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Original research

Heart rate variability and psychometric responses to overload and tapering in collegiate sprint-swimmers

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ABSTRACT

Objectives: The purpose of this study was to evaluate cardiac-parasympathetic and psychometric responses to competition preparation in collegiate sprint-swimmers. Additionally, we aimed to determine the relationship between average vagal activity and its daily fluctuation during each training phase.
Design: Observational.
Methods: Ten Division-1 collegiate sprint-swimmers performed heart rate variability recordings (i.e., log transformed root mean square of successive RR intervals, lnRMSSD) and completed a brief wellness questionnaire with a smartphone application daily after waking. Mean values for psychometrics and lnRMSSD ($\text{lnRMSSD}_{\text{mean}}$) as well as the coefficient of variation ($\text{lnRMSSD}_{\text{cv}}$) were calculated from 1 week of baseline (BL) followed by 2 weeks of overload (OL) and 2 weeks of tapering (TP) leading up to a championship competition.
Results: Competition preparation resulted in improved race times ($p < 0.01$). *Moderate* decreases in $\text{lnRMSSD}_{\text{mean}}$, and *Large to Very Large* increases in $\text{lnRMSSD}_{\text{cv}}$, perceived fatigue and soreness were observed during the OL and returned to BL levels or peaked during TP ($p < 0.05$). Inverse correlations between $\text{lnRMSSD}_{\text{mean}}$ and $\text{lnRMSSD}_{\text{cv}}$ were *Very Large* at BL and OL ($p < 0.05$) but only *Moderate* at TP ($p > 0.05$).
Conclusions: OL training is associated with a reduction and greater daily fluctuation in vagal activity compared with BL, concurrent with decrements in perceived fatigue and muscle soreness. These effects are reversed during TP where these values returned to baseline or peaked leading into successful competition. The strong inverse relationship between average vagal activity and its daily fluctuation weakened during TP.

1. Introduction

In competitive sporting events such as swimming, overload training and tapering are typical periodization strategies used to achieve peak performance at competition. Intensified training may facilitate performance supercompensation that is realized as fatigue dissipates in response to a reduction in training load (i.e., tapering).[1] However, the increased training load associated with intensified training may put athletes at risk of non-functional overreaching or experiencing illness or injury.[2] An alternative strategy of maintaining loads within the recovery capacities of athletes during intensification phases may support greater performance improvements than pursuing purposeful overreaching.[2] Therefore, monitoring the training response of athletes throughout this time period may be useful for evaluating individual training adaptation and thus guiding the training process.[3]

A physiological parameter for monitoring training effects in swimmers and growing in popularity among coaches and sports medicine practitioners is heart rate variability (HRV).[4] HRV reflects central regulation of the heart via autonomic innervation and can be acquired non-invasively in field settings. Vagal indices of HRV have been shown to be sensitive to training phase (e.g., overload and taper) and performance in competitive swimmers. For example, Garet et al. found reduced nocturnal-HRV and 400 m performance in regional level, teen-aged swimmers during an intensive training period.[5] Additionally, increases in HRV during tapering have been related to improved performance in swimmers of a variety of race distances.[5–7] However, the majority of investigations pertaining to HRV and competition preparation in swimming and among other sports, almost exclusively involve endurance events. For example, recent reviews concern HRV as it relates primarily to aerobic adaptations, endurance performance and the monitor-

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Table 1
External training load details for each phase preceding competition.

Training load	Baseline	Overload		–	Taper	
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Total distance (m)	32,004	38,405	33,832	34,747	32,918	25,603
Distance >160 bpm (m)	3932	5761	5304	3658	3200	1829
Distance Race Int. (m)	2560	4664	3704	2652	1920	1280

m = meters; – = week of which heart rate variability and wellness data were not included in the analysis; Distance >160 bpm = weekly distance covered with a pulse rate >160 beats per minute; Distance Race Int. = weekly distance covered at race intensity.

ing of endurance-sport athletes.[3,8,9] Therefore, how useful HRV monitoring is for athletes participating in anaerobic events such as sprint-swimming remains to be determined.

The use of one time-domain HRV parameter reflective of cardiac-parasympathetic activity, the logarithm of the root mean square of successive R–R intervals (lnRMSSD), has been proposed as the preferred marker for use among athletes in ambulatory, resting conditions.[3,8,9] Due to the labile nature of cardiac-parasympathetic activity, it is recommended that lnRMSSD be monitored near daily and averaged (i.e., lnRMSSD$_{\text{mean}}$) to derive meaningful information pertaining to training status.[10,11] However, no previous longitudinal investigation involving swimmers has acquired HRV data with such frequency, likely due to time constraints when using traditional or nocturnal HRV recording methodology. An additional benefit of daily acquisition of HRV is that it enables the quantification of daily fluctuation, assessed via the coefficient of variation (lnRMSSD$_{\text{cv}}$), representing perturbations to cardiac-autonomic homeostasis.[12] An increased lnRMSSD$_{\text{cv}}$ has been associated with lower fitness,[13,14] higher perceived fatigue and increased training load in team-sports.[15] Moreover, a recent study found that higher lnRMSSD$_{\text{mean}}$ was related to a smaller lnRMSSD$_{\text{cv}}$ ($r = -0.53$), suggesting that greater vagal activity may reflect greater resilience or capacity for training stress.[16] Thus, the evolution of ones HRV trend (i.e., increasing or decreasing) and the degree of fluctuation within, appear to be valuable characteristics that coaching and sports medicine staff can use for evaluating individual responses to training. However, lnRMSSD$_{\text{cv}}$ has not been reported in many previous studies as a result of isolated and infrequent HRV recordings. Furthermore, the relationship between lnRMSSD$_{\text{mean}}$ and lnRMSSD$_{\text{cv}}$ has not been evaluated during different training phases.

The purpose of this study was: (1) to determine how periods of overload and tapering effect lnRMSSD trends preceding competition and (2) to assess the relationship between lnRMSSD$_{\text{mean}}$ and lnRMSSD$_{\text{cv}}$ at each training phase in collegiate sprint-swimmers. It was hypothesized that lnRMSSD would decrease and fluctuate to a greater extent during overload, concurrent with a reduction in perceived wellness and that these effects would be reversed in response to tapering. In addition, we hypothesized that greater average vagal activity would relate to less daily fluctuation at each phase of training.

2. Methods

Ten Division-1 sprint-swimmers (n = 7 male; age = 21 ± 1.6 years; height = 187 ± 7.3 cm; weight = 84.4 ± 7.3 kg; n = 3 female; age = 21 ± 1.5 years; height = 173.6 ± 8.2 cm; weight = 68.8 ± 5.2 kg) from the National Collegiate Athletic Association (NCAA) were recruited for this study. These athletes compete in a variety of short distance events including: 50 m free (n = 6), 100 m free (n = 8), 200 m free (n = 5), 100 m back stroke (n = 3), 100 m fly (n = 4), 200 m fly (n = 1), 100 m breast stroke (n = 1) and 200 m breast stroke (n = 1). Prior to participation, all subjects provided written informed consent and obtained medical clearance from the sports medicine staff. Ethical approval for this study was granted by the institutional review board for human participants.

Data collection took place during the 2015 NCAA competitive season, capturing the preparatory period of a championship competition. All athletes took part in an overload and tapering phase preceding competition. All training sessions in the pool were planned and implemented by the head coach while strength and conditioning (S&C) training was implemented by the S&C coach. Training content and structure were not influenced by the researchers. To assess the effect of training phase on cardiac-parasympathetic activity and psychometrics, data was obtained from three distinct phases including baseline (BL), overload (OL) and taper (TP).

HRV data was self-measured daily by the athletes with a validated smartphone application and optical pulse-wave finger sensor (PWFS) apparatus (i.e., photoplethysmograph) that inserts into the headphone slot of a mobile device. This tool has been shown to provide accurate time-domain HRV analysis compared with electrocardiography.[17] Each morning after waking and elimination, the subjects would perform a seated HRV recording. Once seated comfortably, the subjects were instructed to insert their left index finger into the PWFS and open the ithlete$^{\text{TM}}$ HRV application on their mobile device. After allowing 1-min for stabilization[18] the subjects initiated an HRV recording while remaining motionless, breathing spontaneously and with their left hand held still, within 20 cm of their chest. The application utilizes a 1-min HRV recording to determine lnRMSSD[19] and expresses this value on a 100-point scale by multiplying it by 20 (i.e., lnRMSSD × 20).[20]

Psychometrics were evaluated daily via the smartphone application immediately following HRV recordings. Subjects rated their perceived level of sleep quality, fatigue, muscle soreness, stress and mood on a 9-point scale from an electronic questionnaire adapted from McLean et al.[21] Ratings closer to 1 and 9 represented poorer and greater wellness perceptions, respectively.

External training load data was obtained from the head coach. Training load parameters include weekly total distance covered, weekly distance covered with pulse rate >160 beats per minute (bpm) and weekly distance covered at race intensity (Table 1). Total distance covered was 20% and 5.7% above BL during week 1 and 2 of OL, respectively. Subsequently, total distance was reduced to BL and 20% below BL during the final two-weeks of TP, respectively. Distance covered with pulse rate >160 bpm was 44.6% and 34.9% above BL during week 1 and 2 of OL, respectively. Subsequently, distance covered with pulse rate >160 bpm was reduced to 18.6% and 53.5% below BL during the final two-weeks of TP, respectively. Distance covered at race intensity was 82% and 44.7% above BL during week 1 and 2 of OL, respectively. Subsequently, distance covered at race intensity was reduced to 25% and 50% below BL during the final two-weeks of TP, respectively. Therefore, the OL period was characterized with a substantial increase in training intensity with total volume only varying by ≥20%. Though training was preplanned, variations for individuals were made at the discretion of the coach based on factors such as perceived fatigue, performance in the pool and pulse rate recovery between sets. BL training consisted of 19.5 h of total training time including three 1-h resistance training sessions and nine 1.5–2-h pool sessions. The training time and structure remained the same during the OL weeks, however

Table 2
Comparison of heart rate variability and wellness parameters between training phases.

	Phase (mean ± SD)			Comparison statistics (p, ES)		
	BL	OL	TP	BL vs. OL	OL vs. TP	BL vs. TP
$\text{lnRMSSD}_{\text{mean}}$	82.5 ± 6.7	77.9 ± 7.1	84.8 ± 4.4	<0.01, −0.67	<0.01, 1.18	0.09, 0.41
$\text{lnRMSSD}_{\text{cv}}$	6.7 ± 1.8	10.1 ± 4.5	6.4 ± 2.0	<0.01, −0.98	<0.01, 1.05	0.43, −0.18
Sleep	6.4 ± 1.0	5.9 ± 1.0	7.0 ± 0.9	0.17, −0.50	<0.01, 1.16	0.04, 0.63
Fatigue	5.8 ± 1.2	4.3 ± 0.9	5.9 ± 0.7	0.01, −1.41	<0.01, 1.98	0.85, 0.10
Soreness	5.8 ± 1.3	4.6 ± 0.9	6.0 ± 0.9	0.04, −1.07	<0.01, 1.56	0.59, 0.18
Stress	6.6 ± 1.4	6.3 ± 1.5	6.7 ± 1.6	0.49, −0.21	0.39, 0.26	0.66, 0.07
Mood	7.1 ± 1.2	6.8 ± 1.4	7.2 ± 1.2	0.24, −0.23	0.13, 0.31	0.31, 0.08

ES = Effect Size; BL = Baseline; OL = Overload; TP = Taper; $\text{lnRMSSD}_{\text{mean}}$ = the mean logarithm of the root mean square of successive RR intervals multiplied by 20; $\text{lnRMSSD}_{\text{cv}}$ = coefficient of variation of the logarithm of the root mean square of successive RR intervals multiplied by 20.

training content differed (Table 1). During TP, weekly total training time was reduced to approximately 15.5 h and included three 1-h resistance training sessions and seven 1.5–2-h pool sessions. Sundays were reserved for passive rest throughout each phase.

Data are expressed as mean ± SD. The Kolmogorov–Smirnov test was used to assess data normality. A paired-samples t-test was used to compare race times recorded from the current competition with preceding best race times from the 2014–2015 season. One-way analysis of variance for repeated measures with Bonferonni post-hoc tests were used to evaluate differences in HRV and wellness parameters across B, OL and TP training periods. Effect sizes (ES)[22] were calculated for all comparisons to assess the magnitude of changes in HRV and wellness parameters across the three training phases. ES were interpreted qualitatively using the following thresholds: <0.2, trivial; 0.2–0.6, small; 0.6–1.2, moderate; 1.2–2.0, large; 2.0–4.0, very large.[23] Pearson correlation coefficients (r) were used to quantify the relationship between individual $\text{lnRMSSD}_{\text{mean}}$ and $\text{lnRMSSD}_{\text{cv}}$ values during each training phase. The thresholds used for qualitative assessment were: <0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; >0.9 nearly perfect.[23] In order to capture the effects of the various training phases on HRV and wellness parameters, BL values were derived from week 1, OL values were derived from weeks 2–3 and TP was derived from weeks 5–6. Week 4 was omitted because of its similarity to BL and thus may obscure the effects of the varying training load on HRV and wellness parameters (Table 1). Statistical significance was set at $p < 0.05$. Analyses were performed using SPSS software (Version 22.0, IBM Corp, New York, NY, USA) and Microsoft Excel 2016 (Redmond, WA, USA).

3. Results

The Kolmogorov–Smirnov test was not significant ($p > 0.05$) indicating that the assumption of data normality was met. Competition performance significantly improved ($p < 0.01$) with a −1.02 ± 0.61 s (or −1.71 ± 1.31%) reduction in race times. Significant reductions in $\text{lnRMSSD}_{\text{mean}}$, were observed during the OL and returned to BL levels or peaked during TP. $\text{lnRMSSD}_{\text{cv}}$, and perceptions of fatigue and soreness significantly increased during OL and returned to BL levels during TP. Perceived sleep quality significantly improved during TP. Comparison statistics are displayed in Table 2. $\text{lnRMSSD}_{\text{mean}}$ was significantly related to $\text{lnRMSSD}_{\text{cv}}$ at BL ($r = -0.72$, $p = 0.018$, very large), during OL ($r = -0.71$, $p = 0.021$, very large) but not during TP ($r = -0.38$, $p = 0.277$, moderate). Notable training interventions for one athlete (Subject A) were made by the coach throughout the training period due to fatigue and performance decrements. The HRV and wellness trend for this athlete (Subject A) along with another male (Subject B) and female (Subject C) from the group are graphically displayed in Fig. 1 for comparison.

4. Discussion

This study evaluated changes in HRV and wellness parameters in response to OL and TP in Division-1 collegiate sprint-swimmers preceding competition. We found that OL training was associated with a reduction along with greater daily fluctuation in lnRMSSD, concurrent with decrements in perceived fatigue and muscle soreness. These effects were reversed during TP, where these values returned to BL or peaked leading into successful competition. We found very large negative relationships between $\text{lnRMSSD}_{\text{mean}}$ and $\text{lnRMSSD}_{\text{cv}}$ during BL and OL while the relationship was only moderate during TP.

These results are in agreement with a previous investigation in female soccer players where increases in training load resulted in *Small* reductions in supine and standing $\text{lnRMSSD}_{\text{mean}}$, *Moderate* increases in $\text{lnRMSSD}_{\text{cv}}$ and *Large* reductions in perceived wellness.[15] An inverse bell-shaped trend for RMSSD in response to OL and TP derived from isolated HRV recordings has been observed previously among athletes from a variety of endurance sports including swimming[6] and rowing.[24] Schmitt et al.[25] reported reduced and "scattered" vagal activity during periods of fatigue versus non-fatigued states in 57 elite Nordic skiers, agreeing with our finding of reduced $\text{lnRMSSD}_{\text{mean}}$ and increased $\text{lnRMSSD}_{\text{cv}}$ (i.e., scattering of the values) with increased fatigue during OL. Our results are in contrast to previous investigations that observed parasympathetic hyperactivity (i.e., bell-shaped trend) in overreached triathletes in response to OL with a progressive reduction in lnRMSSD toward BL following TP.[11] These conflicting HRV responses fall in line with the two clinical forms of overtraining, characterized by either sympathetic or parasympathetic predominance.[26] However, none of the athletes in the aforementioned studies were diagnosed with the overtraining syndrome, but rather were more appropriately described as overreached. The reduction in average vagal activity during OL observed in the current study is likely a result of the increased anaerobic work load as training intensity, more so than volume appears to have a greater impact on autonomic recovery after training.[9,27] For example, Plews et al.[27] found that waking lnRMSSD showed *Small* increases when training below the first lactate threshold, whilst showing *Small* decreases when training above the second lactate threshold in elite rowers.[27] Furthermore, a recent review of the literature showed that parasympathetic activity is not fully restored to baseline until at least 48 h after high intensity exercise.[9]

The increase in $\text{lnRMSSD}_{\text{cv}}$ during the overload may be explained by the substantial reductions in vagal activity following high intensity training and subsequent parasympathetic rebound roughly 48 h later, previously observed after very intense exercise.[28] The parasympathetic rebound phenomenon has been attributed to dehydration-induced hypervolemia which stimulates baroreflex mediated increases in vagal activity.[28] Thus, in practice, $\text{lnRMSSD}_{\text{cv}}$ may provide valuable insight regarding training adaptation.[12,29] For example, in interpreting the individual HRV

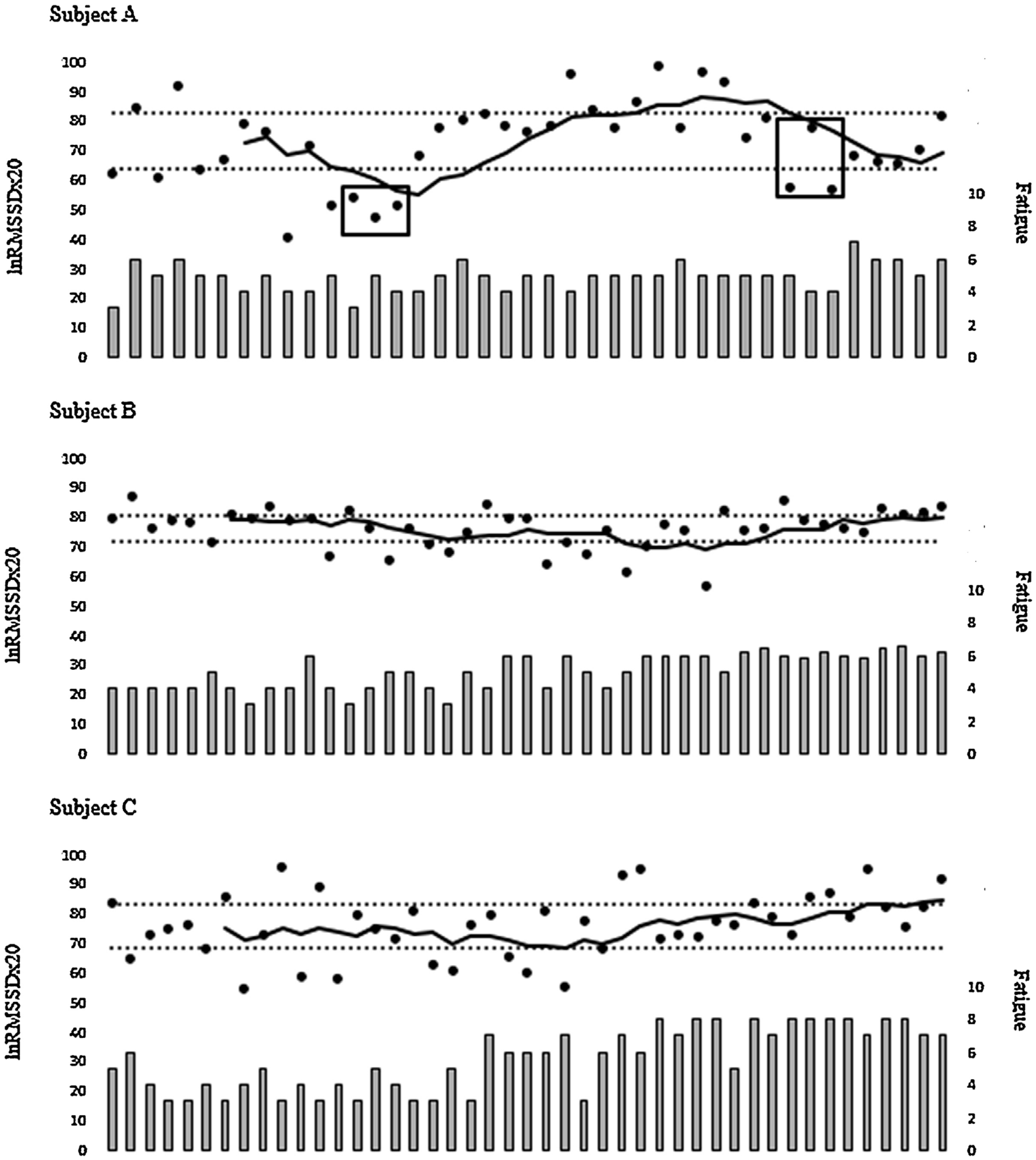

Fig. 1. Individual heart rate variability and perceived fatigue trends for selected subjects A, B and C throughout baseline, overload and tapering. The boxed data points on the trend for Subject A represent the time at which training load was reduced due to fatigue and sluggish performance in the pool. Black dots represent daily logarithm of the root mean square of successive RR intervals multiplied by twenty (lnRMSSD). The solid black line represents that 7-day rolling lnRMSSD average. The horizontal dashed lines represent the smallest worthwhile change (0.5 of the coefficient of variation).[12] The vertical gray bars represent perceived fatigue ratings (1 = very tired, 9 = very fresh).

responses (Fig. 1), it is conceivable that an increased $\mathrm{lnRMSSD_{cv}}$ (e.g. Subject C during the first week of OL) may reflect the initial stage of physiological stress. In contrast, minimal change in $\mathrm{lnRMSSD_{cv}}$ may indicate that the training is well tolerated given that HRV returns to near baseline values within 24 h of a session (e.g., Subject B). In support of this assessment, athletes of higher training status and fitness show faster parasympathetic reactivation following exercise and typically present a smaller $\mathrm{lnRMSSD_{cv}}$.[9,13,14] Finally, suppression of vagal activity beyond the typical 48-h period (>3 days below baseline) may reflect a more severe level of physiological perturbation and possible need for training intervention (e.g., Subject A). Of note, Subject A presented with the highest $\mathrm{lnRMSSD_{cv}}$ at baseline (11.1% vs. group average of 6.75%) and subsequently responded the least favorably to the commencement of OL, requiring more rest and reduced training than other subjects. However, the interventions made for subject A were effective as competition performance improved in his 3 events by an average of 1.04 s.

Nakamura et al.[16] found a large relationship ($r = -0.53$) between $\mathrm{lnRMSSD_{mean}}$ and $\mathrm{lnRMSSD_{cv}}$ in professional futsal players throughout a 5-week preseason. The current study differed by evaluating this relationships during each training phase. Interestingly, the relationship observed in the current study changed from *Very Large* during BL and OL to *Moderate* during TP. We speculate that this may be explained by the heterogeneity among swimmers in response to the taper and time required to fully recover and achieve peak performance.[30] This may reflect appropriateness of the taper duration and training content on an individual basis. Future research is needed to explore this hypothesis.

Limitations of the current study include recording only external training load and lack of performance assessment during OL. Therefore, it is unclear whether athletes were functionally-overreached and if the performance improvement was a result of supercompensation. The use of a pulse-wave finger sensor for daily HRV measures can also be considered a limitation, however the convenience and affordability of this method facilitates subject compliance and frequent data collection. Future experimental research on HRV-guided training during competition preparation as well case studies highlighting individual responses to OL and TP are encouraged to improve upon the practical application of cardiac-parasympathetic monitoring in field settings.

5. Conclusion

Overload training in collegiate sprint-swimmers resulted in a reduction and greater daily fluctuation in cardiac-parasympathetic activity, as well as greater perceived fatigue and muscle soreness compared with baseline. These responses were reversed during a taper where these values returned to baseline or peaked leading into successful competition. The strong relationships between average vagal activity and its daily fluctuation observed at baseline and overload weakened during the taper.

Practical implications

- Monitoring competition preparation in sprint-swimmers with ultra-short lnRMSSD and a brief wellness questionnaire derived from a smartphone application demonstrated sensitivity to variations in training phase.
- Reduced $\text{lnRMSSD}_{\text{mean}}$ with greater day-to-day fluctuation (i.e., increased $\text{lnRMSSD}_{\text{cv}}$) may serve as an indication of inadequate recovery.
- Tracking of these variables in conjunction with other markers of recovery status (e.g., perceived wellness) may therefore be useful for monitoring the effects of overload periods and guiding training load manipulation leading into competition.

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