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Heart Rate Variability in College Football Players throughout Preseason Camp in the Heat

Authors
Andrew A. Flatt[1, 2], Jeff Allen[3], Amy Bragg[4], Clayton Keith[4], Ryan Earley[4], Michael R. Esco[3]

Affiliations
1 Health Sciences and Kinesiology, Georgia Southern University – Armstrong Campus, Savannah, United States
2 Kinesiology, University of Alabama, Tuscaloosa, United States
3 Athletics, University of Alabama, Tuscaloosa, United States
4 Biological Sciences, University of Alabama, Tuscaloosa, United States

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Correspondence
Andrew A. Flatt
Health Sciences and Kinesiology, Georgia Southern University – Armstrong Campus,
11935 Abercorn Street,
31419-1909 Savannah,
United States
Tel.: + 1912-344-3150, Fax: + 1912-344-9874
aflatt@georgiasouthern.edu

ABSTRACT

We aimed to characterize cardiac-autonomic responses to a 13-day preseason camp in the heat among an American college football team. Players were categorized as linemen (n = 10) and non-linemen (n = 18). RHR, natural logarithm of the root-mean square of successive differences multiplied by twenty (LnRMSSD), and subjective wellbeing (LnWellness) were acquired daily. Effect sizes ± 90 % confidence interval showed that for linemen, LnRMSSD decreased (moderate) on day 2 (71.2 ± 10.4) and increased (moderate) on day 12 (87.1 ± 11.2) relative to day 1 (77.9 ± 11.2) while RHR decreased (small–moderate) on days 6, 7, and 12 (67.7 ± 9.3–70.4 ± 5.5 b·min-1) relative to day 1 (77.1 ± 10.1 b·min-1). For non-linemen, LnRMSSD increased (small–large) on days 3–5, 7, 12, and 13 (83.4 ± 6.8–87.6 ± 8.5) relative to day 1 (80.0 ± 6.5) while RHR decreased (small–large) on days 3–9, 12, and 13 (62.1 ± 5.2–67.9 ± 8.1 b·min-1) relative to day 1 (70.8 ± 6.2 b·min-1). Decrements in LnWellness were observed on days 4–10 and 13 for linemen (moderate) and on days 6–9, 12, and 13 for non-linemen (small–moderate). Despite reductions in LnWellness, cardiac-autonomic parameters demonstrated responses consistent with heat-acclimation, which possibly attenuated fatigue-related decrements.

Introduction

The highest concentration of physical training throughout the American college football schedule is allocated to preseason camp [1], accounting for the annual peak in creatine kinase concentrations [2] and musculoskeletal injury rates [3]. Moreover, the late preparatory period takes place during summer where a combination of heat, humidity, and protective equipment requirements contribute to an increased risk of heat-related illness [4, 5]. Decrements in subjective wellbeing and physical performance outputs have been reported during this phase of training [6], which may negatively impact nearing competition outcomes. With exceptionally large body mass and lower aerobic fitness than non-linemen [7], linemen tolerate intensive training in the heat less favorably than non-linemen. For example, linemen experience greater increases in core temperature, higher sweat rates [8], and exhibit a similar mean exercising heart rate (HRex) despite covering less total and high speed running distance compared with non-linemen during preseason training [9]. Laboratory simulations in the heat indicate that lineman perform drills at ~79 % of maximum HR and maintain blood lactate levels > 5 mmol · L, reflecting high anaerobic demands [10]. Thus, further investigation into potential differences in training responses between linemen and non-linemen is warranted for establishing practical and effective player-monitoring strategies.

Markers of cardiac-autonomic function such as resting heart rate (RHR) and its variability (HRV) are objective, non-invasive physiological markers that can be easily obtained with mobile devices [11], and represent convenient indicators of cardiovascular recovery status [12]. Athletes who demonstrate progressive increases in HRV throughout preseason training in other football codes generally exhibit positive adaptations such as a reduced HRex and increased aerobic fitness [13–16]. However, excessive loads during training camps may lead to overreaching, causing decrements in HRV, baroreceptor sensitivity, subjective wellbeing, and performance capacity [17]. During spring camp, only linemen demonstrated large reductions in HRV ~20 h post-training ($p < 0.05$), despite lower PlayerLoads than non-linemen [18]. Considering spring camp involved primarily non-consecutive day training in temperate conditions, concerns were expressed that linemen may experience sustained autonomic imbalance during preseason camp, where consecutive-day sessions are performed, sometimes twice per day, and in hot and humid conditions [18].

Intensive football training combined with adaptations to training in the heat may create opposing influences on cardiac-autonomic modulation. Acclimation to ~12 days of exercise in the heat facilitates a slower rise in HRex, an increased sweat rate to maintain a lower core temperature, and plasma volume (PV) expansion that improves myocardial efficiency [19]. Thus, combined heat stress and increased training load serve as potent stimuli for improving training capacity and thermophysiological adaptations in football players [20] that may reduce RHR and increase HRV [21]. Alternatively, unique anthropometric characteristics of football players and the intense physical demands of preseason training [1–3] may overtax the athletes, resulting in converse RHR and HRV responses. Therefore, we aimed to characterize cardiac-autonomic responses throughout preseason training among college football players. We hypothesized that non-linemen would exhibit more favorable changes than non-lineman based on off-season responses [18].

Materials and Methods

Participants

Division-1 players (n = 28) who participated in all training sessions and remained uninjured throughout the observation period were included in the study. Players were ≥ 18 years of age and categorized as linemen (n = 10, height = 191.6 ± 4.7 cm, weight = 131.2 ± 12 kg) and non-linemen (n = 18, height = 187.4 ± 4.4 cm, weight = 96.2 ± 9.4 kg). All subjects provided written informed consent to participate in the study. Approval for this study was obtained from the Institutional Review Board and complied with the ethical standards of the International Journal of Sports Medicine [22].

Preseason camp

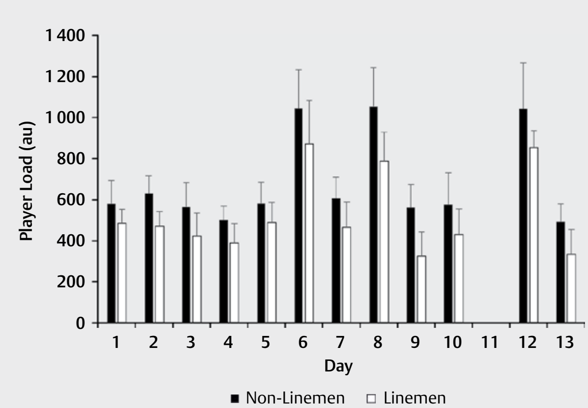
This was an observational study involving the Football Bowl Subdivision national champions from the previous competitive season. RHR, HRV, subjective wellbeing, fasted body mass, and microsensor-derived training load were acquired on each training day throughout preseason camp. The camp involved 15 football sessions across 13 days. Heat acclimation guidelines were followed as previously described, with protective equipment progressively phased-in over the first 5 days [20]. Two-a-day practices occurred 3 times on non-consecutive days (i. e., days 6, 8, and 12). Complete passive rest was provided on day 11. Football training sessions were 2–2.5 h in duration and performed outdoors on natural grass (n = 12 sessions) or indoors on an artificial fieldturf (n = 3 sessions, days 5, 7, and 9). Average environmental conditions during outdoor training sessions were: temperature = 31.1 ± 4.2 °C; relative humidity = 70.7 ± 16.4 %; heat index = 38.1 ± 6.5 °C.

Training load

PlayerLoad [23] was obtained via 100 Hz tri-axial accelerometer (Catapult Innovations, Melbourne, Australia) to represent total workloads from each training session. Data were acquired following the same methods used during spring camp [18]. All subjects wore the same microsensor for each training session, positioned between the scapulae, fastened to their shoulder pads in a custom-built cartridge. Due to preferential allocation of microsensors to non-linemen by coaching staff, only data from 5 linemen could be obtained. Thus, daily PlayerLoad values are presented in ▶ **Fig. 1** for descriptive purposes only.

Heart rate measures

RHR-derived parameters were obtained using the same tools and procedures from spring camp [18]. Measures were performed at least 90 min post-prandial while subjects were seated comfortably on an athletic training table. Once seated, subjects were given a tablet with an optical pulse-wave finger sensor (PWFS, HRV Fit LTD. Southampton, UK) inserted into the headphone slot. The PWFS detects pulse-rate via photoplethysmography and has demonstrated acceptable agreement with electrocardiograph-derived HRV [11]. Following at least 1 min for stabilization [24], the subjects would initiate a supervised 1-min measure while remaining quiet, still, and breathing spontaneously. Adjacent normal pulse–pulse (PPn) interval differences are automatically processed for artifacts using the following algorithm: $(PPn - PPn\text{-}1)^2 < (40 * \mathrm{Exp}(120/PRave))^2$, where PRave is the average pulse rate calculated since initiation of the recording. The application provides the RHR and the natural logarithm of the root mean square of successive differences (LnRMSSD) which is multiplied by 20 to fit a ~100-point scale. LnRMSSD is a vagal-related HRV parameter recommended for use in field-settings [25].



▶ **Fig. 1** Daily PlayerLoad values for linemen and non-linemen.

▶ **Table 1** Combined group (n = 28) mean ± standard deviation for daily resting heart rate (RHR), the natural logarithm (Ln) of the root mean square of successive differences multiplied by twenty (RMSSD), body mass Oxford, and subjective wellbeing (LnWellness).

	RHR (b·min^{-1})	LnRMSSD	Body Mass (kg)	LnWellness
Day 1	73.0 ± 8.1‡	79.3 ± 8.2	109.2 ± 20.4 *	1.91 ± 0.24 *
Day 2	73.0 ± 9.0	77.9 ± 10.8	109.0 ± 20.5	1.84 ± 0.24
Day 3	71.9 ± 9.2	79.9 ± 9.7	108.8 ± 20.4	1.82 ± 0.23
Day 4	66.7 ± 9.5	81.9 ± 10.5	109.0 ± 20.4	1.82 ± 0.24
Day 5	69.1 ± 7.0	80.6 ± 8.2	109.5 ± 20.6 *	1.83 ± 0.20
Day 6	68.1 ± 7.8	80.5 ± 10.9	109.4 ± 20.4 *	1.78 ± 0.22
Day 7	66.8 ± 7.9†	83.6 ± 11.0†	107.9 ± 20.0†	1.78 ± 0.25
Day 8	67.5 ± 8.7	80.7 ± 11.0	108.5 ± 19.9	1.76 ± 0.24
Day 9	70.4 ± 8.7	80.2 ± 9.9	108.0 ± 20.2	1.78 ± 0.23
Day 10	71.8 ± 7.4	79.4 ± 9.0	–	1.85 ± 0.20
Day 11	–	–	–	–
Day 12	64.2 ± 7.4 *	87.4 ± 9.4 *	108.9 ± 20.8	1.82 ± 0.25
Day 13	67.9 ± 7.5	81.9 ± 8.5	107.7 ± 20.4†	1.78 ± 0.25

RHR: * = different from days 1–3, 9 and 10 ($p < 0.05$); † = Different from days 1–3 and 10 ($p < 0.05$); ‡ = different from days 4, 7, 8, 12 and 13 ($p < 0.05$). LnRMSSD: * = different from all days except day 7 ($p < 0.05$); † = different from day 2 ($p < 0.05$). Body Mass: * = different from days 7, 9 and 13 ($p < 0.05$); † = different from all days except days 8 and 9 ($p < 0.05$). LnWellness: * = different from days 3, 6–9 and 13 ($p < 0.05$).

Wellness

In conjunction with HRV, subjective wellbeing facilitates interpretation of the coping response to intensified training [25–27]. Following HRV recordings, a brief questionnaire adapted from McLean et al. [28] appears on the tablet screen allowing subjects to rate their perceived level of sleep quality, fatigue, muscle soreness, stress and mood on a 9-point scale. A rating of 5 represented feeling "okay" while ratings < 5 were incrementally more negative and ratings > 5 were incrementally more positive [27]. Daily subjective measures were averaged intra-individually to yield a global wellness score for analysis [14].

Body mass

Short-term changes in post-waking body mass provide a convenient and non-invasive means of indirectly monitoring hydration status in athletes [29]. Daily body mass was recorded before breakfast to the nearest 0.1 kg using a calibrated digital scale (Tanita Corporation, Arlington Heights, IL, USA). Body mass was obtained each day throughout preseason camp, excluding day 10 and 11. Subjects wore dry athletic shorts for weigh-ins.

Statistical analysis

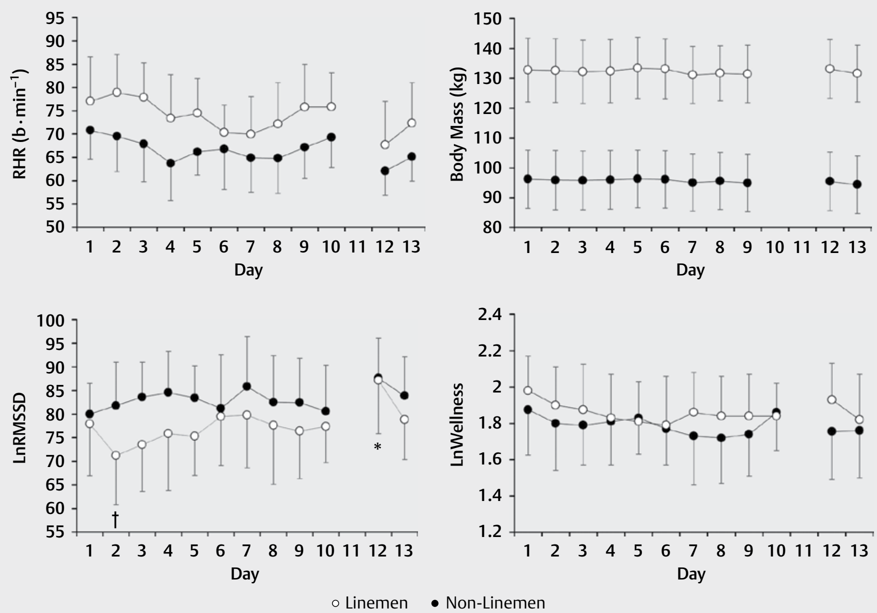
Ln transformations were applied to the non-normally distributed ($p < 0.05$) wellness data (LnWellness). Linear mixed models were used to examine variation in RHR, LnRMSSD, LnWellness, and body mass. Position (i. e., linemen vs. non-linemen) was included as a fixed main effect, day as a fixed within-subjects repeated measure, the position × day interaction as a fixed main effect, and athlete identification as a random effect. Post-hoc analyses were performed using Tukey tests. Standardize differences were calculated for all comparisons using Hedges effect size ± 90 % confidence interval (ES ± 90 %CI) [30]. ES were interpreted qualitatively as follows: < 0.2, trivial; 0.2–0.59, small; 0.6–1.19, moderate; 1.2–1.9, large; > 2.0, very large [31]. If the 90 % CI crossed the trivial zone, the effect was deemed unclear [32]. P values < 0.05 were considered statistically significant. Data analyses were performed using JMP 13 (SAS Institute, INC., Cary, NC, USA).

Results

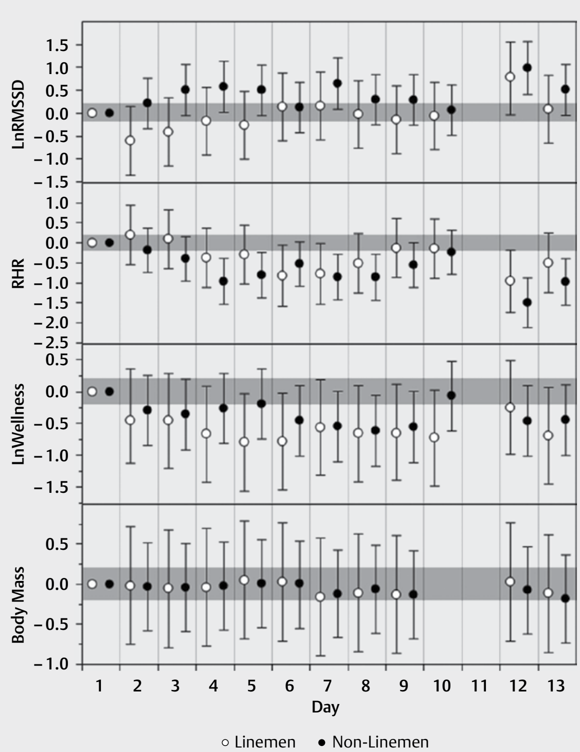
Main effects for position ($p = 0.002$) and day ($p < 0.0001$) were observed for RHR. RHR for non-linemen (66.4 ± 7.2 b · min^{-1}) was lower than linemen (73.8 ± 8.6 b · min^{-1}) ($p = 0.002$, ES = -0.93 ± 0.68). As a combined group (n = 28), RHR on day 12 was lower than days 1–3, 9, and 10 ($p < 0.001$–0.038, ES = –0.40 ± 0.41– -1.05 ± 0.47). Additionally, RHR on days 1 and 2 were higher than days 4, 7, 8, and 13 ($p < 0.001$–0.048, ES = 0.66 ± 0.45–0.77 ± 0.46) (▶ **Table 1**). Though non-significant ($p > 0.05$), ES showed that non-linemen displayed small–large RHR reductions on days 3–9, 12, and 13 while linemen displayed small–moderate reductions on days 6, 7, and 12 (▶ **Fig. 3**).

A position × day interaction was observed for LnRMSSD ($p = 0.036$) (▶ **Fig. 2**). LnRMSSD on day 2 for lineman was lower than days 7 and 12 for non-linemen ($p = 0.007$–0.027, ES = -1.35 ± 0.70 – -1.73 ± 0.76). Additionally, linemen demonstrated greater LnRMSSD on day 12 relative to days 2–5, 8, 9, and 10 (within-linemen, $p = 0.0001$–0.042, ES = 0.76 ± 0.76–1.41 ± 0.82). Though non-significant ($p > 0.05$), a moderate reduction in LnRMSSD was observed for linemen on day 2 relative to day 1 (▶ **Fig. 3**). No within-non-linemen effects were observed ($p > 0.05$), however ES showed small – moderate increases in LnRMSSD on days 3–5, 7, 12, and 13 relative to day 1 (▶ **Fig. 3**). A main effect for day was also observed ($p < 0.0001$). As a combined group (n = 28), LnRMSSD on day 12 was greater than all other days except day 7 ($p < 0.05$, ES = 0.54 ± 0.45–0.93 ± 0.47) (▶ **Table 1**).

A main effect for day was observed for LnWellness ($p < 0.0001$). As a combined group (n = 28), LnWellness on day 1 was greater than days 3, 6–9, and 13 ($p < 0.0001$–0.039, ES = 0.38 ± 0.45–0.62 ± 0.45) (▶ **Table 1**). Though non-significant ($p < 0.05$), ES analysis showed



▶ **Fig. 2** Daily resting heart rate (RHR), natural logarithm of the root mean square of successive differences multiplied by 20 (LnRMSSD), body mass, and subjective wellbeing (LnWellness) for linemen and non-linemen. * = different from days 2–5, 8, 9 and 10 ($p < 0.05$) (within-linemen). † = different from days 7 and 12 for non-linemen (between-groups).



▶ **Fig. 3** Effect size ± 90 % confidence interval relative to day 1 for resting heart rate (RHR), natural logarithm of the root mean square of successive differences multiplied by twenty (LnRMSSD), body mass, and subjective wellbeing (LnWellness). The shaded area represents the trivial zone.

moderate decrements in LnWellness on days 4–10 and 13 for linemen and small–moderate decrements on days 6–9, 12, and 13 for non-linemen (▶ **Fig. 3**).

Main effects for position ($p < 0.0001$) and day ($p < 0.0001$) were observed for body mass. Body mass for non-lineman (95.6 ± 9.5 kg) was lower ($p < 0.0001$, ES = 3.74 ± 1.04) than lineman (132.3 ± 9.6 kg). As a combined group (n = 28), body mass on days 5 and 6 and were unclearly greater than each day that followed 2 per-day sessions (i. e., days 7, 9, and 13, $p < 0.0001–0.014$, ES = 0.07 ± 0.44–0.09 ± 0.44) (▶ **Table 1**). ES analysis showed that all within-group changes in body mass were unclear (▶ **Fig. 3**).

Daily between-position mean ± standard deviation for RHR, LnRMSSD, LnWellness, and body mass are displayed in ▶ **Fig. 2**. ES ± 90 % CI relative to day 1 are displayed in ▶ **Fig. 3**.

Discussion

We observed cardiac-autonomic responses throughout preseason camp in the heat among American college football players. The main findings were: 1) only lineman experienced a moderate ES reduction in LnRMSSD, which was observed after their first exposure to training in the heat; 2) non-linemen experienced earlier and more substantial ES reductions in RHR and increases in LnRMSSD than linemen, despite small–moderate decrements in LnWellness among both groups and; 3) RHR and LnRMSSD were lowest and highest, respectively, for both groups on day 12 following passive rest.

The primary divergence in RHR measures between groups was observed on day 2, where linemen demonstrated a moderate ES reduction in LnRMSSD while non-lineman demonstrated an unclear increase (▶ **Fig. 3**). This initial response to training is consistent with the between-position LnRMSSD responses observed during spring camp [18] and the early competitive period [33]. Possible explanations for the reduction in LnRMSSD among linemen have previously been discussed [18] and pertain to differences in aerobic fitness, body mass and composition, anaerobic workloads, and fluid losses between groups [12]. We note however that the moderate ES reduction in LnRMSSD among linemen in the current study occurred despite limited body contacts, as protective equipment was phased in across the first few days, along with intense physical contact. Thus, violent collisions characteristic of line-play would not have contributed to a reduced LnRMSSD observed on day 2.

While concomitant reductions in LnRMSSD and subjective wellbeing are expected during intensive training periods [17, 34], hot environmental conditions may confound or inverse this association [25]. Laboratory-controlled heat acclimation (90-min cycling per day for 13 days at 50 % of maximal oxygen uptake in 40 °C) has been shown to increase RMSSD and reduce RHR [21]. Improvements in RHR parameters have also been observed from training in the heat among elite athletes (comparable to non-linemen), despite decrements in perceptual indices [13, 14]. For example, a study involving elite Australian football players during a training camp (~32 °C) reported progressive increases in post-submaximal exercise vagal-related HRV and reductions in submaximal HRex, which were associated with increases in PV and improved intermittent running performance [14]. Buchheit showed that after an initial reduction, post-waking LnRMSSD progressively increased above baseline and peaked on day 7 among competitors in the "Marathon des Sables" over a one-week period in ~50 °C, concurrent with increased perceived fatigue [25]. We found that non-linemen exhibited earlier and more favorable changes than linemen for RHR (small–large ES reductions on 9 days versus small–moderate reductions on only 3 days) and LnRMSSD (small–moderate ES increases on 6 days versus a moderate increase on only 1 day, ▶ **Fig. 3**). This may indicate better adaptation to training among the physically smaller and more aerobically-fit players [35], who also displayed smaller and less-frequent ES decrements in LnWellness compared with linemen.

The short-term changes in RHR measures observed here and elsewhere [13, 14] are likely attributable to PV expansion, an established adaptation to heat acclimation [19]. Hypervolemia induced by intravenous saline infusion [36] or exercise in the heat [37] has been shown to increase resting or post-submaximal exercise RMSSD. Increased cardiac-parasympathetic activity is a reflex response to volume overload, mediated by cardiopulmonary and arterial mechanoreceptors and baroreceptors that signal for vagal efferent outflow upon loading [36]. Though we were unable to obtain invasive measures in these athletes, a previous study among college football players (n = 6 lineman, 4 non-lineman) throughout 8 days of preseason camp reported that after an initial ~5 % reduction, PV progressively increased above baseline by ~4 % on day 4 and ~10 % on day 8 [38]. Increases in PV of this magnitude (> 4 %) have been associated with increased post-submaximal exercise LnRMSSD 48 h after intense exercise in the heat [37].

Both groups displayed their lowest RHR and highest LnRMSSD values on day 12 following passive rest, preceded by 10 consecutive days of training. The "parasympathetic rebound" phenomenon is typically observed 48 h post-exercise [12, 37]. Our finding indicates that the effects of preseason training on cardiac-autonomic activity may not be fully realized when performing consecutive-day training and highlights the benefits of a day of passive rest amidst intense training in the heat, particularly for linemen. Though "parasympathetic rebound" has been attributed to hypervolemia [37], other factors such as temporarily alleviated physical and mental stress from training may have contributed to increased parasympathetic modulation, as previously observed in team-sport athletes following a weekend of passive rest [39].

Within-group changes in body mass were unclear and individual coefficients of variation (CV) indicate small inter-individual differences among players (non-linemen CV = 0.95 ± 0.27 %, linemen CV = 1.05 ± 0.35 %). In general, body mass stability (e. g., no progressive increase or decrease at the group level) is consistent with a previous study in college football players during preseason camp when adopting heat acclimation guidelines [20]. We interpret the stability in body mass as a general indication that hydration status was maintained [29] but acknowledge that this would be a poor surrogate to infer changes in PV. Thus, lack of PV analysis is a limitation of the current investigation and we caution readers that our interpretation of the changes in RHR-derived parameters is therefore based on previous findings [13, 14, 37, 38]. Lack of direct markers of fitness and performance among the players is also a limitation of the current study and should be included in future research. Another limitation is that RHR parameters were acquired ~2 hours earlier on days 6, 8 and 12 due to earlier training times to accommodate two per-day sessions.

Limitations notwithstanding, this is the first study to characterize daily cardiac-autonomic responses to preseason training in the heat among an elite college football team with potentially important practical implications. For instance, linemen should be monitored closely within the first few days of preseason training in the heat to ensure that decrements in HRV are not sustained throughout camp. Additionally, while the observed improvements in cardiac-autonomic activity are interpreted as a positive adaptation to training in the heat [14], practitioners should be aware that heat acclimation responses may attenuate expected fatigue-related decrements that may occur in the absence of environmental heat stress [17, 27, 34]. Thus, increased HRV and reduced RHR in this context seem to reflect physiological adaptation but not subjective wellbeing, indicating that cardiac-autonomic and perceptual indices are independent training response markers. Practitioners are therefore encouraged to interpret changes in RHR-derived parameters throughout training in the heat as status markers specific to the cardiovascular system that may reflect changes in aerobic fitness and heat acclimation, which can improve even in the presence of elevated muscle damage, soreness and fatigue [13, 14, 21]. Alternatively, perceptual measures may serve as more appropriate markers of recovery status that potentially inform on daily changes in the volume and intensity of movement variables (e. g., high-intensity running and accelerations) performed during training [6]. While further research is needed to confirm these interpretations, our findings support the use of both objective physiological and subjective psychological variables for monitoring adaptation and recovery in college football players throughout preseason camp in the heat.

Conclusion

Despite reductions in subjective wellbeing throughout preseason camp, cardiac-autonomic parameters demonstrated responses consistent with heat acclimation. Non-linemen exhibited earlier and more frequent day-to-day improvements in RHR and HRV than linemen. For both positions, RHR and LnRMSSD were lowest and highest, respectively, following a day of passive rest. While improvements in RHR-derived parameters may reflect desirable physiological adaptations to training in the heat, they should not be used to infer perceptual recovery status in college football players.

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Conflict of interest

The authors have no conflict of interest to declare.

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