HEART RATE VARIABILITY AND TRAINING LOAD AMONG NATIONAL COLLEGIATE ATHLETIC ASSOCIATION DIVISION 1 COLLEGE FOOTBALL PLAYERS THROUGHOUT SPRING CAMP

ANDREW A. FLATT,[1,2] MICHAEL R. ESCO,[1] JEFF R. ALLEN,[3] JAMES B. ROBINSON,[3] RYAN L. EARLEY,[4] MICHAEL V. FEDEWA,[1] AMY BRAGG,[5] CLAY M. KEITH,[3] AND JONATHAN E. WINGO[1]

[1]Exercise Physiology Laboratory, Department of Kinesiology, University of Alabama, Tuscaloosa, Alabama; [2]Department of Health Sciences, Armstrong State University, Savannah, Georgia; [3]Department of Athletics, Sports Medicine, University of Alabama, Tuscaloosa, Alabama; [4]Department of Biological Sciences, University of Alabama, Tuscaloosa, Alabama; and [5]Department of Athletics, Sports Nutrition, University of Alabama, Tuscaloosa, Alabama

ABSTRACT

Flatt, AA, Esco, MR, Allen, JR, Robinson, JB, Earley, RL, Fedewa, MV, Bragg, A, Keith, CM, and Wingo, JE. Heart rate variability and training load among National Collegiate Athletic Association Division 1 college football players throughout spring camp. *J Strength Cond Res* 32(11): 3127–3134, 2018—The purpose of this study was to determine whether recovery of cardiac-autonomic activity to baseline occurs between consecutive-day training sessions among positional groups of a collegiate football team during Spring camp. A secondary aim was to evaluate relationships between chronic (i.e., 4-week) heart rate variability (HRV) and training load parameters. Baseline HRV (lnRMSSD_BL) was compared with HRV after ~20 hours of recovery before next-day training (lnRMSSDpost20) among positional groups composed of SKILL ($n = 11$), MID-SKILL ($n = 9$), and LINEMEN ($n = 5$) with a linear mixed model and effect sizes (ES). Pearson and partial correlations were used to quantify relationships between chronic mean and coefficient of variation (CV) of lnRMSSD (lnRMSSD_chronic and lnRMSSDcv, respectively) with the mean and CV of PlayerLoad (PL_chronic and PL_cv, respectively). A position × time interaction was observed for lnRMSSD ($p = 0.01$). lnRMSSD_BL was higher than lnRMSSDpost20 for LINEMEN ($p < 0.01$; ES = large), whereas differences for SKILL and MID-SKILL were not statistically different ($p > 0.05$). Players with greater body mass experienced larger reductions in lnRMSSD ($r = -0.62$, $p < 0.01$). Longitudinally, lnRMSSDcv was significantly related to body mass ($r = 0.48$) and PL_chronic ($r = -0.60$). After adjusting for body mass, lnRMSSDcv and PL_chronic remained significantly related ($r = -0.43$). The ~20-hour recovery time between training sessions on consecutive days may not be adequate for restoration of cardiac-parasympathetic activity to baseline among LINEMEN. Players with a lower chronic training load throughout camp experienced greater fluctuation in lnRMSSD (i.e., lnRMSSDcv) and vice versa. Thus, a capacity for greater chronic workloads may be protective against perturbations in cardiac-autonomic homeostasis among American college football players.

KEY WORDS parasympathetic, autonomic, monitoring, sport physiology, sport science, recovery

INTRODUCTION

Despite a demanding training schedule and high injury rate in American football (26), research pertaining to training status monitoring among American football players pales in comparison with sports such as soccer and rugby. American football players vary in physical and performance characteristics because of unique positional requirements. For example, receivers and defensive backs (SKILL) experience the greatest running demands and thus tend to have the fastest sprinting speeds, lowest body and fat mass, and greatest aerobic fitness level among positional groups (32,36). By contrast, offensive and defensive linemen (LINEMEN) have the lowest running demands but regularly encounter physical bouts in which they must displace their opponent to gain or defend field position (26,36). LINEMEN, therefore, have the highest maximal strength, greatest body and fat mass, and lowest aerobic fitness level of the various positional groups (32). Linebackers, running backs, and tight-ends (MID-SKILL) experience playing demands characteristic of both SKILL and LINEMEN and thus tend to display physical and fitness characteristics intermediate to these positions (26,32,36). Given that body mass, playing demands and physiological responses to training vary by position (26), recovery duration

---

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

32(11)/3127–3134

Journal of Strength and Conditioning Research

requirements may also differ among position. However, this topic has received little investigation.

Wearable devices using triaxial accelerometers (microsensors) are capable of measuring movement profiles of athletes during sports play. Wearable microsensors are attractive to coaches because the physical demands of competition or training can be quantified with minimal burden to the athlete. Though training load monitoring is becoming more popular in American football (35–37), its use in conjunction with recovery status indicators among football players has not been well studied. This research is needed because external training load does not provide information regarding internal physiological responses and there exists substantial interindividual variation in responses and adaptation to training (24).

A recovery status metric gaining popularity among sports teams is resting heart rate variability (HRV). Heart rate variability reflects autonomic modulation of the heart and can be measured noninvasively with inexpensive field tools such as smartphone applications (13,15,28). Vagally mediated HRV is considered a global marker of homeostasis and reflects cardiovascular recovery after a training session (33). For example, vagal-HRV suppression is observed for 24–48 hours after intense training (33) with the return to baseline possibly reflecting the optimal state for subsequent intensive training (22). Cardiac-parasympathetic recovery from exercise is affected by factors such as fitness level, exercise intensity, and alterations in fluid balance (33). Because fitness level, body mass, as well as fluid balance and thermoregulatory responses to training vary among positional groups in American football (9,32), daily cardiac-autonomic responses inferred from vagal HRV may also differ among positions and thus provide useful recovery status information.

Greater daily fluctuation in cardiac-parasympathetic activity (assessed by the coefficient of variation [CV]) has been associated with lower maximal oxygen uptake ($\dot{V}O_2max$) (14), lower intermittent running performance (2,7,14,16), and greater fatigue during intensified training (17,18). An athlete's chronic training load (i.e., 4-week average) is sometimes used as an indicator of training capacity or fitness level (21). Hypothetically, players who perform greater chronic training loads (i.e., SKILL) should have a lower CV of vagal HRV, whereas those who perform lower chronic workloads (i.e., LINEMEN) would be expected to display a greater CV. This would build on previous findings that less fit individuals experience greater perturbations in cardiac-autonomic homeostasis than more fit individuals (7,14,16). However, no previous studies have evaluated relationships between chronic training load and chronic vagal-HRV trends in American football players.

The purpose of this study was to determine whether recovery of cardiac-autonomic activity to baseline occurs between consecutive-day training sessions among positional groups of a collegiate football team. A secondary aim was to assess relationships between football players' chronic workloads and chronic vagal-HRV trends (i.e., mean and CV) from an annual Spring training camp.

Methods

Experimental Approach to the Problem

This was a prospective observational cohort study that evaluated cardiac-autonomic responses to training among positional groups of an elite college football team during their 2016 Spring training camp. The research design and methodology were devised according to the predetermined program and structure of the training camp, which the researchers did not influence. Vagal-HRV and external training load were acquired each football training day throughout the 4-week Spring camp. For the first objective, we assessed whether vagal HRV returned to baseline levels between consecutive-day training sessions (i.e., after ~20 hours of recovery) among positional groups. For the second objective, relationships between chronic external training load and chronic vagal HRV (i.e., mean and CV) from the 4-week camp were evaluated.

Subjects

Twenty-five Division 1 football players from a National Collegiate Athletics Association team volunteered for this study. This was the national championship winning team from the preceding competitive season. Only players aged 18 years and older and on athletic scholarship were included. Volunteers were grouped based on position as previously described (26) (SKILL: $n = 11$; age = 20 ± 1 years; height = 187.7 ± 4.0 cm; body mass = 90.2 ± 4.3 kg; MID-SKILL: $n = 9$; age = 20 ± 1 years; height = 188.8 ± 5.5 cm; body mass = 103.8 ± 4.4 kg; and LINEMEN: $n = 5$; age = 22 ± 1 years; height = 192.5 ± 2.8 cm; body mass = 131.1 ± 10.6 kg). All athletes obtained medical clearance from the sports medicine staff and provided written informed consent for their involvement as research participants. Study approval was granted by the University of Alabama institutional review board.

Procedures

Spring Camp. Spring camp was held between mid-March and mid-April and involved 4 weeks of football training. Two-hour football practices were held on Monday, Wednesday, and Friday of week 1; Monday, Wednesday, Friday, and Saturday of weeks 2 and 3; and Tuesday, Thursday, and Saturday of week 4. Forty-five minutes full-body resistance training sessions of fewer sets and lower intensity (≤85% of 1 repetition maximum) relative to workouts preceding Spring camp were held on Tuesdays and Thursdays throughout weeks 1–3. Sundays were reserved for passive rest. Before Spring camp, all players participated in an 8-week off-season strength and conditioning program. Outdoor temperatures during training were 21.7 ± 2.8° C.

Training Load. Training load parameters were obtained from football sessions using triaxial accelerometers (Catapult

Table 1. Model effects and the natural logarithm of the root mean square of successive RR interval difference (lnRMSSD) values among and between positional groups and across time.*

Model effect	F	df	p	Mean ± SD lnRMSSD		
Position	4.24	2, 22	0.028	SKILL: 82.4 ± 7.6	MID-SKILL: 76.4 ± 8.0	LINEMAN: 71.0 ± 10.3†
Time	18.47	1, 22	<0.001	BL: 80.0 ± 7.3	Post: 76.0 ± 10.7‡	
Position × time	5.46	2, 22	0.012	SKILL BL: 82.8 ± 7.2 SKILL post: 82.0 ± 8.3	MID-SKILL BL: 78.4 ± 6.2 MID-SKILL post: 74.4 ± 9.5	LINEMAN BL: 76.6 ± 8.6 LINEMAN post: 65.4 ± 9.5§

*BL = baseline; post = 20-hour post-training.
†$p \le 0.05$ vs. SKILL across all time-points.
‡$p \le 0.05$ vs. BL across all groups.
§$p \le 0.05$ vs. BL for LINEMEN.

Innovations, Melbourne, Australia) at a sampling rate of 100 Hz. These devices measure full-body acceleration in 3 planes: anteroposterior, mediolateral, and vertical. Subjects wore the same device each session, positioned between the scapulae, and fixed in place on their shoulder pad in a custom-built cartridge. After each practice session, training load data were downloaded to a laptop for analysis. The training load parameter used for this study was total PlayerLoad. This parameter has demonstrated acceptable reliability and reflects total external workload including running, jumping, changes of direction, and body contacts (3). In addition, variation in PlayerLoad has been related to injury occurrence in college football players (37). PlayerLoad is expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each vector and divided by 100 (3).

Physiological Assessments. Fasted body mass was measured on a calibrated digital scale (Tanita Corporation, Arlington Heights, IL, USA) at the training facility before Spring camp. Heart rate variability data were obtained in the athletic training facility at least 90 minute after team breakfast and before any physical activity (25). Subjects verbally confirmed that caffeinated beverages were not consumed before data acquisition. Heart rate variability recordings were obtained while subjects were seated comfortably on an athletic training table 60–90 minute before training. Once seated, participants were handed a tablet device (iPad2; Apple, Inc., Cupertino, CA, USA) with a validated optical pulse-wave finger sensor (HRV Fit Ltd., Southampton, United Kingdom) inserted into the headphone slot (13). Subjects were instructed to insert their left index finger into the finger sensor cuff and to select their name from the team roster previously uploaded onto the application (ithlete Team; HRV Fit Ltd). Subjects would then initiate a 1-minute HRV recording while remaining quiet and breathing naturally (30). All HRV recordings were preceded by at least 1 minute for stabilization (24). The application provides the time domain vagal-HRV index of the natural logarithm of the root mean square of successive RR intervals (lnRMSSD). The lnRMSSD is multiplied by 20 to fit an approximate 100-point scale for simplified interpretation (15). The application is equipped with an irregular pulse-rate detection algorithm which excludes interpulse intervals <500 ms and >2000 ms. In addition, adjacent normal pulse–pulse (PPn) interval differences are automatically examined using the following formula: $(\mathrm{PPn} - [\mathrm{PPn} - 1])^2 < (40 \times \mathrm{Exp}\ [120/\mathrm{PRave}])^2$, where PRave is the average pulse rate calculated since commencement of the recording.

Statistical Analyses

Data normality was confirmed with the Shapiro-Wilk test ($p > 0.05$). To determine whether lnRMSSD returned to baseline between consecutive-day football training sessions, we compared baseline lnRMSSD (lnRMSSD_BL) to lnRMSSD after the ~20-hour recovery period between training sessions (lnRMSSDpost20). The intraindividual mean lnRMSSD from Monday, Wednesday, and Friday of week 2 represented lnRMSSD_BL as each of these training sessions were separated by ≥44 hours. Saturday of the same week represented lnRMSSDpost20 as it was preceded by only ~20-hour rest before the next session. Compliance for HRV measures for this component was 100%. A linear mixed model was used to examine variation in lnRMSSD among positions and between lnRMSSD_BL and lnRMSSDpost20. Position was included as a fixed effect, time (lnRMSSD_BL vs. lnRMSSDpost20) as a fixed within-subjects repeated measure, the position × time interaction as a fixed effect, and athlete identification as a random effect. Tukey honest significant difference (HSD) was used for post hoc analyses. We evaluated the magnitude of the change in lnRMSSD between conditions with Cohen's d effect sizes (ES) ± 90% confidence limits (CLs) (8). Effect sizes were interpreted qualitatively as follows: <0.2, trivial; 0.2–0.59, small; 0.6–1.19, moderate; 1.2–1.9, large; and >2.0, very large (20). The effect was deemed unclear if the CL crossed thresholds for both substantially positive (0.20) and negative (−0.20) values (1). Individual change variables for lnRMSSD were calculated (lnRMSSDpost20 − lnRMSSD_BL, ΔlnRMSSD).

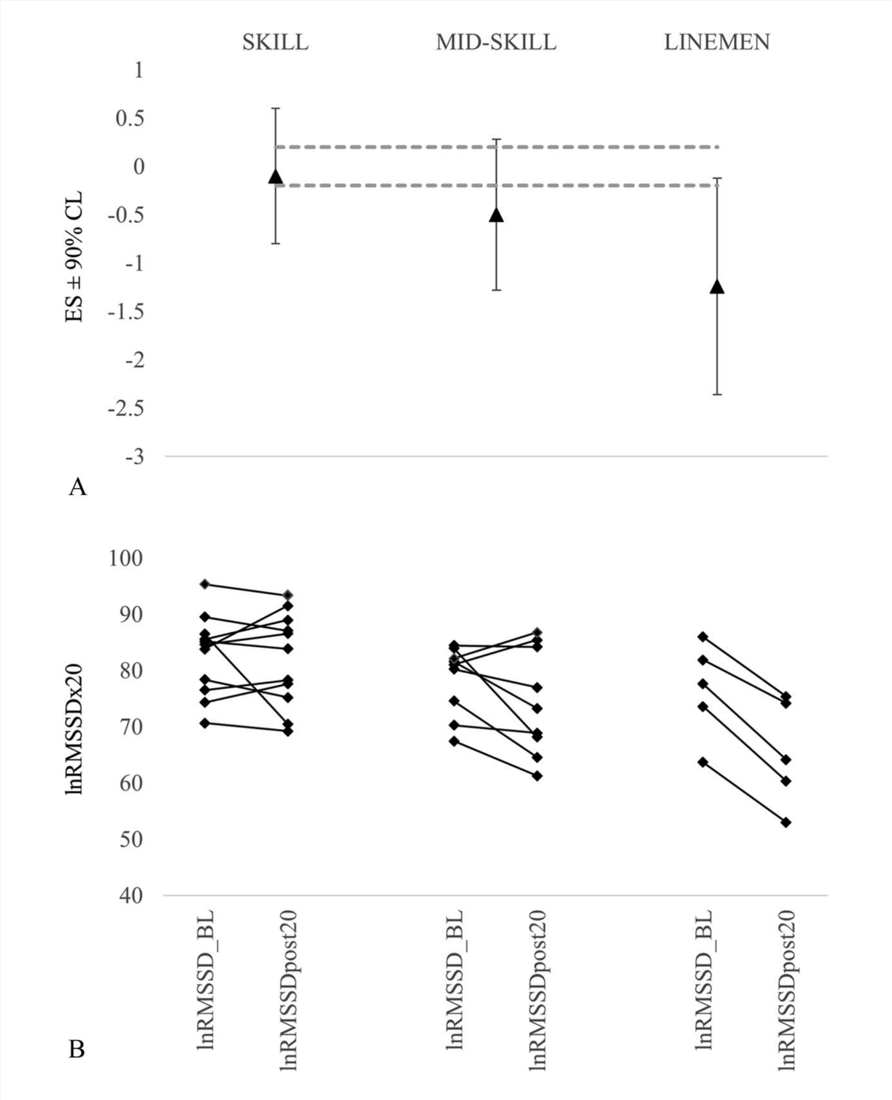

Figure 1. A) Effect size ± 90% confidence limits (ES ± 90% CLs) comparison between baseline natural logarithm of the root mean square of successive RR interval differences (lnRMSSD_BL) with lnRMSSD after 20 hours of rest (lnRMSSDpost20) among positional groups. The horizontal dashed lines represent thresholds for a small effect (0.20 to −0.20). B) Individual lnRMSSD_BL and lnRMSSDpost20 values among positional groups.

The relationship between ΔlnRMSSD and body mass was quantified via Pearson correlation. PlayerLoad values derived from the same days as lnRMSSD_BL were compared among positions with a 1-way analysis of variance (ANOVA), Tukey HSD post hoc analysis, and ES.

Pearson correlations were used to quantify relationships between the mean and CV of PlayerLoad, (PL_chronic and PLcv, respectively) with the mean and CV of lnRMSSD (lnRMSSD_chronic and lnRMSSDcv, respectively) derived from the entire 4-week training camp (i.e., all training days). The thresholds used for qualitative assessment of the correlations were as follows: <0.1, trivial; 0.1–0.29, small; 0.3–0.49, moderate; 0.5–0.7, large; 0.7–0.89, very large; and >0.9 nearly perfect (20). Positional differences in lnRMSSDcv were evaluated with a 1-way ANOVA, Tukey HSD post hoc analysis, and ES. Compliance for HRV measures for this component was 93.4 ± 8.7%. Statistical procedures were performed using JMP Pro 13 (SAS Institute, Inc., Cary, NC, USA) and Excel 2016 (Microsoft Corp., Redmond, WA, USA). p values ≤ 0.05 were considered statistically significant. Data are reported as mean ± *SD* unless noted otherwise.

RESULTS

A significant effect was found for PlayerLoad values derived from the same days as lnRMSSD_BL ($p < 0.0001$). Baseline PlayerLoad values for SKILL, MID-SKILL, and LINEMEN were 623.7 ± 60.6 au, 556.8 ± 53.6 au, and 450.0 ± 29.2 au, respectively. Post hoc comparisons revealed that PlayerLoad values for SKILL were significantly higher than LINEMAN ($p < 0.0001$, ES = 3.27 ± 1.27, very large) and MID-SKILL ($p = 0.029$, ES = 1.16 ± 0.79, moderate). In addition, MID-SKILL baseline PlayerLoad was significantly greater than LINEMEN ($p = 0.005$, ES = 2.25 ± 1.10, very large).

A significant position × time interaction was found for lnRMSSD. Model effects and lnRMSSD values are presented in Table 1. Post hoc comparisons revealed that lnRMSSD_BL was significantly higher than lnRMSSDpost20 for LINEMEN ($p < 0.01$; ES = large), whereas differences for SKILL ($p = 0.998$; ES = unclear) and MID-SKILL ($p = 0.343$; ES = unclear) were not statistically significant. Interaction ES and individual lnRMSSD responses are graphically displayed in Figure 1A, B, respectively.

SKILL had greater lnRMSSD than LINEMEN (Table 1; ES = 1.35 ± 0.96; large). In addition, evaluated as a group ($n = 25$), lnRMSSD_BL was higher than lnRMSSDpost20 (Table 1; ES = 0.44 ± 0.47; small). We observed a large and significant negative relationship between ΔlnRMSSD and body mass (Figure 2A), indicating that greater reductions in lnRMSSD occurred among players with greater body mass.

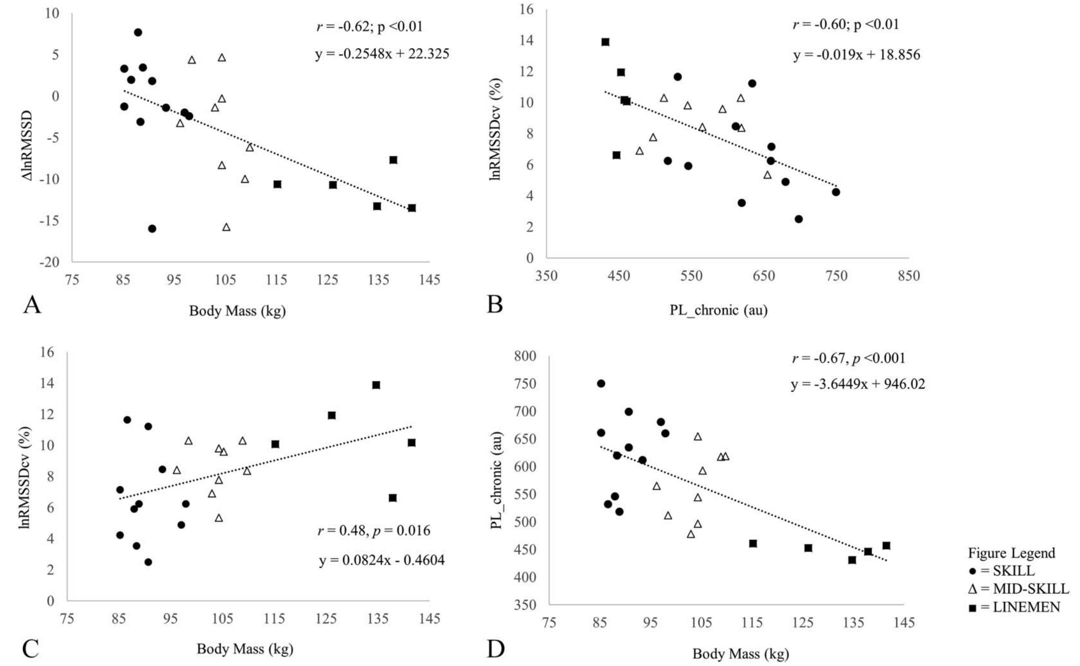

Figure 2. A) Scatterplot representing the relationship of the difference in natural logarithm of the root mean square of successive RR interval differences from baseline (lnRMSSD_BL) and 20-hour post-training (lnRMSSDpost20) (i.e., lnRMSSDpost20 − lnRMSSD_BL = ΔlnRMSSD) with body mass. B) Scatterplot representing the relationship between the coefficient of variation of lnRMSSD (lnRMSSDcv) and average PlayerLoad (PL_chronic) from the entire 4-week camp. C) Scatterplot representing the relationship between lnRMSSDcv and body mass. D) Scatterplot representing the relationship between PL_chronic and body mass.

A significant effect for lnRMSDcv was observed ($p < 0.05$). SKILL, MID-SKILL, and LINEMEN lnRMSSDcv values were 6.5 ± 2.9%, 8.5 ± 1.7%, and 10.5 ± 2.7%, respectively. Post hoc analysis showed that lnRMSSDcv for SKILL was significantly lower than LINEMEN ($p \leq 0.05$, ES $= -1.41 \pm 0.97$, large) but not MID-SKILL ($p > 0.05$, ES $= -0.82 \pm 0.76$, moderate). In addition, MID-SKILL lnRMSSDcv was not significantly different from LINEMEN ($p > 0.05$, ES $= -0.96 \pm 1.28$, unclear).

The lnRMSSD_chronic did not show significant relationships with PL_chronic ($r = 0.33, p = 0.109$), PLcv ($r = 0.16, p = 0.436$), or body mass ($r = -0.36, p = 0.073$). There was a large, significant negative relationship between lnRMSSDcv and PL_chronic (Figure 2B) and a moderate, significant positive relationship between lnRMSSDcv and body mass (Figure 2C). The lnRMSSDcv did not relate with PLcv ($r = 0.025$ $p = 0.907$). Body mass showed a large, significant negative relationship with PL_chronic (Figure 2D). After adjusting for body mass via partial correlation analysis, the negative relationship between lnRMSSDcv and PL_chronic remained significant ($r = -0.42, p = 0.034$, moderate).

Discussion

This study evaluated daily and chronic lnRMSSD responses to training among an elite college football team throughout Spring camp. The novel finding was that daily lnRMSSD responses to a football training session differ by position. ~Twenty hours after a practice session, LINEMEN show substantial reductions from baseline, whereas SKILL and MID-SKILL were recovered to within or near baseline values. Longitudinally, lnRMSSDcv was inversely related to PL_chronic, independent of body mass.

Previous studies among youth and elite adult soccer and rugby players have found that daily cardiac-parasympathetic activity is not significantly affected by training sessions at the group level (4,12,34), but is substantially reduced 1-day post-competition among youth players (4,12). During a <1 week training camp, elite adult rugby players showed small reductions in lnRMSSD after the first day of training and remained suppressed for the duration of camp (25). Excluding LINEMEN, our findings tend to agree with the previous literature considering SKILL players are reasonably comparable to soccer players and MID-SKILL players are reasonably comparable to rugby players with regards to physical characteristics (23).

Despite substantially smaller PlayerLoad values than SKILL and MID-SKILL, LINEMEN demonstrated large reductions in lnRMSSDpost20, indicating inadequate cardiovascular recovery between sessions. A recent systematic review determined that cardiac-parasympathetic recovery from exercise is slower in individuals with lower aerobic fitness and is suppressed for longer durations (~48 hours) after high intensity, anaerobic exercise (33). We speculate that numerous factors related to body mass, fitness, and exercise intensity may have contributed to the suppressed lnRMSSDpost20 in LINEMEN. For example, during 60 minutes of simulated football training, LINEMEN displayed an average exercise intensity corresponding to 79% of maximum HR, a respiratory exchange ratio >0.90, and blood lactate levels $>5.0\ \mathrm{mmol \cdot L^{-1}}$ (19). As such, LINEMEN may experience a substantial anaerobic workload during training due to both lower aerobic fitness and movement demands that depend more heavily on the expression of strength and power (e.g., repeated blocking, tackling, and short sprints). Moreover, LINEMEN are more sedentary than other positions between efforts because of smaller distances covered, necessitating less jogging (29). This provides less active recovery for LINEMEN in addition to reduced convective heat loss compared with SKILL (11). Indeed, LINEMEN experience the greatest internal core temperatures and fluid loss during training which may increase cardiac strain (10). Deren et al. (10) demonstrated that LINEMEN experience a progressive increase in exercise HR beyond 30 minutes of cycling in the heat at a workload that elicits a heat production of $350\ \mathrm{W \cdot m^{-2}}$, whereas SKILL demonstrated no such change in HR. Although continuous cycling is dissimilar from football training, the cardiovascular response may be relevant. Dehydration-induced hypovolemia is thought to contribute to suppressed lnRMSSD in the 24- to 48-hour postexercise period (33). Accordingly, unloading of cardiopulmonary baroreceptors facilitates sympathoexcitation to maintain peripheral resistance and combat the reduction in cardiac output consequent to reduced stroke volume (31). It has been hypothesized that lnRMSSD may not return to baseline after intense exercise until plasma volume has been restored (6). Collectively, lower aerobic fitness, larger body mass, greater reliance on anaerobic-glycolytic metabolism during training, and disturbed fluid balance may all have contributed to the delayed cardiac-parasympathetic recovery in LINEMEN.

Whether unrecovered lnRMSSD affects performance or injury risk in football players remains unclear, particularly during periods when sessions are held more frequently (e.g., preseason). Hypothetically, consistent inadequate recovery may lead to suppressed lnRMSSD over prolonged periods which has been associated with high perceived fatigue, illness, and decrements in running performance (16,18,27). We speculate that LINEMEN may be at greater risk of inadequate recovery when training over several consecutive days based on their daily lnRMSSD responses to training observed in this study. Thus, future research evaluating cardiac-autonomic responses to more frequent training among LINEMEN is warranted.

Relationships between chronic training load and lnRMSSD parameters have not previously been investigated in American football. Although indirect, chronic training load is sometimes used as a surrogate for fitness level (21). We did not find a significant relationship between lnRMSSD_chronic and PL_chronic, possibly because weekly changes in averaged lnRMSSD relate more with fitness (5,16) than lnRMSSD averaged over chronic periods. Previous studies found that lnRMSSDcv is inversely related to $\dot{V}O_2$max and intermittent-running performance in soccer players (2,7,14,16). We observed a significant inverse relationship between lnRMSSDcv and PL_chronic after adjusting for body mass. This suggests that training capacity (inferred from PL_chronic) may be a determinant of lnRMSSDcv in football players during Spring camp, a period where overreaching is unlikely to occur due to mostly nonconsecutive-day training. This distinction is important because more intensified (e.g., preseason) or stressful (e.g., competitive season) periods may increase lnRMSSDcv and alter its relationship with PL_chronic. Another explanation may be that lnRMSSDcv is reflecting position-specific training effects, where LINEMEN experience more physiologically disruptive demands from line-play, exacerbated by their size and fitness level relative to other positions. Additional research is needed to determine what information lnRMSSDcv provides in the context of fitness and training adaptation in football players.

Although HRV data collection was standardized according to recent recommendations (25), there is greater potential for "noise" when acquired at the facility versus postwaking and thus is a limitation of this study. In addition, HRV data were only collected on football training days, and therefore the lnRMSSD values do not reflect all days of the week. The inclusion of only 5 LINEMEN is also a limitation, and thus further research is needed to support the current findings. It must also be considered that the lnRMSSD responses from this observation period may not reflect what occurs during training in hotter conditions with more frequent training sessions. Finally, relationships between chronic workloads and fitness have not been investigated in American football players; thus, we caution readers that our interpretation of lnRMSSDcv reflecting training capacity is, therefore, speculative.

Approximately 20 hours after a football training session, lnRMSSD values were suppressed for LINEMEN, whereas SKILL and MID-SKILL values returned to near or within baseline. Players with greater body mass showed the greatest reductions in lnRMSSD in response to training. Over the 4-week camp, players who performed the lowest chronic workloads experienced greater fluctuation in lnRMSSD (i.e., lnRMSSDcv) and vice versa. Therefore, training capacity may be a determinant of lnRMSSD trends in football players during Spring camp.

PRACTICAL APPLICATIONS

During Spring camp, LINEMEN did not attain cardiac-parasympathetic recovery to baseline between consecutive-day training sessions, potentially making them susceptible to autonomic nervous system imbalance during more intensive training periods. Longitudinally, a capacity for greater chronic workloads may be protective against daily perturbations in cardiac-autonomic homeostasis based on the inverse relationship between PL_chronic and lnRMSSDcv.

Obtaining compliance from athletes to perform daily HRV measures at home after waking is challenging and in some cases prohibitive of the implementation of HRV monitoring. This study showed that standardized, 60-second lnRMSSD recordings acquired via mobile devices at the training facility may provide meaningful information regarding training responses among football players. This may make HRV monitoring a more convenient process for coaching and support staff.

ACKNOWLEDGMENTS

The authors extend their thanks to the Alabama football players and staff for their participation in this study. The authors also thank Aaron Brosz for his assistance throughout the study. The authors have no conflicts of interest to disclose.

REFERENCES

1. Batterham, AM and Hopkins, WG. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perf* 1: 50–57, 2006.
2. 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 Sports Physiol Perf* 8: 400–409, 2013.
3. Boyd, LJ, Ball, K, and Aughey, RJ. The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. *Int J Sports Physiol Perf* 6: 311–321, 2011.
4. Bricout, VA, DeChenaud, S, and Favre-Juvin, A. Analyses of heart rate variability in young soccer players: The effects of sport activity. *Autonom Neurosci* 154: 112–116, 2010.
5. Buchheit, M, Chivot, A, Parouty, J, Mercier, D, Al Haddad, H, Laursen, P, and Ahmaidi, S. Monitoring endurance running performance using cardiac parasympathetic function. *Eur Appl Physiol* 108: 1153–1167, 2010.
6. Buchheit, M, Laursen, PB, Al Haddad, H, and Ahmaidi, S. Exercise-induced plasma volume expansion and post-exercise parasympathetic reactivation. *Eur J Appl Physiol* 105: 471–481, 2009.
7. 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.
8. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Hillsdale, NJ: L. Erlbaum, 1988.
9. Davis, JK, Baker, LB, Barnes, K, Ungaro, C, and Stofan, J. Thermoregulation, fluid balance, and sweat losses in American football players. *Sports Med* 46: 1–15, 2016.
10. Deren, TM, Coris, EE, Bain, AR, Walz, SM, and Jay, O. Sweating is greater in NCAA football linemen independently of heat production. *Med Sci Sports Exerc* 44: 244–252, 2012.
11. Deren, TM, Coris, EE, Casa, DJ, DeMartini, JK, Bain, AR, Walz, SM, and Jay, O. Maximum heat loss potential is lower in football linemen during an NCAA summer training camp because of lower self-generated air flow. *J Strength Cond Res* 28: 1656–1663, 2014.
12. Edmonds, RC, Sinclair, WH, and Leicht, AS. Effect of a training week on heart rate variability in elite youth rugby league players. *Int J Sports Med* 34: 1087–1092, 2013.
13. Esco, MR, Flatt, AA, and Nakamura, FY. Agreement between a smart-phone pulse sensor application and ECG for determining lnRMSSD. *J Str Cond Res* 31: 380–385, 2017.
14. Flatt, AA, Esco, M, Nakamura, FY, and Plews, DJ. Interpreting daily heart rate variability changes in collegiate female soccer players. *J Sports Med Phys Fitness* 57: 907–915, 2017.
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. Evaluating individual training adaptation with Smartphone-derived heart rate variability in a collegiate female soccer team. *J Strength Cond Res* 30: 378–385, 2016.
17. Flatt, AA and Esco, MR. Smartphone-derived heart-rate variability and training load in a women's soccer team. *Int J Sports Physiol Perf* 10: 994–1000, 2015.
18. Flatt, AA, Hornikel, B, and Esco, MR. Heart rate variability and psychometric responses to overload and tapering in collegiate sprint-swimmers. *J Sci Med Sport* 20: 606–610, 2017.
19. Hitchcock, KM, Millard-Stafford, ML, Phillips, JM, and Snow, TK. Metabolic and thermoregulatory responses to a simulated American football practice in the heat. *J Strength Cond Res* 21: 710–717, 2007.
20. 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.
21. Hulin, BT, Gabbett, TJ, Lawson, DW, Caputi, P, and Sampson, JA. The acute: Chronic workload ratio predicts injury: High chronic workload may decrease injury risk in elite rugby league players. *Br J Sport Med* 50: 231–236, 2016.
22. Kiviniemi, AM, Hautala, AJ, Kinnunen, H, and Tulppo, MP. Endurance training guided individually by daily heart rate variability measurements. *Eur J Appl Physiol* 101: 743–751, 2007.
23. Kuhn, W, Reilly, T, Clarys, J, and Stibbe, A. Comparative Analysis of Selected Motor Performance Variables in American Football, Rugby Union and Soccer Players. In: *Science and Football II*. T Reilly, J Clarys, and A Stibbe, eds. London, England: Chapman & Hall, 1993. pp. 62–69.
24. Mann, TN, Lamberts, RP, and Lambert, MI. High responders and low responders: Factors associated with individual variation in response to standardized training. *Sports Med* 44: 1113–1124, 2014.
25. Nakamura, FY, Pereira, LA, Esco, MR, Flatt, AA, Moraes, JE, Cal, AC, and Loturco, I. Intra-and inter-day reliability of ultra-short-term heart rate variability in rugby union players. *J Strength Cond Res* 31: 548–551, 2017.
26. Pincivero, DM and Bompa, TO. A physiological review of American football. *Sports Med* 23: 247–260, 1997.
27. 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.
28. Plews, DJ, Scott, B, Altini, M, Wood, M, Kilding, AE, and Laursen, PB. Comparison of heart rate variability recording with smart phone photoplethysmographic, Polar H7 chest strap and electrocardiogram methods. *Int J Sport Physiol Perf*, 2017. Epub ahead of print.
29. Rhea, MR, Hunter, RL, and Hunter, TJ. Competition modeling of American football: Observational data and implications for high school, collegiate, and professional player conditioning. *J Strength Cond Res* 20: 58–61, 2006.
30. Saboul, D, Pialoux, V, and Hautier, C. The impact of breathing on HRV measurements: Implications for the longitudinal follow-up of athletes. *Eur J Sport Sci* 13: 534–542, 2013.
31. Saitoh, T, Ogawa, Y, Aoki, K, Shibata, S, Otsubo, A, Kato, J, and Iwasaki, K. Bell-shaped relationship between central blood volume and spontaneous baroreflex function. *Autonom Neurosci* 143: 46–52, 2008.

32. Smith, D and Byrd, R. Body composition, pulmonary function and maximal oxygen consumption of college football players. *J Sports Med Phys Fitness* 16: 301–308, 1976.
33. Stanley, J, Peake, JM, and Buchheit, M. Cardiac parasympathetic reactivation following exercise: Implications for training prescription. *Sports Med* 43: 1259–1277, 2013.
34. Thorpe, RT, Strudwick, AJ, Buchheit, M, Atkinson, G, Drust, B, and Gregson, W. Tracking morning fatigue status across in-season training weeks in elite soccer players. *Int J Sport Physiol Perf* 11: 947–952, 2016.
35. Wellman, AD, Coad, SC, Goulet, GC, Coffey, VG, and McLellan, CP. Quantification of accelerometer derived impacts associated with competitive games in NCAA Division I college football players. *J Strength Cond Res* 31: 330–338, 2017.
36. Wellman, AD, Coad, SC, Goulet, GC, and McLellan, CP. Quantification of competitive game demands of NCAA Division I college football players using global positioning systems. *J Str Cond Res* 30: 11–19, 2016.
37. Wilkerson, GB, Gupta, A, Allen, JR, Keith, CM, and Colston, MA. Utilization of practice session average inertial load to quantify college football injury risk. *J Strength Cond Res* 30: 2369–2374, 2016.