympathetic nervous system, connected with respiration and blood pressure changes.
- LF/HF ratio, reflecting the interaction of both types of autonomic modulations
- VLF component (component of the very low frequency ranges from 0.00-0.04 Hz) modulated by the other factors, such as the renin-angiotensinogen system.

Results

Table 1: Mean Age of the Study Participants

	<i>N</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Mean</i>	<i>Std. Deviation</i>
Age	45	8.00	24.00	13.6000	3.42053

The ages of the participants varied from 8 to 24 years (Table 1), with a mean age of 13.6 years and a standard deviation (SD) of 3.42. This shows that the sample for the study was largely made up of adolescents, with a little variation, but mostly bunched around early teenage years.

Table 2: Distribution of the Participants depending upon Sex

		<i>Frequency</i>	<i>Percent</i>
Sex	Male	23	51.1
	Female	22	48.9
	Total	45	100.0

Distribution of the Participants depending upon Sex

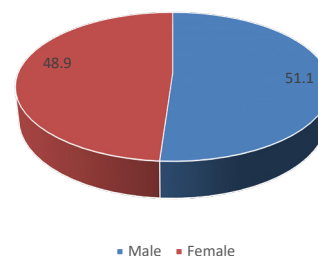


Figure 1: Distribution of Participant depending upon sex

Out of the 45 volunteers, 23 (51.1%) were males and 22 (48.9%) were females, representing a close to even gender split in the study population (Table 2, Figure 1).

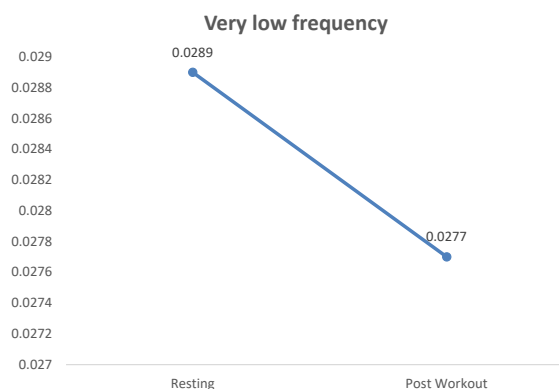


Figure 2: Graph showing changes in Very low frequency (Hz) in Resting and Post-workout state

Table 3: Mean Distribution of the Very Low Frequency (Hz) in Resting and Post-Workout State

	<i>State</i>	<i>N</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Mean</i>	<i>Std. Deviation</i>
Very low frequency	Resting	45	.00	.04	.0289	.00975
	Post Workout	45	.00	.04	.0277	.00952

The very low frequency (VLF) component decreased slightly after exercise (mean = 0.0277 Hz) from the resting state (mean = 0.0289 Hz), with very little change (SD $\approx$ 0.0097 in both conditions) (Table 3, Figure 2), suggesting limited variability and a small workout-induced shift.

Table 4: Mean Distribution of the VLF power (ms²) in Resting and Post-Workout State

	<i>State</i>	<i>N</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Mean</i>	<i>Std. Deviation</i>
VLF power (ms ²)	Resting	45	.00	302.00	41.1556	68.56250
	Post workout	45	.00	296.00	37.4889	65.25496

The VLF power dropped slightly from 41.16 ms² (rest) to 37.49 ms² (post-exercise), with quite large standard deviations ($\approx 65\text{--}69$ ms²), indicating great variability between participants, and a negligible effect of workout on this measure (Table 4, Figure 3).

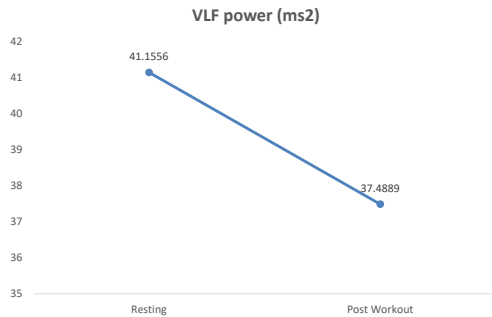


Figure 3: Graph showing changes in VLF Power (ms²) in Resting and Post-workout state

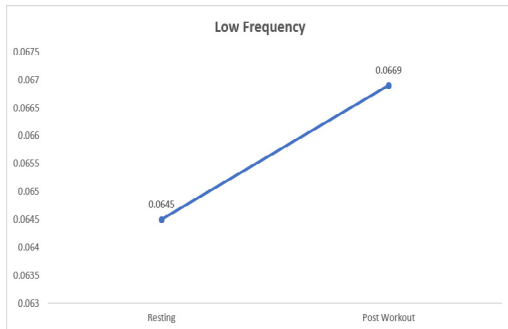


Figure 4: Graph showing changes Low frequency (Hz) in Resting and Post-Workout state

Table 5: Mean Distribution of the Low Frequency (Hz) in Resting and Post-Workout State

	State	N	Mini- mum	Maxi- mum	Mean	Std. Deviation
Low Frequency	Resting	45	.04	.13	.0645	.02217
	Post Workout	45	.04	.13	.0669	.02218

The frequency of low was marginally higher at 0.0669 Hz (post-exercise) compared to 0.0645 Hz (rest), and both had an SD of 0.022 (Table 5, Figure 4). This indicates LF frequency was more or less constant, notwithstanding the workout.

Table 6: Mean Distribution of the LF power (ms²) in Resting and Post-Workout State

	State	N	Mini- mum	Maxi- mum	Mean	Std. Deviation
LF Power (ms ²)	Resting	45	1.00	1712.00	99.6222	267.68038
	Post Workout	45	5.00	1730.00	104.7778	270.64333

LF power rose minimally from 99.62 ms² (rest) to 104.78 ms² (post-workout), albeit with very large variability (SD $\approx 267\text{--}270$

ms²) (Table 6, Figure 5), suggesting that the reaction to work out within this range was not consistent across subjects.

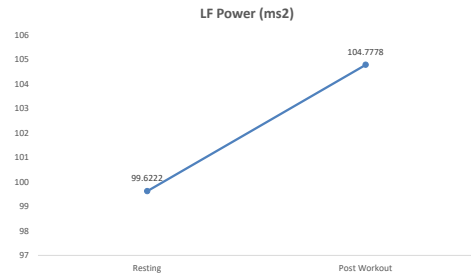


Figure 5: Graph showing changes in LF Power (ms²) in Resting and Post-Workout state

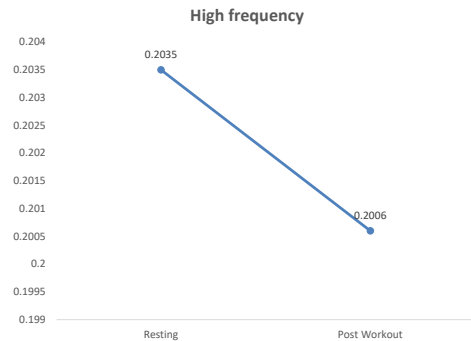


Figure 6: Graph showing changes in High Frequency (Hz) in Resting and Post-Workout state

Table 7: Mean Distribution of the High Frequency (Hz) in Resting and Post-Workout State

	State	N	Mini- mum	Maxi- mum	Mean	Std. Deviation
High frequency	Resting	45	.15	.32	.2035	.05283
	Post Workout	45	.14	.32	.2006	.05221

HF values were stable before and after workout (0.2035 Hz and 0.2006 Hz respectively), with a relatively small SD of about 0.052 (Table 7, Figure 6), indicating little effect of workout on HF frequency.

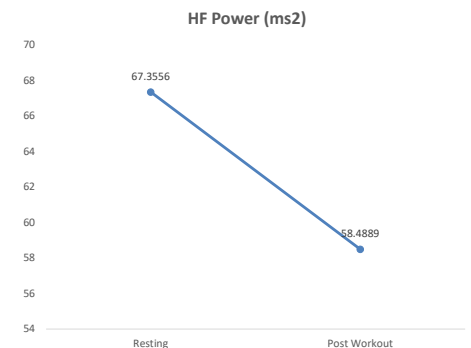


Figure 7: Graph showing changes in HF Power (ms²) in Resting and Post-Workout state

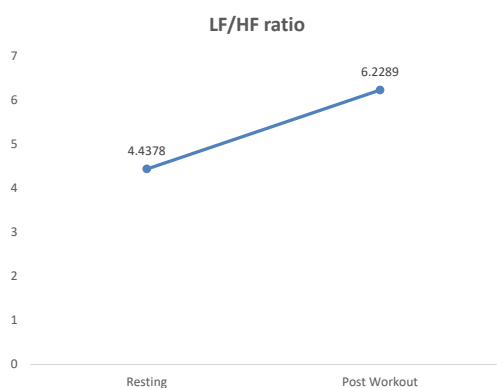
Table 8: Mean Distribution of the HF Power (ms²) in Resting and Post-Workout State

	State	N	Mini- mum	Maxi- mum	Mean	Std. Deviation
HF Power (ms ²)	Resting	45	1.00	1301.00	67.3556	247.32718
	Post Workout	45	1.00	1150.00	58.4889	215.24950

HF power dropped from 67.36 ms² (rest) to 58.49 ms² (post-workout), with high SDs ($\approx$ 215–247 ms²), indicating wide variation (Table 8, Figure 7). Although the mean dropped, the reduction was not statistically significant.

Table 9: Mean Distribution of the LF/HF ratio in Resting and Post-Workout State

	State	N	Mini- mum	Maxi- mum	Mean	Std. Deviation
LF/HF ratio	Resting	45	.20	8.10	4.4378	2.00128
	Post Workout	45	.30	10.00	6.2289	2.46592

**Figure 8:** Graph showing changes in LF/HF in Resting and Post-Workout state

There was a significant rise in LF/HF ratio after workout (6.23) from resting (4.44), with statistical significance ($p = 0.000$) (Table 9, Figure 8). This indicates a movement towards sympathetic dominance after exercise.

Discussion

Study began with hypothesis Swimmers maintain high HRV i.e. Parasympathetic output during resting as well as post-workout due to long term training and deep breathing pattern during workout. Swimming performance is influenced by a multitude of factors that interact in complex ways, including physiological, biomechanical, genetic, and environmental elements. Understanding these factors is crucial for optimizing training and enhancing competitive outcomes. Physiological factors such as muscular strength, which is an essential factor for effective propulsion of water, and the ability to manage lactate, as lactate accumulation affects endurance and sprint performance.^[5]

The VLF component usually gives an idea about recordings other than the sympathetic and parasympathetic systems, for example renin-angiotensinogen system. It is not significant parameter for study. VLF mean frequency in resting is mean = 0.0289 Hz and in post-workout mean = 0.0277 Hz. And VLF power is mean 41.1556 ms² in resting and mean 37.4889 ms² in post-workout.

In our study, swimmers exhibit a high LF value at rest as well as post-workout. In resting mean value of LF frequency is 0.645 HZ, while post-workout is 0.669 Hz, showing an increased frequency post-workout.

The mean value of LF Power in resting is 99.622 ms² and in post-workout, 104.7778 ms², which also reflects an increase in LF power in post-workout, but these values are significantly higher compared to HF power, which reflects sympathetic dominance in resting as well as in the post-workout state.

The LF component of HRV is often associated with sympathetic activity, and its assessment can help in understanding the athlete's recovery and readiness for subsequent training sessions. Research indicates that LF power is influenced by various factors, including exercise intensity and respiratory patterns^[6] and in swimmers, LF values tend to increase post-workout. Increased training loads correlate positively with LF power, suggesting that as swimmers train more intensely, their autonomic regulation improves, reflected in higher LF values.^[7]

In the study mean value of HF frequency in resting is 0.2035 Hz and 0.2006 in post-workout, and power in ms² is 67.3556 in resting and 58.48 in post-workout state, indicating that drop in HF frequency and power in post-workout. but this power is reduced compared to LF power, suggesting that low HF power, i.e. low parasympathetic tone in resting as well as post-workout state.^[8] suggested that the HF component of HRV can increase significantly in swimmers, indicating enhanced parasympathetic activity during rest. In the post-workout state, there is a drop-in parasympathetic activity due to activation of the sympathetic system.

The LF/HF ratio in trained athletes is a measure used to assess autonomic nervous system balance, specifically the sympathovagal balance, through heart rate variability (HRV). In our study, mean LF/HF ratio is 4.4378 in resting and 6.2289 in post-workout state which significantly high in resting as well as post-workout, as per previous studies the normal range of the LF/HF ratio in swimmers is 0.87 to 2.79, this study also suggest that spontaneous breathing frequency may also affect on the LF/HF ratio.^[9] but due to high LF power compared to HF power and high LF/HF ratio in both resting as well as in post-workout may suggest sympathetic dominance and indicator of Overtraining or poor recovery status.

Conclusion

FFT parameters such as LF, HF, and LF/HF ratio suggest that there is sympathetic dominance in swimmers in both the resting as well as post-workout states.

FFT parameter with high power of LF, high LF/HF ratio and factors in history taking may suggest poor recovery and overtraining, but these parameters have limited values.

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No.

Conflict of interest

No.

Ethical approval

Yes.

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