Individual Heart Rate Variability Responses to Preseason Training in High Level Female Soccer Players

Andrew A. Flatt,[1] Michael R. Esco,[1] and Fábio Y. Nakamura[2]

[1]*Department of Kinesiology, Exercise Physiology Laboratory, University of Alabama, Tuscaloosa, Alabama; and* [2]*State University of Londrina, Londrina, Brazil*

Abstract

Flatt, AA, Esco, MR, and Nakamura, FY. Individual heart rate variability responses to preseason training in high level female soccer players. *J Strength Cond Res* 31(2): 531–538, 2017–The purpose of this study was to track changes in training load (TL) and recovery status indicators throughout a 2-week preseason and to interpret the meaning of these changes on an individual basis among 8 division-1 female soccer players. Weekly averages for heart rate variability (logarithm of the root mean square of successive R-R interval differences [lnRMSSD]), TL, and psychometrics were compared with effect sizes (ESs) and magnitude-based inferences. Relationships were determined with Pearson correlations. Group analysis showed a very likely moderate decrease for total TL (TTL) (TTL week 1 = 1,203 ± 198, TTL week 2 = 977 ± 288; proportion = 1/2/97, ES = −0.93) and a likely small increase in lnRMSSD (week 1 = 74.2 ± 11.1, week 2 = 78.1 ± 10.5; proportion = 81/14/5, ES = 0.35). Fatigue demonstrated a very likely small improvement (week 1 = 5.03 ± 1.09, week 2 = 5.51 ± 1.00; proportion = 95/4/1; ES = 0.45), whereas the other psychometrics did not substantially change. A very large correlation was found between changes in TL and lnRMSSD ($r = -0.85$), whereas large correlations were found between lnRMSSD and perceived fatigue ($r = 0.56$) and soreness ($r = 0.54$). Individual analysis suggests that 2 subjects may benefit from decreased TL, 2 subjects may benefit from increased TL, and 4 subjects may require no intervention based on their psychometric and lnRMSSD responses to the TL. Individual weekly changes in lnRMSSD varied among subjects and related strongly with individual changes in TL. Training intervention based on lnRMSSD and wellness responses may be useful for preventing the accumulation of fatigue in female soccer players.

Key Words vagal, monitoring, parasympathetic, women, fatigue

Address correspondence to Andrew A. Flatt, aflatt@crimson.ua.edu.

31(2)/531–538

Journal of Strength and Conditioning Research

Introduction

National Collegiate Athletic Association (NCAA) regulations for division-1 women's soccer programs allow less than 3 weeks for teams to prepare for the upcoming competitive season. This brief preseason training period is typically comprised of a high content of on- and off-field training, exposing the athletes to an abrupt increase in training load (TL) that may put individuals at risk of overreaching or sustaining injury (19,36). Therefore, teams often use monitoring strategies with their athletes to track TL and recovery status to manage player fatigue throughout training (3,12,30).

Heart rate monitoring systems are often used to objectively quantify internal TL during soccer sessions (1). This provides information to coaching personnel regarding duration of exercise at specific intensities for individual athletes. From these data, TL values (e.g., training impulse [TRIMP]) (24) can be derived. Recovery status indicators are also useful to coaching personnel as considerable interindividual variation exists in how athletes respond to training (11). Furthermore, non–training-related factors such as sleep quality and psychological stressors are known to impact recovery in athletes and therefore affect how one copes with training (10,29). Thus, recovery status markers complement TL data by helping to differentiate athletes who may not have sufficiently recovered from previous training sessions and may facilitate better decision-making with regard to program management.

Resting heart rate variability (HRV) is an objective physiological marker that has been used as an indicator of recovery status in various athletic populations (37). Heart rate variability reflects neural control of the heart via sympathetic and parasympathetic innervations. Vagal indices of HRV such as the logarithm of the root mean square of successive R-R interval differences (lnRMSSDs) reflect cardiac-parasympathetic modulation, are sensitive to fatigue, and have been useful in evaluating individual training adaptation in soccer players (8,16,17). The return of lnRMSSD to baseline after exercise has been related to clearance of plasma catecholamine, lactate, and other metabolic byproducts in addition to restoration of fluid balance and body temperature (37).

Therefore, cardiac-parasympathetic activity is considered a "global" marker of homeostasis that reflects various facets of recovery and may explain why planning intense training when HRV is at or above baseline may be useful for improving endurance performance (37). However, it is currently unclear how other recovery status indicators such as testosterone to cortisol ratio, inflammation, and muscle damage relate to HRV. Thus, HRV alone may not necessarily reflect recovery of all physiological systems. Some of the appealing attributes of lnRMSSD monitoring are that it can be accurately assessed in only 2 minutes (1 minute for stabilization and 1 minute for recording) (14,18,27,31); it can be recorded conveniently in the field by the athletes with a Smartphone application (15), and it may only require as little as 3 averaged recordings per week to provide meaningful training status information (16,35).

Previous research suggests that the weekly mean of lnRMSSD (lnRMSSDmean) provides a better reflection of training status than once per week recordings (25,34). Although limited to 2 investigations, follow-up studies have found that lnRMSSDmean derived from as few as 3 days per week sufficiently capture 7-day mean values (16,35), making implementation more convenient for sports teams. The coefficient of variation of lnRMSSDmean (lnRMSSDcv) represents daily fluctuation, with higher CV values being associated with lower fitness and greater training stress and vice versa (11). A recent study involving female soccer players showed that lnRMSSDmean and lnRMSSDcv related to perceived TL and wellness during weeks of varying TL (16). In addition, lnRMSSDmean ($r = 0.50$) and lnRMSSDcv ($r = -0.74$) changes during the first 3 weeks of a 5-week conditioning program correlated with changes in intermittent running capacity in a collegiate women's soccer team (17). Thus, it appears that monitoring lnRMSSDmean and lnRMSSDcv values throughout training will provide important information pertaining to fatigue and adaptation. However, research describing and analyzing lnRMSSD changes on an individual basis in team sports are limited. Providing interpretation of individual responses can provide novel insight to coaches and sports scientists regarding the practical implementation of lnRMSSD monitoring in field settings.

Psychometric (i.e., wellness) parameters can be acquired via brief questionnaires that provide subjective ratings of recovery status (e.g., fatigue, muscle soreness, mood, stress, sleep quality) that can enhance interpretation of lnRMSSD changes (12). This is because cardiac-autonomic activity is sensitive to a variety of physical and perceived psychological stressors and may therefore obscure the relationship between lnRMSSD and TL (38). In this sense, lnRMSSD may change unfavorably with or without increased TL, thus necessitating interventions for minimizing non–training-related (i.e., life-style) stressors as opposed to reducing TLs (38).

The advancements in lnRMSSD data collection methodology (i.e., ultrashort recordings via Smartphone) are still new, and research in this area is limited. Further investigation into the efficacy of these methodological advancements for being useful for athlete monitoring is warranted. The purpose of this investigation was to observe the relationship between weekly changes in TL and ultrashort, Smartphone-derived lnRMSSD in high-level collegiate female soccer players during a preseason training camp. It was hypothesized that changes in lnRMSSD would relate with changes in TL but that there would likely be some athletes who respond well (i.e., improve lnRMSSD despite increased TL) and vice versa. It was further hypothesized that psychometric variables would serve as useful markers for aiding the interpretation of lnRMSSD changes on an individual basis. Although group data will be discussed, particular attention will be given to individual analysis.

Methods

Experimental Approach to the Problem

This was a single-group observational study that monitored objectively measured internal TL and select recovery status variables during preseason training in division-1 female soccer players. Waking lnRMSSD, TL and psychometrics (i.e., perceived recovery status measures) were averaged and compared between weeks with effect sizes (ESs) and magnitude-based inferences. Relationships between weekly changes in lnRMSSD, TL and psychometrics were quantified with Pearson correlations. In addition, analyses were performed on an individual basis in attempt to interpret how each athlete was coping with training based on the selected recovery status variables.

Subjects

Eight female NCAA division-1 soccer players (age = 20.2 ± 1.8 years; height = 167.2 ± 6.3 cm; weight = 62.5 ± 9.9 kg) volunteered to participate in this investigation. All subjects completed health history questionnaires and provided written informed consent after being informed of the details and risks of their involvement in this study. All subjects were free from cardiovascular, metabolic, and orthopedic disorders. This study was approved by the Institutional Review Board for Human Participants.

Procedures

Training Structure. Preseason training began on Wednesday of week 1 and lasted until Thursday of week 3, at which point, regular season competitions began. Week 1 (i.e., Wednesday–Sunday) was excluded from analysis, as this time was used to familiarize the subjects with measuring HRV via their Smartphone and the accompanying hardware. Details of the training structure for weeks 2 and 3 of the preseason period can be viewed in Table 1. Practice sessions lasted between 90 and 120 minutes and consisted of skill development, technical/tactical drills, and small-sided games. Scrimmages were intersquad matches involving 30-minute halves. Regeneration sessions were held on days following scrimmages or competitions and involved a 30-minute session consisting of low-intensity aerobic work on

Table 1. Microcycle structure for week 2 and week 3 of training camp.*

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Wk 2							
AM	RT, Pr	Regen	Pr		Regen	Pr	Scrm
PM	Scrm			Scrm		Pr	
Wk 3							
AM	Regen	RT, Pr	Pr	RT, Pr		Regen	
PM					Comp		Comp

*AM = morning; PM = evening; RT = resistance training; Pr = soccer practice; Regen = regeneration; Scrm = Scrimmage; Comp = competition.

an Airdyne cycle, mobility drills, self-myofascial release, and static stretching. Resistance training (RT) sessions lasted 30 minutes and involved total-body workouts consisting of power cleans, squats, dumbbell presses, inverted rows, and unilateral lower body exercises. Subjects were familiar with all RT exercises from off-season training.

Fitness Testing. Intermittent running capacity was evaluated on the opening day of preseason training (i.e., Wednesday of week 1) as part of standard player evaluations that are routinely conducted each year by the coach. Fitness was evaluated via the Yo-Yo Intermittent Recovery Test, level 1 (Yo-Yo IRT-1). The YoYo IRT-1 test was administered on an indoor turf field in the same facility that off-season training took place. All athletes were familiar with the test from previous evaluations. The test was administered over portable speakers in accordance with established guidelines (5). The test involves progressive 2 × 20-m shuttle runs with 10-second relief periods (2 × 5-m walking) between shuttles. The total distance accumulated in meters by each athlete was recorded.

Training Load. Before all training sessions, subjects moistened and fitted a heart rate monitor around their chests at the level of the xyphoid process, against their skin, underneath the elastic of their sports bra. Heart rate data during training were recorded via radio telemetry (Polar Team2, VantageNV; Polar Electro, Kempele, Finland, Europe) and were uploaded to a laptop computer after the final session of each day using the accompanying Polar Team2 software. A TL value (i.e., Polar TRIMP) is calculated automatically by the Polar Team2 software. Polar TRIMP (28) uses a modified formula originally proposed by Banister (6) and has been used previously for TL quantification in female soccer players (2). Training load data was transferred to a spreadsheet for analysis.

Heart rate variability. Subjects were provided with the ithlete application and accompanying pulse-wave finger sensor (PWFS) (HRV Fit Ltd., Southampton, United Kingdom) that inserts into the headphone slot of a Smartphone or tablet device. The PWFS used in this study has been cross-validated in a previous investigation using a modified version of the ithlete application that allowed for raw data extraction for comparison with an electrocardiogram (21). The ithlete HRV application uses a 1-minute recording to calculate lnRMSSD. One-minute lnRMSSD measures have been shown to be sufficient for valid assessment compared with standard 5-minute measures in athletes (14,18,31) and are sensitive to training-induced lnRMSSD changes (27). The application provides automatic pulse interval processing that corrects for irregular heartbeats (i.e., intervals <500 ms and >1,800 ms). The lnRMSSD value provided by the application is modified to fit a ~100-point scale by multiplying the lnRMSSD by 20 (15).

Subjects were instructed to perform their HRV measures in the seated position (37) after waking and elimination and to allow 1-minute for stabilization before the recording period (18,27). Once seated, the subjects would insert the PWFS into their Smartphone and then insert their left index finger into the PWFS and initiate the ithlete application. Holding the left hand stable and within 20 cm of their chest, the subjects would then begin an HRV recording. The subjects were instructed to breathe spontaneously (7) throughout the 1-minute recording period, as this was preferred over paced breathing among a team of female soccer players in a previous study (16). Upon completion of an HRV measure, the subjects completed a wellness questionnaire on the application (discussed in *Psychometrics*). Immediately upon completion of the waking-HRV measure, the data were automatically uploaded to a web-based interface (ithlete Team System) for analysis by the coach and researchers. Wednesday–Sunday of week 1 served as a trial period for the subjects with the ithlete system for familiarization of the procedures. Weekly lnRMSSDmean values were derived from a minimum of 4 measures per week (8,16,35), with the actual number of acquired recordings being 5.6 ± 1.0 and 5.5 ± 0.76 for weeks 2 and 3, respectively.

Psychometrics. After their HRV measures, subjects completed a brief questionnaire adapted from McLean et al. (26)

Table 2. Individual fitness level and changes in lnRMSSDmean and training load across the 2-week training camp.*

	YoYo IRT-1 (m)	lnRMSSDmean		Effect size, Qualitative inference	Daily TL (au)		Effect size, Qualitative inference	Total TL (au)	
		Wk 2, Mean ± *SD* (CV)	Wk 3, Mean ± *SD* (CV)		Wk 2, Mean ± *SD*	Wk 3, Mean ± *SD*		Wk 2	Wk 3
Subject 1	1,640	92.3 ± 3.9 (4.2)	90.6 ± 7.6 (7.5)	−0.30, small	165.4 ± 97.6	201.0 ± 124.8	0.32, small	1,158	1,005
Subject 2	1,520	84.2 ± 7.5 (8.9)	87.0 ± 2.9 (3.4)	0.55, small	204.5 ± 138.7	267.6 ± 166.5	0.41, small	1,432	1,388
Subject 3	1,680	82.2 ± 3.7 (4.5)	82.6 ± 3.6 (4.3)	0.09, trivial	195.5 ± 70.4	203.6 ± 98.2	0.09, trivial	1,173	1,018
Subject 4	1,120	76.1 ± 10.3 (13.5)	73.6 ± 9.0 (12.2)	−0.26, small	194.8 ± 97.3	272.8 ± 170.0	0.58, small	1,364	1,364
Subject 5	840	67.2 ± 4.0 (7.8)	86.9 ± 5.6 (6.5)	4.07, very large	183.1 ± 47.3	115.2 ± 68.8	−1.17, moderate	1,282	576
Subject 6	1,240	66.6 ± 3.6 (5.4)	76.8 ± 4.5 (5.9)	2.50, very large	139.5 ± 49.2	127.6 ± 70.2	−0.20, small	977	638
Subject 7	1,480	63.8 ± 3.9 (6.2)	63.3 ± 5.3 (8.3)	−0.12, trivial	196.1 ± 93.6	209.4 ± 131.9	0.11, trivial	1,373	1,047
Subject 8	1,200	61.4 ± 6.8 (11.2)	63.9 ± 2.4 (3.8)	0.54, small	132.3 ± 77.3	167.2 ± 115.1	0.36, small	872	836

*lnRMSSDmean = weekly mean logarithm of the root mean square of successive R-R interval differences; CV = coefficient of variation; TL = training load; m = meters; au = arbitrary units; Wk, week.

Table 3. Comparison of the weekly mean psychometric variables.*

	Sleep			Fatigue			Stress			Soreness			Mood		
	Wk 2	Wk 3	ES	Wk 2	Wk 3	ES	Wk 2	Wk 3	ES	Wk 2	Wk 3	ES	Wk 2	Wk 3	ES
S 1	6.00	6.20	0.17	3.70	4.60	0.97	5.14	3.80	−1.57	5.0	4.80	−0.49	5.28	4.80	−0.49
S 2	7.40	6.33	−0.93	6.60	6.66	0.03	6.60	5.66	−0.70	6.40	6.33	−0.06	7.20	6.33	−1.0
S 3	7.00	6.75	−0.13	6.16	6.50	0.37	6.66	6.75	0.10	4.83	5.75	0.64	7.16	7.75	0.75
S 4	6.20	6.60	0.19	6.00	5.80	−0.13	6.00	6.80	0.69	6.00	5.80	−0.12	6.20	7.40	1.2
S 5	4.57	5.50	0.69	4.14	5.00	1.33	5.28	4.75	0.50	3.85	4.50	0.95	5.14	4.50	0.65
S 6	6.00	5.75	−0.09	5.00	6.50	2.00	5.00	6.25	1.80	4.75	6.25	3.22	5.75	6.75	0.94
S 7	4.66	4.80	0.21	4.66	5.00	0.92	5.33	5.40	0.13	4.66	4.40	−0.29	5.50	6.00	1.17
S 8	5.25	4.25	−0.90	4.00	4.00	0	5.50	5.25	−0.46	4.50	3.75	−0.95	6.25	5.50	−0.76
Mean ± *SD*	5.88 ± 1.02	5.77 ± 0.88	−0.12	5.03 ± 1.09	5.51 ± 1.00	0.45	5.69 ± 0.65	5.58 ± 1.02	−0.13	5.01 ± 0.82	5.20 ± 0.96	0.22	6.06 ± 0.80	6.13 ± 1.17	0.07
Prop QI	18/33/49 unclear			95/4/1 very likely			21/35/44 unclear			59/28/13 unclear			40/36/24 Unclear		

*S = subject; ES = effect size; QI = qualitative inference; Wk = week.

regarding the subjects' perceived sleep quality, muscle soreness, mood, fatigue, and stress using the ithlete application. The questionnaire asks the subjects to rate each variable on a 9-point scale. A rating of 5 represented feeling "Okay" while higher and lower ratings than 5 represented better or worse perceptions of the given parameter, respectively. Psychometric data were automatically uploaded to the Web-interface upon completion for analysis.

Statistical Analyses

Data are expressed as mean and *SD*. Standardized differences (i.e., ESs) (13) were calculated for individual and group changes in daily mean TL that excluded rest days (ΔDTL), total weekly TL (ΔTTL), and lnRMSSDmean (ΔlnRMSSD) using the following qualitative thresholds: 0–0.2 was trivial; 0.2–0.6 was small; 0.6–1.2 was moderate; 1.2–2.0 was large; and >2.0 was very large (22). Magnitude-based inferences were also used to compare ΔDTL and ΔTTL, and ΔlnRMSSD group changes using the spreadsheet available at http://www.sportsci.org/index.html. The quantitative chances for a weekly change in TL and lnRMSSD having higher, similar, or lower values were assessed qualitatively as follows: <1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99%, very likely; and >99%, almost certain (22). If the chance of higher or lower differences was >5%, then the true difference was assessed as unclear (22). Pearson product moment correlation coefficients were used to quantify the relationship between ΔTL and ΔlnRMSSD as well as for ΔlnRMSSD and changes in psychometric variables. An *r*-value between 0 and 0.30 was considered small, 0.31 and 0.49 as moderate, 0.50 and 0.69 as large, 0.70 and 0.89 as very large, and 0.90 and 1.00 as near perfect (22).

Results

Group analysis showed an unclear small increase for ΔDTL (daily TL [DTL] week 2 = 176.4 ± 27.6, DTL week 3 = 195.5 ± 57.7; proportion = 74/19/7, ES = 0.45) and a very likely moderate decrease for ΔTTL (total TL [TTL] week 2 = 1,203 ± 198, TTL week 3 = 977 ± 288; proportion = 1/2/97, ES = −0.85). A likely small increase (lnRMSSD week 2 = 74.2 ± 11.1, lnRMSSD week 3 = 78.1 ± 10.5; proportion = 81/14/5, ES = 0.35) was found for ΔlnRMSSD. Fatigue demonstrated a very likely small improvement from week 2 to week 3, whereas the other pyschometric parameters did not meaningfully change (Table 3). Individual changes for lnRMSSD, TL, and

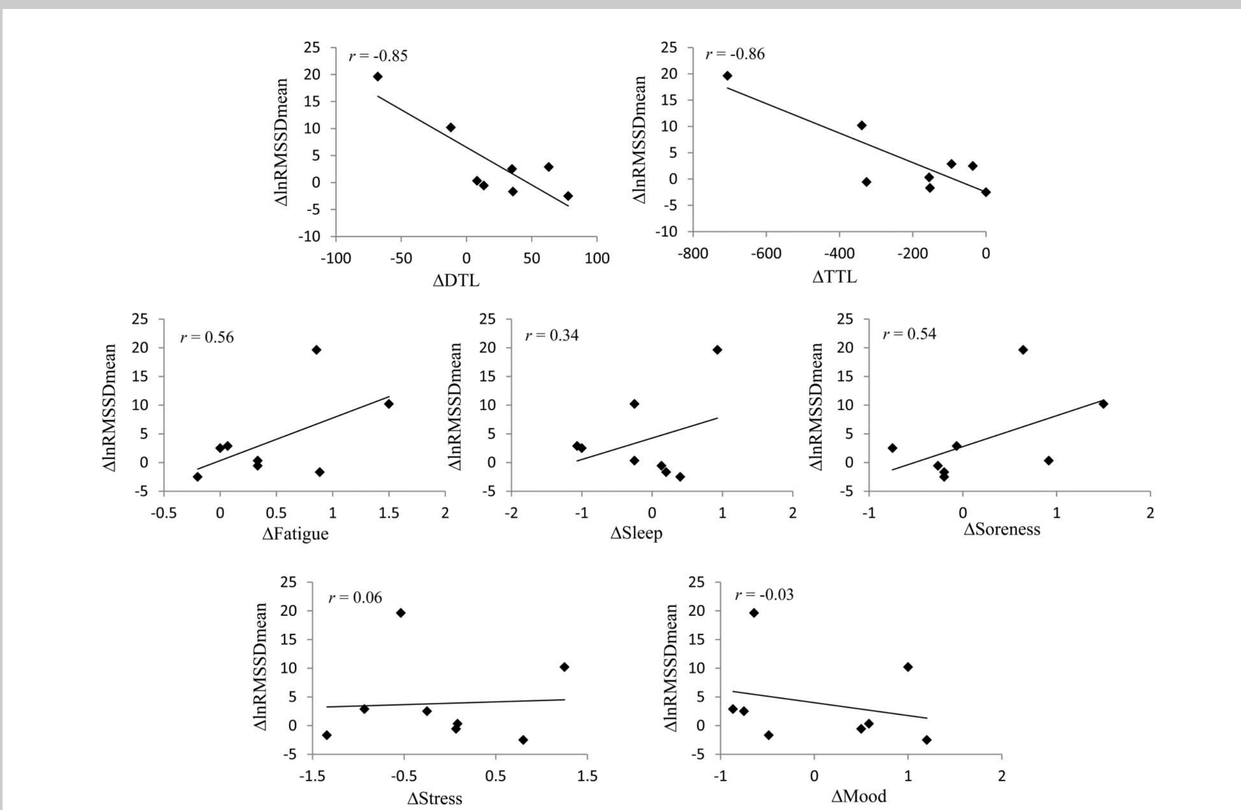

Figure 1. Scatterplot's representing relationships between ΔlnRMSSD and ΔDTL, ΔTTL and psychometric variables. ΔlnRMSSD = weekly mean change in log transformed root mean square of successive R-R interval differences; ΔDTL = weekly mean change in daily training load; ΔTTL = weekly change in total training load.

psychometrics varied and can be viewed in Tables 2 and 3. Very large negative correlations were found between ΔDTL, ΔTTL, and ΔlnRMSSDmean while small to large correlations were found between ΔlnRMSSDmean and changes in psychometric variables (Figure 1).

Discussion

The main finding of the current study for the group analysis was that weekly changes in TL showed very large relationships with the weekly changes in lnRMSSDmean. Increased TL was associated with decreased lnRMSSDmean; decreased TL was associated with increased lnRMSSDmean; and unchanged TL resulted in no substantial changes in lnRMSSDmean. Of the psychometric parameters, changes in fatigue and soreness showed the strongest relationships with ΔlnRMSSD.

These findings agree with previous research in collegiate female soccer players who showed small increases in lnRMSSDmean (ES = 0.29) after a reduction in weekly perceived TL (16). The changes in lnRMSSDmean were interpreted as a positive response due to a concomitant improvement in wellness variables (ES = 0.72). Relationships between HRV and TL have also been observed in other sports disciplines where lnRMSSD decreased with greater TL but increased with reduced TL (23,32). Cardiac-parasympathetic activity can take between 24 and 72 hours to return to baseline after intense training (37). As such, suppressed lnRMSSDmean would indicate that full recovery of cardiac-parasympathetic activity was unattained while baseline or elevated lnRMSSDmean would indicate that recovery was adequate. Thus, a reduced lnRMSSDmean implies incomplete restoration of homeostatic balance, at least with regard to cardiac-parasympathetic activity (37). Furthermore, suppressed indices of cardiac-parasympathetic activity have been associated with overtraining (33,38). Finally, increases in lnRMSSD recovery after training may be associated with improved fitness in soccer players (9). Thus, ensuring that lnRMSSD values that do not remain chronically suppressed may help prevent fatigue accumulation and facilitate greater training adaptation (17).

The following interpretations of the individual HRV and wellness responses to the preseason training camp are based on findings from previous research and our observation of the subjects. We caution the reader that this is partly speculative given that additional markers of TL and recovery status were not evaluated to provide confirmation. Nevertheless, subjects 2 and 8 demonstrated opposite lnRMSSD responses compared with the rest of the team. These subjects showed small increases in lnRMSSDmean despite small increases in DTL. This may suggest that the increase in DTL was well tolerated by these individuals. This interpretation is supported by the considerable decrease in lnRMSSDcv observed in these subjects. Previous research found that increases in lnRMSSDmean and decreases in lnRMSSDcv within the first 3 weeks of a training program in collegiate female soccer players were associated with greater eventual improvements in YoYo IRT-1 (17). Therefore, subjects 2 and 8 appeared to adapt positively to the training camp based on these lnRMSSD changes. Perceived fatigue did not change in either subject; however, decreases in the other psychometric categories were observed. Although the lnRMSSD changes in subjects 2 and 8 may be interpreted as a positive coping response to training, some psychometric variables suggest that further increases in TL should be done with caution.

Subject 1 showed small decreases in lnRMSSDmean and a considerable increase in lnRMSSDcv in response to small increases in DTL. These changes are particularly concerning because this subject was the second most fit athlete in the study (YoYo IRT-1 values in Table 2) and a veteran player. Increased lnRMSSDcv values have been shown to occur in low-fit or fatigued soccer players (11,16). An underlying variable that may potentially explain the lnRMSSD changes observed in subject 1, apart from TL, might be the greater perceived stress levels during week 3, which showed the largest decrease (i.e., negative change, ES = −1.57) in any wellness parameter observed in the entire group. Perceived stress has been shown to be a contributor to non-functional overreaching along with decreases in RMSSD among elite female athletes (38).

Subject 4 demonstrated small decreases in lnRMSSDmean in response to small increases in DTL in addition to having the highest lnRMSSDcv of the group in both weeks. This is likely explained by the TL increase along with relatively low fitness (11). Low fitness levels may make athletes susceptible to greater homeostatic perturbation in response to training, reflected by large fluctuation in lnRMSSD (11). Although lnRMSSD changes were similar among subjects 1 and 4, we suggest that the changes for subject 1 may be more due to perceived stressors, whereas the changes in subject 4 may be attributable to her relatively low fitness and high TL. Based on a previous finding that a reduced lnRMSSDmean along with a reduced lnRMSSDcv was related to non-functional overreaching (33), we interpret a reduced lnRMSSDmean and increased lnRMSSDcv (demonstrated by subjects 1 and 4) to be a less severe negative change in cardiac-parasympathetic activity. This is because increased lnRMSSDcv indicates that lnRMSSD oscillated upward and downward throughout the week, potentially reflecting changes in fatigue and recovery (33). This is in contrast to a reduced lnRMSSDmean concurrent with a reduced lnRMSSDcv that has been associated with non-functional overreaching (33), which indicates that cardiac-parasympathetic activity remained suppressed with no return or recovery toward baseline throughout the week (i.e., chronic suppression). Thus, it is possible that the progression of going from moderately fatigued to overreached may be characterized first by a decrease in lnRMSSDmean and increased lnRMSSDcv followed by a reduced lnRMSSDcv while lnRMSSDmean remains suppressed. Further research is required to support this hypothesis.

Subjects 5 and 6 both experienced very large increases in lnRMSSDmean along with moderate and small decreases in

DTL, respectively. These subjects did not receive much playing time during competitions in week 3 which is why their TLs decreased so much relative to the other subjects. Perceived fatigue and soreness levels improved in both subjects. The increases in lnRMSSDmean were therefore attributed to a reduction in physical stress (16). Training status and fitness appear to be factors effecting lnRMSSD changes (37). These athletes were not starters and had low fitness relative to the rest of the group, possibly explaining their low lnRMSSDmean values during week 2 and subsequent very large rebound (i.e., increase in lnRMSSDmean) in week 3 when loads were reduced.

Last, subjects 3 and 7 showed trivial changes in both lnRMSSDmean and DTL along with similar lnRMSSDcv values. Psychometric values for subjects 3 and 7 also remained relatively unchanged and therefore these individuals appeared to be adequately coping with training. Collectively, the interpretations of lnRMSSD changes across the training camp described above suggest that subjects 1 and 4 may benefit from reduced TL to prevent overaccumulation of fatigue and further worsening of lnRMSSD values in the forthcoming week. Subjects 5 and 6 may benefit from increased TLs, as they appeared well recovered based on the very large increase in lnRMSSDmean, improved psychometric indices, and to compensate for the lack of playing time during competitions. The TLs for subjects 2, 3, 7, and 8 showed no change or small increases in lnRMSSDmean and no change or decreases in lnRMSSDcv, and the subjects appeared to be tolerating training adequately and likely required no intervention.

Frequent quantification of TLs and physiological/psychological adaptations to training can potentially be used to guide training and prevent excessive fatigue accumulation on an individual basis. Since it has been recently shown that functional overreaching (reduced performance with concomitant high perceived fatigue) is not a necessary strategy to improve performance, even after TL reduction (i.e., tapering) (4), implementation of field-based monitoring systems may be helpful in preventing prolonged fatigue states. This may be achieved with adequate program management by monitoring the imposed TL and subsequent recovery status indicators of each athlete (20).

The soccer team was inaccessible to the researchers before training camp which prevented acquisition of baseline lnRMSSD data and is a limitation of the current study. Additionally, the small sample size is a limitation; however, the individual analysis of the subjects may provide novel insight that cannot be gained when evaluating grouped averages from large samples. As only internal TL was quantified in the current study, non-fatiguing performance tests such as countermovement jumps and external TL (i.e., time-motion analysis) should be considered for future research to compare with lnRMSSD changes. Other indicators of fatigue and recovery (e.g., neuroendocrine changes, inflammatory markers, and muscle damage) should also be evaluated along with lnRMSSD and wellness in future studies to improve upon the current interpretation of individual responses. Finally, relying on self-reported measures to account for non-training stress may be considered a limitation. In conclusion, weekly lnRMSSDmean correlated with changes in TL. Individual analysis suggests that small TL modification for 50% of the subjects may support training adaptations and prevent the accumulation of excess fatigue.

Practical Applications

Monitoring individual lnRMSSD responses to training in conjunction with TL and psychometrics may provide objective rationale for coaches to strategically manipulate TLs on an individual basis to manage fatigue in female soccer players. Decreased lnRMSSDmean was associated with increased training stress. Reducing TL for individual athletes who demonstrate unfavorable psychometric and lnRMSSD changes (e.g., reduced lnRMSSDmean and increased lnRMSSDcv) in response to intense training may help prevent excess fatigue accumulation. Large increases in lnRMSSDmean in response to reduced TL along with improved psychometrics may indicate that higher TLs would be well tolerated. Individuals who demonstrate no changes in lnRMSSD and psychometric values would appear to be tolerating training adequately and may require no modification to TL.

Acknowledgments

The authors thank the UA Women's Soccer players, coaching staff, athletic training staff, and strength and conditioning coach for their participation. No funding was provided for this study. Materials used in this study for HRV analysis (i.e., PWFS and ithlete applications) were provided by HRV Fit Ltd. Athlete management software was provided by CoachMePlus (Buffalo, NY, USA).

References

1. Alexandre, D, Da Silva, CD, Hill-Haas, S, Wong del, P, Natali, AJ, De Lima, JR, Bara-Filho, MG, Marins, JJ, Garcia, ES, and Karim, C. Heart rate monitoring in soccer: Interest and limits during competitive match play and training, practical application. *J Strength Cond Res* 26: 2890–2906, 2012.
2. Alexiou, H and Coutts, AJ. A comparison of methods used for quantifying internal training load in women soccer players. *Int J Sports Physiol Perform* 3: 320–330, 2008.
3. Arcos, AL, Martínez-Santos, R, Yanci, J, Mendiguchia, J, and Méndez-Villanueva, A. Negative associations between perceived training load, volume and changes in physical fitness in professional soccer players. *J Sport Sci Med* 14: 394–401, 2015.
4. Aubry, A, Hausswirth, C, Louis, J, Coutts, AJ, and LE Meur, Y. Functional overreaching: The key to peak performance during the taper? *Med Sci Sport Exerc* 46: 1769–1777, 2014.
5. Bangsbo, J, Iaia, FM, and Krustrup, P. The Yo-Yo intermittent recovery test: A Useful Tool for Evaluation of Physical Performance in Intermittent Sports. *Sports Med* 38: 37–51, 2008.
6. Banister, EW. Modeling elite athletic performance. In *Physiological Testing of Elite Athletes.* H Green, J McDougall, and H Wenger, eds. Champaign, IL: Human Kinetics, 1991. pp. 403–424.

7. Bloomfield, DM, Magnano, A, Bigger, JT, Rivadeneira, H, Parides, M, and Steinman, RC. Comparison of spontaneous vs. metronome-guided breathing on assessment of vagal modulation using RR variability. *Am J Physiol Heart Circ Physiol* 280: H1145–H1150, 2001.
8. Boullosa, DA, Abreu, L, Nakamura, FY, Muñoz, VE, Domínguez, E, and Leicht, AS. Cardiac autonomic adaptations in elite spanish soccer players during preseason. *Int J Sport Physiol Perform* 8: 400–409, 2013.
9. Buchheit, M, Chivot, A, Parouty, J, Mercier, D, Al Haddad, H, Laursen, PB, and Ahmaidi, S. Monitoring endurance running performance using cardiac parasympathetic function. *Eur J Appl Physiol* 108: 1153–1167, 2010.
10. Buchheit, M, Cholley, Y, and Lambert, P. Psychometric and physiological responses to a preseason competitive camp in the heat with a 6-hour time difference in elite soccer players. *Int J Sport Physiol Perform* 11: 176–181, 2016.
11. Buchheit, M, Mendez-Villanueva, A, Quod, MJ, Poulos, N, and Bourdon, P. Determinants of the variability of heart rate measures during a competitive period in young soccer players. *Eur J Appl Physiol* 109: 869–878, 2010.
12. Buchheit, M, Simpson, BM, Garvican-Lewis, LA, Hammond, K, Kley, M, Schmidt, WF, Aughey, RJ, Soria, R, Sargent, C, Roach, GD, Claros, JC, Wachsmuth, N, Gore, CJ, and Bourdon, PC. Wellness, fatigue and physical performance acclimatisation to a 2-week soccer camp at 3,600 m (ISA3600). *Br J Sport Med* 47: i100–i106, 2013.
13. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*(2nd ed.). Hillsdale, NJ: Lawrence Erlbaum, 1988.
14. Esco, MR and Flatt, AA. Ultra-short-term heart rate variability indexes at rest and post-exercise in athletes: Evaluating the agreement with accepted recommendations. *J Sports Sci Med* 13: 535–541, 2014.
15. Flatt, AA and Esco, MR. Validity of the ithlete smart phone application for determining ultra-short-term heart rate variability. *J Hum Kinet* 39: 85–92, 2013.
16. Flatt, AA and Esco, MR. Smartphone-derived heart-rate variability and training load in a women's soccer team. *Int J Sport Physiol Perform* 10: 994–1000, 2015.
17. Flatt, AA and Esco, MR. Evaluating individual training adaptation with smartphone-derived heart rate variability in a collegiate female soccer team. *J Strength Cond Res* 30: 378–385, 2016.
18. Flatt, AA and Esco, MR. Heart rate variability stabilization in athletes: Towards more convenient data acquisition. *Clin Physiol Funct Imaging*. DOI: 10.1111/cpf.12233. E-pub ahead of print.
19. Gabbett, TJ and Domrow, N. Relationships between training load, injury, and fitness in sub-elite collision sport athletes. *J Sport Sci* 25: 1507–1519, 2007.
20. Gaudino, P, Iaia, F, Strudwick, A, Hawkins, R, Alberti, G, Atkinson, G, and Gregson, W. Factors influencing perception of effort (session rating of perceived exertion) during elite soccer training. *Int J Sport Physiol Perf* 10: 860–864, 2015.
21. Heathers, JA. Smartphone-enabled pulse rate variability: An alternative methodology for the collection of heart rate variability in psychophysiological research. *Int J Psychophysiol* 89: 297–304, 2013.
22. Hopkins, W, Marshall, S, Batterham, A, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3–13, 2009.
23. Iellamo, F, Legramante, JM, Pigozzi, F, Spataro, A, Norbiato, G, Lucini, D, and Pagani, M. Conversion from vagal to sympathetic predominance with strenuous training in high-performance world class athletes. *Circulation* 105: 2719–2724, 2002.
24. Impellizzeri, FM, Rampinini, E, Coutts, AJ, Sassi, A, and Marcora, SM. Use of RPE-based training load in soccer. *Med Sci Sport Exerc* 36: 1042–1047, 2004.
25. Le Meur, Y, Pichon, A, Schaal, K, Schmitt, L, Louis, J, Gueneron, J, Vidal, PP, and Hausswirth, C. Evidence of parasympathetic hyperactivity in functionally overreached athletes. *Med Sci Sports Exerc* 45: 2061–2071, 2013.
26. McLean, BD, Coutts, AJ, Kelly, V, McGuigan, MR, and Cormack, SJ. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *Int J Sport Physiol Perform* 5: 367–383, 2010.
27. Nakamura, FY, Flatt, AA, Pereira, LA, Ramirez-Campillo, R, Loturco, I, and Esco, MR. Ultra-short-term heart rate variability is sensitive to training effects in team sports players. *J Sport Sci Med* 14: 602–605, 2015.
28. Nissilä, J and Kinnunen, H. *Heart Rate Based Training Load and Recovery Time Estimation*. Kempele, Finland: Polar Electro Oy, 2008. pp. 1–4.
29. Noon, MR, James, RS, Clarke, ND, Akubat, I, and Thake, CD. Perceptions of well-being and physical performance in English elite youth footballers across a season. *J Sport Sci* 33: 2106–2115, 2015.
30. Oliveira, R, Leicht, A, Bishop, D, Barbero-Álvarez, JC, and Nakamura, F. Seasonal changes in physical performance and heart rate variability in high level futsal players. *Int J Sport Med* 34: 424–430, 2013.
31. Pereira, LA, Flatt, AA, Ramirez-Campillo, R, Loturco, I, and Nakamura, FY. Assessing shortened field-based heart-rate-variability-data acquisition in team-sport athletes. *Int J Sport Physiol Perform* 11: 154–158, 2016.
32. Pichot, V, Roche, F, Gaspoz, JM, Enjolras, F, Antoniadis, A, Minini, P, Costes, F, Busso, T, Lacour, J, and Barthelemy, JC. Relation between heart rate variability and training load in middle-distance runners. *Med Sci Sport Exerc* 32: 1729–1736, 2000.
33. Plews, DJ, Laursen, PB, Kilding, AE, and Buchheit, M. Heart rate variability in elite triathletes, is variation in variability the key to effective training? A case comparison. *Eur J Appl Physiol* 112: 3729–3741, 2012.
34. Plews, DJ, Laursen, PB, Kilding, AE, and Buchheit, M. Evaluating training adaptation with heart-rate measures: A methodological comparison. *Int J Sport Physiol Perform* 8: 688–691, 2013.
35. Plews, DJ, Laursen, PB, Le Meur, Y, Hausswirth, C, Kilding, AE, and Buchheit, M. Monitoring training with heart rate-variability: How much compliance is needed for valid assessment? *Int J Sports Physiol Perform* 9: 783–790, 2014.
36. Rogalski, B, Dawson, B, Heasman, J, and Gabbett, TJ. Training and game loads and injury risk in elite Australian footballers. *J Sci Med Sport* 16: 499–503, 2013.
37. Stanley, J, Peake, JM, and Buchheit, M. Cardiac parasympathetic reactivation following exercise: Implications for training prescription. *Sport Med* 43: 1259–1277, 2013.
38. Tian, Y, He, ZH, Zhao, JX, Tao, DL, Xu, KY, Earnest, CP, and Mc Naughton, LR. Heart rate variability threshold values for early-warning nonfunctional overreaching in elite female wrestlers. *J Strength Cond Res* 27: 1511–1519, 2012.