Effect of Competitive Status and Experience on Heart Rate Variability Profiles in Collegiate Sprint-Swimmers

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Abstract

Flatt, AA, Hornikel, B, Nakamura, FY, and Esco, MR. Effect of competitive status and experience on heart rate variability profiles in collegiate sprint-swimmers. *J Strength Cond Res* XX(X): 000–000, 2021—Interindividual differences in training history may be a determinant of heart rate variability (HRV) profiles in collegiate sprint-swimmers and may account for differences observed between elite and subelite athletes. We therefore compared HRV profiles among national-level and conference-level sprint-swimmers while accounting for individual swim-training history. Twenty-eight short-distance swimmers (18 men and 10 women) recorded post-waking HRV throughout a 4-week standardized training period. The 4-week mean ($_M$) and coefficient of variation ($_{CV}$, a marker of daily fluctuation) were calculated for resting heart rate (RHR) and the natural logarithm of the root mean square of successive differences (LnRMSSD). Swimmers were categorized as national-level ($n = 12$) or conference-level ($n = 16$) competitors. Years of competitive experience was documented for each individual to index training history. $p < 0.05$ was considered statistically significant. No sex-related differences were observed for any variables ($p > 0.05$). $LnRMSSD_M$ (effect size [ES] = 0.95), $LnRMSSD_{CV}$ (ES = −1.18), RHR_{CV} (ES = −1.05), and competitive experience (ES = 1.23) differed between status groups ($p < 0.05$). Accounting for multicollinearity between competitive experience and LnRMSSD variables ($p < 0.05$), competitive experience remained associated with $LnRMSSD_M$ ($r = 0.44$, $p = 0.02$). With competitive experience included as a covariate, differences in $LnRMSSD_M$ between status groups disappeared ($p > 0.05$, ES = 0.31). National-level swimmers exhibit higher and more stable LnRMSSD than that of their conference-level teammates throughout standardized training. Differences in trend characteristics were attributed to training age. This information may assist practitioners with interpreting interindividual differences in HRV profiles throughout training periods among a mixed roster of athletes.

Key Words: autonomic, parasympathetic, athlete monitoring, sport science, cardiovascular

Introduction

Heterogeneity in adaptation to swim training poses a unique challenge for coaching staff who program for a diverse group of athletes. American collegiate swim rosters include male and female competitors with varying training backgrounds and performance capabilities. Thus, volume and intensity of loads from standardized training programs may be excessive for some and insufficient for others. An individualized training method may be an effective alternative to standardized programming (37), although such an approach is not without challenges of its own. For example, an ongoing awareness of individual training status is necessary to match the stimulus with the evolving capacity of the athlete. Thus, remaining adequately informed requires monitoring efforts by the coach and compliance with routine evaluation from the athletes (33).

The autonomic nervous system plays a fundamental role in the adaptive process to physical training (20). Acute sympathetic stimulation aids the circulatory and neuromuscular systems with meeting the demands of physical exercise (6). During recovery, parasympathetic reactivation facilitates restorative processes (37) that build resistance to future exposures (14). As an effector organ regulated by autonomic innervation, the heart is sensitive to excitatory adrenergic and inhibitory cholinergic signaling (27). Thus, resting heart rate (RHR) and its variability (HRV) are commonly used to reflect cardiac-autonomic functioning in competitive swimmers (2,11,15). Recent investigations support the use of HRV tracking for reflecting variation in workload, subjective fatigue status, and changes in performance throughout swim training (2,11,13,15). However, there exists considerable interindividual variation in HRV profiles among athletes within a sport, despite similarity in age and physical characteristics (34). Heterogeneity in HRV trends complicates interpretation. Therefore, further investigation into the determinants of cardiac-autonomic parameters throughout a preparatory period would aid practitioners in analyzing trends and providing training and lifestyle guidance for athletes.

Two important characteristics of an athletes' resting HRV profile are (a) how high or low their absolute values are (2,15,20) and (b) the magnitude of day-to-day fluctuations (5,10,14). In nonathletic older adults, these characteristics are independent predictors of cardiovascular morbidity and mortality (7,23). Regardless of athletic background, higher and more stable vagal-HRV parameters are generally reflective of a healthy and desirable profile, although some exceptions exist (26). Cross-sectional studies indicate that up to approximately half

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of the variation in one's HRV can be explained by genetics (24). Other sources of variation are modifiable and include environmental, (patho) physiological, psychological, and lifestyle factors (9).

Exercise training such as swimming is a potent modulator of HRV (38) and stimulatory effects seem to continue with chronic conditioning (40). Thus, interindividual differences in training history may be a determinant of HRV trend characteristic in collegiate sprint-swimmers and may account for competitive status-related differences observed between elite and subelite athletes (34). However, the influence of competitive status and training history on HRV profiles in swimmers throughout a preparatory conditioning period has yet to be investigated. Therefore, we aimed to compare HRV profiles among national-level and conference-level sprint-swimmers while accounting for individual swim-training history. We hypothesized that (a) HRV profiles would differ between status groups and (b) these differences would be partly explained by swim-training age.

Methods

Experimental Approach to the Problem

This was a prospective observational study comparing HRV profiles between collegiate national-level and conference-level sprint-swimmers throughout a standardized training period. Associations between years of competitive experience (a variable used to reflect training age) and HRV parameters were quantified. Differences between status groups were subsequently evaluated while including experience as a covariate.

Subjects

Twenty-eight short-distance swimmers values reported as mean and *SD*, ($n = 18$ men, age [range = 19–25] = 21.7 ± 1.7 years, height = 187.5 ± 8.9 cm, body mass = 83.7 ± 7.0 kg, $n = 10$ women, age = 20.4 ± 0.8 years, height = 169.0 ± 7.8 cm, body mass = 65.6 ± 5.9 kg) who completed daily HRV measures and participated in all training sessions throughout the observation period were included in the study. All swimmers were members of the same Division-1 National Collegiate Athletics Association (NCAA) program and competed exclusively in events ≤200 m. The competitive experience of the sample based on when they began participating in competitive swimming was 11.6 ± 4.0 years. Details regarding typical training frequency, duration, and emphasis for various age ranges are provided in Table 1. Subjects were categorized as national-level ($n = 12$, 4 women, 9 men) or conference-level ($n = 16$, 6 women, 10 men) competitors based on whether they qualified for the NCAA tournament in the previous season to separate higher-level swimmers from lower-level swimmers. National-level swimmers qualified for the NCAA tournament by either achieving the established automatic qualification standard ("A" standard) or invitation ("B" standard) during the regular season. National Collegiate Athletics Association qualifiers represent the national top 30 and 40 athletes in each event for men and women, respectively. The national group included 6 Olympic-level swimmers. This study was approved by the University of Alabama Institutional Review Board (IRB), and the subjects were informed of the benefits and risks of the investigation before signing an institutionally approved written informed consent document to participate in the study.

Procedures

Training Period. Data were collected during a 4-week pre-season training period during the fall academic semester. Details of the swimming volume and intensity load are presented in Table 2. Weekly training consisted of 19.5 hours of total training time including three, 1-hour resistance training sessions and nine 1.5–2-hour pool sessions. Double sessions were performed on Monday, Tuesday, and Friday with single sessions on Wednesday, Thursday, and Saturday. Sundays were recovery days with no resistance training or pool sessions. During a typical week, 3 sessions emphasized aerobic training, 4 sessions emphasized anaerobic speed work, and 2 sessions were mixed. Resistance training sessions were performed Monday, Wednesday, and Friday before the afternoon swimming session. Resistance training sessions emphasized total body strength. Sessions included multijoint barbell movements (e.g., power clean, squats, bench press, performed at ~70% of 1 repetition maximum), dumbbell exercises, and resistance band exercises. A typical session included 8–12 exercises performed for 3–4 sets of 8–12 repetitions.

Heart Rate Parameters. Daily measures of RHR and HRV were derived from an optical pulse wave finger sensor paired with a smartphone application (ithlete, HRV Fit Ltd., Southampton, United Kingdom). The validity of this tool for determining time-domain HRV parameters has previously been established (8). Standardized recording procedures were replicated from a previous study (11) and involved a 1-minute HRV recording preceded by a 1-minute stabilization period. Measures were self-performed at their residence in the seated position, immediately after waking and urinating. Recordings were predominantly performed between 5:30–6:00 AM, although some measures were performed approximately 1–2 hours later on off-days (i.e., Sundays). The parameters evaluated by the application include RHR and logarithm of the root-mean square of successive differences (LnRMSSD), a vagal-mediated HRV index recommended for use in field settings (37). The within-subject coefficient of variation (CV) for LnRMSSD across a 7-day baseline period in collegiate sprint-swimmers using the same recording tools and methodology was 6.7 ± 1.8%, indicating acceptable interday reliability (11). Artifacts and ectopic beats were filtered through an automated processing algorithm as follows:

$$(\mathrm{PPn} - [\mathrm{PPn} - 1])^2 < (40 \times \mathrm{Exp}[120/\mathrm{PRavg}])^2$$

where PRavg is the average pulse rate calculated since commencement of the recording.

Immediately after an HRV recording, data were automatically uploaded to a cloud-based server for analysis. All swimmers had access to their daily HRV results. The 4-week mean (RHR_M and $LnRMSSD_M$) was used to index absolute values, which may be misrepresented from single-time point assessment (26). The CV (RHR_{CV} and $LnRMSSD_{CV}$) was calculated intraindividually to represent the relative level of fluctuation in measures throughout the observation period (5). The coefficient of variation was calculated as follows: (*SD*/mean) × 100.

Subjective Indicators. After daily HRV assessment, swimmers completed a brief wellness questionnaire through the HRV application (11,13). On a 1–9 sliding scale, ratings of perceived sleep quality, muscle soreness, stress, mood, and fatigue were submitted. Ratings of 5 represented feeling "okay." Higher and lower ratings indicated incrementally better or worse subjective responses, respectively. Subjective categories were averaged intraindividually and summed to produce a global wellness score.

Statistical Analyses

Normal distributions for outcome variables were confirmed with Shapiro-Wilks tests ($p = 0.168–0.712$). Preliminary screening for

Table 1
Swim training details by age.*

Age group (y)	Weekly sessions	Session duration (h)	Weekly structure	Training emphasis	Competitions
5–7	3–5	1–1.5	Singles only	Lower-intensity sessions Stroke fundamentals Basic motor skills and balance Maintain fun aspect	Competition not a focus Some summer league/local meets
8–12	4–5	1.5–2	Singles only	Continued stroke fundamentals Aerobic conditioning	Summer league and local meets
13–16	5–6	1.5–2	Saturday practice Optional doubles 1–2 times per wk	Higher-intensity sessions Specific energy system focus (e.g., sprint, aerobic, and anaerobic)	Taper for biannual peak competition
16–18	6–8	2–2.5	Saturday practice Optional doubles 2–3 times per wk	Large focus on competition Specialization of events (e.g., 100 free vs. 1,500 free vs. different strokes)	Taper for biannual peak competition

*Singles = 1 session per day; doubles = 2 sessions per day; Saturday practice = session occurring on Saturday; Taper = period of reduced training volume preceding competition.

effects of sex on cardiac-autonomic parameters (RHR_M, RHR_{CV}, $LnRMSSD_M$, and $LnRMSSD_{CV}$), wellness, and years of competitive experience was performed with multivariate analysis of variance (MANOVA). No systematic sex-based differences were observed (model effect $p = 0.497$, Figure 1). Therefore, subsequent analyses were conducted with men and women combined ($n = 28$). Multivariate analysis of variance was used to determine the effect of competitive status on cardiac-autonomic parameters, wellness, and years of competitive experience. Homogeneity of covariance assumptions was confirmed for MANOVA models (Box's M-test $p > 0.05$). Hedges' effect sizes (ESs) ± 95% confidence interval (CI) were used to determine standardized differences for all comparisons (21). Magnitudes of the ES were qualitatively interpreted as trivial (<0.20), small (<0.60), moderate (<1.20), large (<2.0), and very large (>2.0) (22). Bivariate associations between cardiac-autonomic parameters and years of competitive experience were quantified with Pearson's correlation coefficient (r). Partial correlations were subsequently used if multicollinearity among variables was observed. Magnitudes of associations were interpreted qualitatively as trivial (<0.1), small (<0.3), moderate (<0.5), large (<0.7), very large (<0.9), and near perfect (<1.0) (22). Analysis of covariance (ANCOVA) for the effect of competitive status was used in the event of significant associations between cardiac-autonomic parameters and years of competitive experience. p values < 0.05 were considered statistically significant. Procedures were performed using JASP 0.10.2 (University of Amsterdam, Amsterdam, The Netherlands) and JMP 13 (SAS Institute Inc., Cary, NC).

Table 2
Planned weekly aerobic (pulse rate <160 b·min^{-1}), anaerobic (pulse rate >160 b·min^{-1}), and total swimming distance.*

	Aerobic (m)	Anaerobic (m)	Total (m)
Week 1	29891.7	3977.6	33869.4
Week 2	31126.2	4937.8	36063.9
Week 3	32337.8	5609.8	37947.6
Week 4	30412.9	4210.8	34623.8
Mean	30942.2	4684.0	35626.2
SD	1059.1	740.4	1795.5
CV (%)	3.4	15.8	5.0

**SD* = standard deviation; CV = coefficient of variation.

Results

A significant model effect was observed for MANOVA based on competitive status ($p = 0.022$). Univariate tests showed that $LnRMSSD_M$ ($p = 0.014$, ES = 0.95 ± 0.80), $LnRMSSD_{CV}$ ($p = 0.005$, ES = −1.18 ± 0.80), RHR_{CV} ($p = 0.010$, ES = −1.05 ± 0.80), and years of competitive experience ($p = 0.004$, ES = 1.23 ± 0.81) differed between conference-level and national-level swimmers (Figure 1). No differences between groups were found for RHR_M ($p = 0.216$) or LnWellness ($p = 0.877$) (Figure 1).

Bivariate correlations showed that competitive experience was associated with $LnRMSSD_M$ ($r = 0.60$, $p < 0.001$) and $LnRMSSD_{CV}$ ($r = -0.52$, $p < 0.01$) and that $LnRMSSD_M$ was associated with $LnRMSSD_{CV}$ ($r = -0.55$, $p < 0.01$) (Figure 2). No associations were found for RHR_M ($r = -0.33$, $p = 0.082$) or RHR_{CV} ($r = -0.15$, $p = 0.462$). Accounting for multicollinearity between LnRMSSD variables, partial correlations showed that competitive experience remained associated with $LnRMSSD_M$ ($r = 0.44$, $p = 0.02$), but not $LnRMSSD_{CV}$ ($r = -0.28$, $p = 0.15$). Thus, ANCOVA was performed to determine if $LnRMSSD_M$ differed between status groups, independent of competitive experience. Assumed equality of variances was confirmed with Levene's test ($p = 0.452$). After controlling for years of competitive experience, there was no difference in $LnRMSSD_M$ between conference-level and national-level swimmers (model effect $p = 0.30$, experience-adjusted values, conference = 4.23 ± 0.41 vs. national = 4.37 ± 0.48, ES = 0.31 ± 0.53).

A visual comparison of RHR and LnRMSSD profiles for one male and one female swimmer from each status group is displayed in Figure 3.

Discussion

We investigated the effect of competitive status on HRV profiles in collegiate sprint-swimmers. An additional aim was to determine if individual training history explained status-related differences in cardiac-autonomic parameters. The main findings were that (a) $LnRMSSD_M$ and $LnRMSSD_{CV}$ were higher and lower, respectively, in national-level vs. conference-level swimmers, and (b) differences in LnRMSSD profiles between status-groups disappeared after controlling for years of competitive experience.

In agreement with the current findings, Plews et al. reported substantially different supine values between competitive

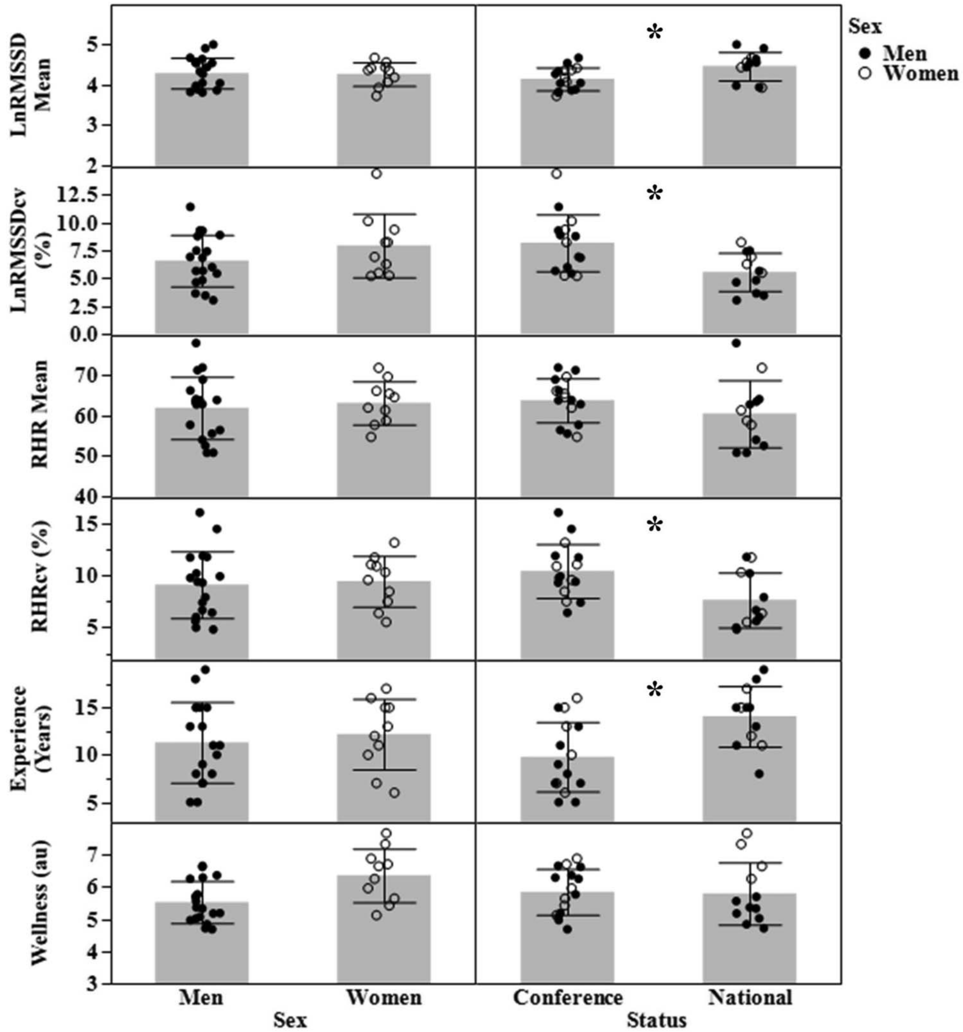

Figure 1. Sex-based and status-based comparisons for cardiac-autonomic parameters, wellness, and competitive experience. LnRMSSD = natural logarithm of the root mean square of successive differences; $LnRMSSD_{CV}$ = coefficient of variation of LnRMSSD; RHR = resting heart rate in beats per minute. *Significantly different ($p < 0.05$).

triathletes ($n = 20$, ≥2 years of competition experience, 6 weekly training sessions) and recreational runners ($n = 10$, ≥1 year of 2 weekly training sessions) for $LnRMSSD_M$ (4.2 ± 0.2 vs. 3.4 ± 0.4) and $LnRMSSD_{CV}$ (6.7 ± 2.9 vs. 10.1 ± 3.4%) (33). However, between-group statistical comparisons were not performed. Proietti el al. compared LnRMSSD derived from 2 in-season recordings among Italian Second Division (4.16 ± 0.30), European League (4.39 ± 0.26), and Champions League (4.45 ± 0.44) soccer teams (34). Logarithm of the root mean square of successive differences for the 2 elite programs were each moderately greater (ES = 0.77–0.82) than the Second Division team (34). Although $LnRMSSD_{CV}$ are less frequently reported than $LnRMSSD_M$, a previous study hints that the magnitude of daily fluctuations in LnRMSSD may discriminate status among a homogenous group of elite athletes. In a sample of 9 Olympic rowers, the 2 gold medalists displayed minimal daily reductions in LnRMSSD after intensive training sessions (>second lactate threshold), indicating faster posttraining cardiac-autonomic recovery and thus a more stable LnRMSSD pattern than the other rowers (32).

Adaptation to a greater history of intensive swim training may help explain the association between years of competitive experience and LnRMSSD characteristics. A previous investigation compared autonomic regulation and cardiac structure and function between prepubertal high-level swimmers ($n = 25$, training 12–14 hours weekly for ≥4 years) and untrained healthy controls ($n = 20$) (38). Results showed that swimmers had significantly greater RMSSD and mean RR interval and greater left ventricular dimensions without differences in septal or posterior wall thickness (38). Similar morphological adaptations in myocardial structure and function were observed in child swimmers ($n = 72$) with a mean 29 months of swim training relative to controls ($n = 72$) (30). Enhanced venous return together with vagal-mediated bradycardia and greater left ventricular capacity increases end-diastolic volume, facilitating greater left ventricle stroke volume to maintain cardiac output (38). Wilhelm et al. (40) demonstrated that RMSSD were greater ($p < 0.05$) in nonelite endurance athletes who accumulated >4,500 lifetime training hours relative to those who accumulated <4,500 hours. Thus, earlier exposure to competitive swimming may contribute to cardiac and autonomic adaptations that persist with chronic training.

The extent to which aerobic fitness accounts for differences in LnRMSSD between status groups and associations with

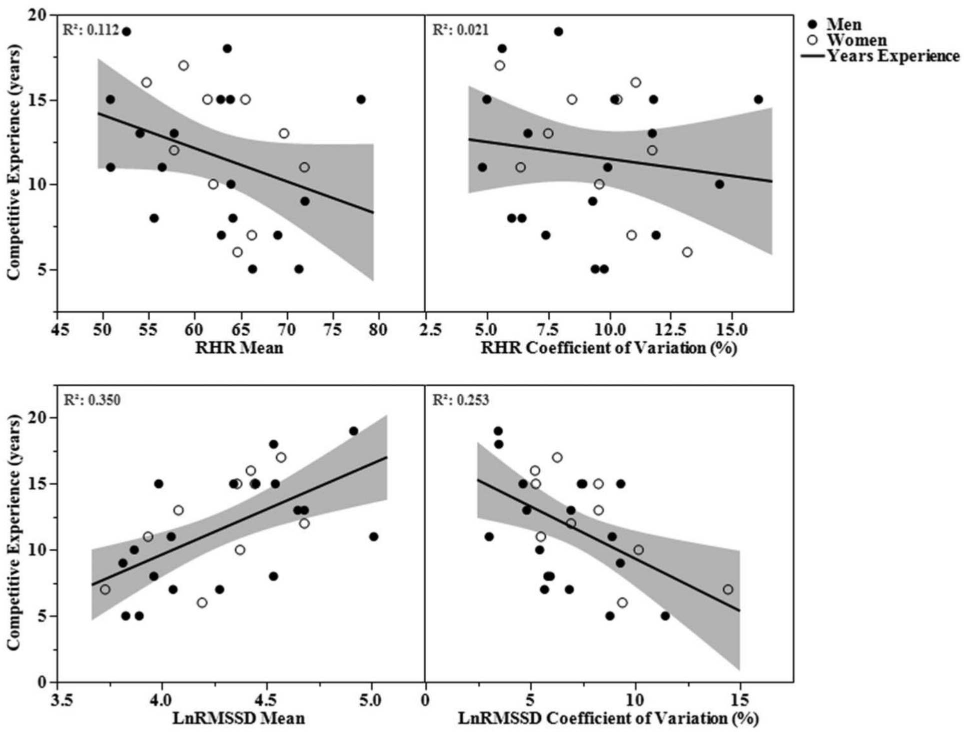

Figure 2. Scatter plots representing associations between years of competitive experience and cardiac-autonomic parameters. RHR mean = mean resting heart rate in beats per minute; LnRMSSD mean = mean natural logarithm of the root mean square of successive differences.

competitive history is unclear. Maximal oxygen uptake ($\dot{V}O_2max$) is a known determinant of autonomic responses to training (37). Individuals with higher $\dot{V}O_2max$ often exhibit higher basal HRV (16), faster postexercise cardiac-parasympathetic reactivation (19), and less day-to-day fluctuations (i.e., lower $LnRMSSD_{CV}$) (10). No differences in RMSSD were found between recreational (n = 9, 49.9 ± 5.5 ms) and professional (n = 12, 59.7 ± 12.1 ms) men's soccer players, possibly because $\dot{V}O_2max$ was similar between groups ($p > 0.05$) (29). $LnRMSSD_{CV}$ varied ($p < 0.05$) as a function of playing position among college football players (skill = 6.5 ± 2.9% vs. mid-skill = 8.5 ± 1.7% vs. linemen = 10.5 ± 2.7%), which was partly attributed to intergroup differences in training capacity, inferred from chronic workloads (12). Moreover, $\dot{V}O_2max$ has been found to be higher in teenage international-level vs. national-level freestyle swimmers (57.6 ± 5.8 vs. 53.2 ± 4.9 ml·kg·min^{-1}, $p < 0.05$) (3), supporting the notion that fitness may partly explain differences in LnRMSSD patterns between status groups.

However, conflicting findings suggest that differences or similarities in cardiac-autonomic activity between status groups may be independent of aerobic fitness. For example, similar ($p > 0.05$) nocturnal RMSSD values have been observed between low-trained (<2 hours weekly aerobic exercise, n = 11, 49.9 ± 7.2 ms) and moderately-trained (4–6 hours weekly aerobic exercise. n = 13, 42.0 ± 8.4 ms) subjects, despite differences in $\dot{V}O_2max$ (61.4 ± 1.3 vs. 45.4 ± 1.8 ml·kg·min^{-1}, $p < 0.05$) (37). Likewise, supine RMSSD was not different between elite-level sprinters and endurance athletes (ES = 0.00), although $\dot{V}O_2max$ was much greater in the endurance group (50.3 ± 2.9 vs. 69.7 ± 3.9 ml·kg·min^{-1}, $p < 0.05$) (1). Nakamura et al. (31) found that aerobic fitness differed between positional groups of a national men's rugby team (ES = 1.35), but seated LnRMSSD did not (n = 17 backs, 3.86 ± 0.85 vs. n = 25 forwards, 3.83 ± 0.63). Indeed, some studies have found no significant association between supine RMSSD and $\dot{V}O_2max$ among healthy (n = 145, r = 0.09) (17) or endurance-trained (n = 35, $p > 0.05$) adults (4). Furthermore, $\dot{V}O_2max$ may be a poor predictor of sprint-swimming performance (25). Although limited by single time-point HRV measures (26), these discrepancies raise uncertainty as to whether fitness level can explain the current findings. Thus, further research is needed to determine if LnRMSSD parameters are associated with years of experience or competitive status, independent of $\dot{V}O_2max$.

A lack of differences in RHR_M between status groups and lack of significant associations between RHR parameters and competitive experience are somewhat surprising given the strong inverse relationship between RMSSD and RHR (39). Human studies have shown that exercise-induced alterations in RHR are influenced by a reduced intrinsic rate as well as enhanced parasympathetic modulation (36) and that intrinsic (28) and autonomic (35) factors can occur independently. The range of seated RHR values in the current study (50.8–78.1 b•min^{-1}) is similar to the range of nocturnal RHR reported among regional-level swimmers (47.6–75.0 b•min^{-1}) (15). In addition, dissociations between RHR and LnRMSSD were found in an aforementioned study that compared cardiac-autonomic parameters between elite and subelite men's soccer teams. Despite having higher LnRMSSD, European League (58.0 ± 4.8 b·min^{-1}) and Champions League (54.8 ± 5.0 b·min^{-1}) players displayed a higher seated RHR (ES = 0.46–1.13) than that of Second Division players (52.4 ± 5.4 b·min^{-1}) (34). As a more specific measure of vagal modulation, LnRMSSD may be a more sensitive training response marker than RHR. Al Haddad et al. investigated the

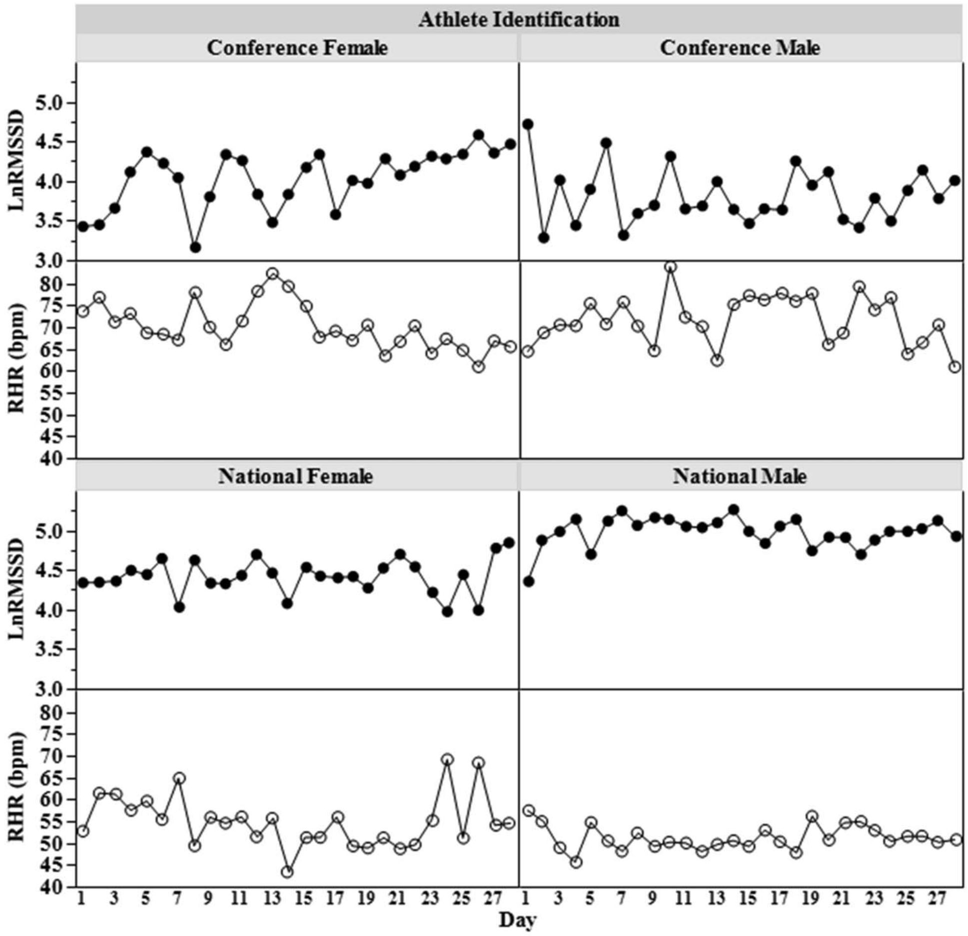

Figure 3. Individual profiles for randomly selected national-level and conference-level male and female sprint-swimmers. The HRV trends show that greater fluctuations are typical among lower-level sprint-swimmers and that the magnitude of daily fluctuation changes over time. Coaches should therefore quantify fluctuation and consider it as an additional indicator of training adaptation. HRV = heart rate variability; RHR = resting heart rate in beats per minute; LnRMSSD = natural logarithm of the root mean square of successive differences.

effects of posttraining cold water immersion or control on daily RHR and LnRMSSD among ≥ national-level swimmers (18). Although similar inverse trends were observed, more frequent statistical changes in LnRMSSD were detected within-conditions and between-conditions (18).

Limitations of the current study include a lack of aerobic fitness assessment and sample size, particularly for assessing sex-related differences. In addition, years of competitive experience does not account for potential participation in nonswimming sports training. The cross-sectional study design also limits conclusions that can be made in regards to whether changes in sprint-swimmers' daily HRV profiles are associated with changes in performance. In addition, stability in cardiac-autonomic function among the national-level swimmers may be indicative of a tolerance for greater workloads based on maintained RHR and HRV parameters. Although, if a greater training stimulus would offer a performance advantage remains to be determined. Thus, whether training loads can be individualized based on LnRMSSD responses to swim training requires further investigation.

The current findings indicate that national-level swimmers generally exhibit higher and more stable LnRMSSD patterns than their conference-level teammates throughout standardized training. The observed differences in LnRMSSD profiles between status groups were attributed to a greater history of training and competing among the national-level competitors. This information may assist practitioners with interpreting interindividual differences in HRV profiles amid training periods among a mixed roster of athletes.

Practical Applications

Sprint-swimmers with a longer history of training and competing exhibit higher and more stable LnRMSSD than less-experienced teammates, possibly due to higher aerobic fitness, a greater familiarity with the training stimulus, or chronic physiological adaptation. Minimal disturbance in autonomic activity (i.e., maintained or increased mean values with improving stability) throughout standardized training may indicate that higher-level and more experienced swimmers could tolerate greater training loads. Knowledge of expected LnRMSSD profiles can be useful to practitioners when interpreting trends in athletes. For example, lower values with greater fluctuations should be expected among lower-level athletes, whereas increased values with greater day-to-day stability may indicate improvements in their ability to tolerate the current workloads. Alternatively, lower and less stable values displayed by a higher-level swimmer may reflect stress, fatigue, or loss of fitness, depending on the context of the current training phase and program. Thus, in practice, additional markers of training status (i.e., workloads, subjective recovery, and performance) should be used to support interpretations of HRV profiles and provide appropriate and targeted guidance for individuals.

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