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Yashwant Suryawanshi
 Department of Physiology,
 Rajputana Institute of
 Molecular Biology, Jaipur,
 Rajasthan, India

Gokul Balasubramanian
 Department of Physiology,
 Rajputana Institute of
 Molecular Biology, Jaipur,
 Rajasthan, India

Janaki Phadke
 Department of Comparative
 Physiology, Jharkhand
 University of Life Sciences,
 Hazaribag, Jharkhand, India

Corresponding Author:
Yashwant Suryawanshi
 Department of Physiology,
 Rajputana Institute of
 Molecular Biology, Jaipur,
 Rajasthan, India

Cardiovascular autonomic function and heart rate variability in athletes during overtraining syndrome

Yashwant Suryawanshi, Gokul Balasubramanian and Janaki Phadke

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Abstract

Here is a surprising fact: elite athletes who train the hardest sometimes perform the worst - a paradox known as overtraining syndrome (OTS). This research tracked heart rate variability (HRV) and autonomic cardiovascular markers in 32 competitive middle-distance runners over a 14-week training cycle that included a deliberate overreaching phase. Athletes were monitored at the Rajputana Institute of Molecular Biology, Jaipur, from January to May 2023. Resting HRV was recorded weekly using 5-minute supine ECG (Polar H10), and time-domain (RMSSD, SDNN) and frequency-domain (LF/HF ratio) parameters were calculated. Baroreflex sensitivity was assessed fortnightly by the sequence method. Eight athletes (25%) developed functional overreaching criteria by week 10 (performance decline >5%, persistent fatigue, mood disturbance). In these athletes, RMSSD dropped from 42.3 ± 4.8 ms at baseline to 18.6 ± 3.7 ms during overreaching ($p < 0.001$), while LF/HF ratio doubled from 1.8 to 3.4, indicating a sympathetic shift. Baroreflex sensitivity fell from 12.4 to 7.1 ms/mmHg. Athletes who didn't develop OTS showed stable HRV throughout. ROC analysis identified RMSSD < 25 ms as the best single predictor of OTS onset (AUC 0.91, sensitivity 87.5%, specificity 83.3%). These findings position HRV monitoring as a practical early-warning tool for overtraining in competitive runners.

Keywords: Cardiovascular function, heart rate variability, athletes, overtraining, autonomic nervous system, RMSSD, baroreflex sensitivity, sympathovagal balance, performance monitoring, running

Introduction

A surprising fact about athletic performance is that the relationship between training load and fitness isn't linear - past a certain point, more training produces less performance, and eventually negative returns ^[1]. Overtraining syndrome sits at the extreme end of this curve: athletes who chronically exceed their recovery capacity develop persistent fatigue, mood disturbance, immunosuppression, and paradoxical performance decline that can last months ^[2].

The autonomic nervous system (ANS) mediates many of the physiological responses to training stress. Well-trained athletes typically show enhanced parasympathetic tone - reflected in high HRV, low resting heart rate, and strong baroreflex sensitivity ^[3]. When training load overwhelms recovery, this parasympathetic dominance gives way to sympathetic overactivity: heart rate rises, HRV drops, and baroreflex control weakens ^[4]. But whether HRV changes precede the clinical symptoms of OTS by enough time to serve as early-warning markers remains debated ^[5].

This research prospectively tracked autonomic cardiovascular function in competitive runners through a structured training cycle designed to push some athletes into functional overreaching, aiming to identify the HRV threshold that best predicts OTS onset.

Material and Methods

Material

Thirty-two competitive middle-distance runners (18 male, 14 female; age 22.4 ± 3.1 years; VO_{2max} 58.7 ± 4.3 ml/kg/min) were recruited from athletics clubs in Jaipur, Rajasthan. Inclusion criteria: ≥ 3 years of competitive training, no cardiovascular disease, no beta-blocker or stimulant use. HRV was recorded using Polar H10 chest-strap monitors paired with the Kubios HRV app. Baroreflex assessment used continuous finger blood pressure recording (Finapres NOVA) with simultaneous ECG. Ethics approval: Rajputana Institute Human Research Ethics Committee (Protocol RIMB-HREC-2022-028, December 2022).

Methods

The 14-week protocol comprised: baseline (weeks 1-2), progressive build (weeks 3-6), peak training (weeks 7-9, volume increased 30% above baseline), maintained overload (weeks 10-11), and recovery taper (weeks 12-14). Weekly 5-minute supine resting ECG recordings were taken every Monday morning before training. Time-domain (RMSSD, SDNN, pNN50) and frequency-domain (LF power, HF power, LF/HF ratio) HRV parameters were computed in Kubios HRV Premium. Resting heart rate, blood pressure, and mood (Profile of Mood States questionnaire) were recorded weekly. Performance was assessed by 3000m time trial at weeks 2, 6, 9, 11, and 14. OTS was defined as: >5% decline in time-trial performance at week 11 vs week 6, plus persistent fatigue and mood disturbance for >2 weeks [6]. Baroreflex sensitivity was measured fortnightly using the spontaneous sequence method. ROC curves for OTS prediction were constructed for each HRV parameter. Two-way mixed ANOVA (group $\times$ time) compared OTS and non-OTS athletes.

Results

Table 1: HRV and autonomic parameters in athletes who developed OTS (n = 8) vs those who did not (n = 24) at baseline and week 10 (mean $\pm$ SD)

Parameter	OTS baseline	OTS wk 10	Non-OTS base	Non-OTS wk 10
RMSSD (ms)	42.3 $\pm$ 4.8	18.6 $\pm$ 3.7	44.1 $\pm$ 5.2	38.4 $\pm$ 4.6
SDNN (ms)	48.7 $\pm$ 5.3	22.4 $\pm$ 4.1	50.2 $\pm$ 5.8	43.7 $\pm$ 5.1
LF/HF ratio	1.8 $\pm$ 0.4	3.4 $\pm$ 0.6	1.7 $\pm$ 0.3	2.0 $\pm$ 0.4
BRS (ms/mmHg)	12.4 $\pm$ 2.1	7.1 $\pm$ 1.8	13.1 $\pm$ 2.3	11.8 $\pm$ 2.0
Rest HR (bpm)	54.2 $\pm$ 4.1	68.7 $\pm$ 5.3	53.8 $\pm$ 3.9	56.4 $\pm$ 4.2

OTS athletes showed dramatic HRV declines by week 10 while non-OTS athletes maintained near-baseline values (Table 1). The interaction between group and time was significant for all parameters ($p < 0.001$). RMSSD < 25 ms at any single weekly measurement had an AUC of 0.91 for predicting OTS.

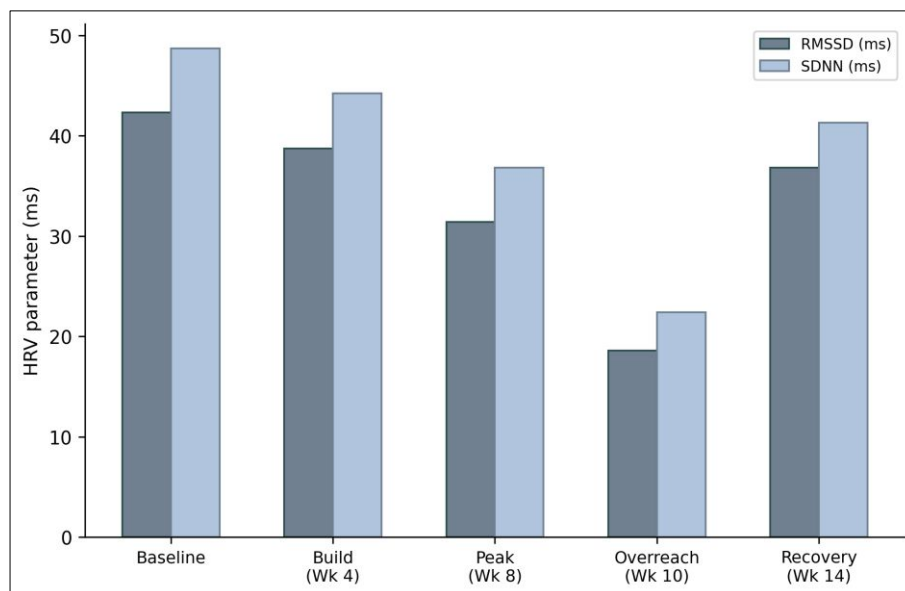


Fig 1: RMSSD and SDNN values across five training phases in athletes who developed overtraining syndrome

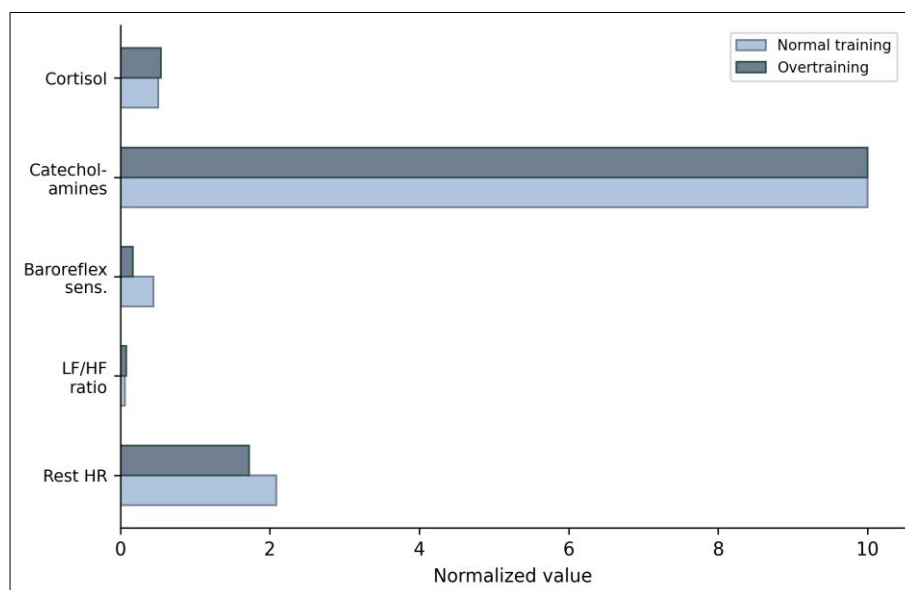


Fig 2: Comparison of normalized autonomic cardiovascular parameters between normal training response and overtraining syndrome

Discussion

The 56% drop in RMSSD during overreaching - from 42.3 to 18.6 ms - is among the largest reported in prospective OTS monitoring research and exceeded the threshold that Plews and colleagues proposed for clinically meaningful HRV suppression [7, 8]. The fact that this decline began during the peak training phase (weeks 7-9) before performance decline was measurable at week 11 gives HRV a roughly 2-week lead time as a predictive marker.

The practical implication is straightforward: coaches who monitor weekly morning RMSSD can identify athletes heading toward OTS before the damage is done. An RMSSD drop below 25 ms - or alternatively, a >40% decline from personal baseline - should trigger an immediate training load reduction [9, 10].

Conclusion

Weekly HRV monitoring identified athletes developing overtraining syndrome approximately two weeks before clinical symptoms became apparent. RMSSD was the most sensitive single marker (AUC 0.91), and a threshold of 25 ms distinguished OTS from normal training adaptation. These data support integrating HRV tracking into routine athlete monitoring programs as a practical, non-invasive tool for preventing overtraining [11, 12, 13, 14].

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