TITLE
Objective measures of strain and subjective muscle soreness differ between positional groups and season phases in American collegiate football.

AUTHOR
McKay, Benjamin; Delaney, Jace A; Larkin, Theresa; et al.

JOURNAL
International Journal of Sports Physiology and Performance

DATE DEPOSITED
18 April 2023

This version available at
https://research.stmarys.ac.uk/id/eprint/5930/

Accepted for publication in the International Journal of Sports Physiology and Performance; March 2023

Objective measures of strain and subjective muscle soreness differ between positional groups and season phases in American collegiate football.

Authors:

Benjamin A. McKay[1, 2]

Jace A. Delaney[3]

Andrew Simpkin[4]

Theresa Larkin[5]

Andrew Murray[6]

Diarmuid Daniels[7]

Charles R. Pedlar[7, 8, 9]

John Sampson[1]

Institutions:

[1] Centre for Medical and Exercise Physiology, School of Medicine, University of Wollongong, New South Wales, Australia

[2] University of Oregon Athletics Department, Oregon, United States of America

[3] Boston Celtics, Massachusetts, United States of America

[4] School of Mathematical and Statistical Sciences, National University of Ireland, Galway, Ireland

[5] Centre of Medical and Exercise Physiology, School of Medicine, University of Wollongong and the Illawarra Health and Medical Research Institute

[6] Institute of Sport, PE & Health Sciences, University of Edinburgh, UK

[7] Orreco Ltd, Business Innovation Unit, National University of Ireland Galway, Ireland

[8] Faculty of Sport, Allied Health and Performance Sciences, St Mary's University, Twickenham, London, United Kingdom

[9] Division of Surgery and Interventional Science, University College London, London, United Kingdom

Abstract

Purpose: To assess objective strain and subjective muscle soreness in '*Bigs*' (Offensive and Defensive Line), '*Combos*' (Tight Ends, Quarterbacks, Line and Running-Backs) and '*Skills*' (Wide Receivers and Defensive Backs) American College Football (ACF) players during off-season, fall-camp and in-season phases.

Methods: Twenty-three male players were assessed once weekly (3-week off-season, 4-week fall-camp, 3-week in-season) for hydroperoxides (FORT), antioxidant capacity (FORD) and oxidative stress index (OSI)), countermovement jump flight-time, reactive strength index modified (RSImod), and subjective soreness. Linear mixed-models analysed the effect of a two within-subject standard deviation change between predictor and dependent variables.

Results: Compared to fall-camp and in-season phases, off-season FORT (P=<.001 and <.001), FORD (P=<.001 and <.001), OSI (P=<.001 and <.001), Flight-time (P=<.001 and <.001), RSImod (P=<.001 and <.001) and soreness (P=<.001 and <.001) were higher for '*Bigs*', whilst FORT (P=<.001 and <.001) and OSI (P=.02 and <.001) were lower for '*Combos*'. FORT was higher for '*Bigs*' compared to '*Combos*' in all phases (P=<.001, .02 and .01). FORD was higher for '*Skills*' compared to '*Bigs*' in off-season (P=.02) and '*Combos*' in-season (P=.01). OSI was higher for '*Bigs*' compared to '*Combos*' (P=<.001) and '*Skills*' (P=.01) during off-season and to '*Combos*' in-season (P=<.001). Flight-time was higher for '*Skills*' in fall-camp compared to '*Bigs*' (P=.04) and to '*Combos*' in-season (P=.01). RSImod was higher for '*Skills*' during off-season compared to '*Bigs*' (P=.02) and '*Combos*' during fall-camp (P=.03), and in-season (P=.03).

Conclusion: Off-season ACF training resulted in higher objective strain and subjective muscle soreness in '*Bigs*' compared to fall-camp and during in-season compared to '*Combos*' and '*Skills*' players.

Introduction

An American Collegiate Football (ACF) team comprises of defensive (defensive line [DL], linebackers [LB] and defensive backs [DB]), offensive (offensive line [OL], tight ends [TE], quarterbacks [QB], running backs [RB] and wide receivers [WR]) and specialist (kickers, punters and long snappers) positional groups. These positions can also be classified according to game-play requirements, as '*Bigs*' (OL and DL), '*Combos*' (QB, TE, LB and RB) or '*Skills*' (WR and DB). When comparing positions that mirror one another (i.e., offensive vs. defensive pairings), the morphological characteristics are similar[1], however, between positional groups there are marked differences[1]. For example, compared to the '*Combos*' position group, '*Bigs*' have been shown to be heavier (28.1-40.4kg) and possess a higher body fat percentage (3.7-15.5%)[1]. Compared to '*Skills*', these differences were observed to be greater for both body mass (7.3k-20.2kg) and body fat percentage (7.2-11.7%)[1]. These differences are likely attributable to the considerably different positional demands of ACF match play. During competition, '*Bigs*' typically 'block' play and engage in wrestling-based combats with similar external outputs (e.g., OL defending the QB for passing or running plays, and creating gaps for the RB and DL, attacking the opposing QB and aiming to prevent runs of the RB). In contrast, for the '*Combos*' group, TE and LBs both block and run depending on the play, whilst within the '*Skills*' group the WRs predominately run and sprint when attempting to catch and run the ball down the field in attack to score a touchdown, with the DB's similarly engaged with the WR to defend the play[2, 3].

Correspondingly, differences in distance, acceleration, and deceleration data (measured using geographical position (GPS) and accelerometry) have been observed between ACF in the above-mentioned positional groups[2, 4]. However, whilst it is recognised the game demands differ with respect to running volumes, the arbitrarily set velocity and acceleration thresholds defined in current research do not consider effort relative to an individual's maximal capability. Yet, considering the known morphological differences between groups and recognising that high speed running is underestimated for slower and overestimated for faster athletes[5] with non-specific zones, an assessment of the physical demands and stressors of ACF may be more suited to an analysis of thresholds relative to an individual's maximal ability.

All playing groups are typically prepared for the ACF season during a summer/winter conditioning phase to develop physical qualities such as strength, power, speed, whilst the spring ball and fall camp phases are designed to develop knowledge, techniques, and execution.

Upon entering the competition phase, the focus shifts to game day preparation, spanning a time frame of 14-weeks and above (when including post-season play)[6, 7]. Several investigations have captured subjective wellness during an ACF season[8, 9], whilst objective markers have shown decreased squat and countermovement jump (CMJ) performance at half time when compared to pregame measures, and higher cortisol concentrations in starters compared to the red shirt group (players deferring a year of eligibility typically to focus on development)[10]. Relative to the pre-season, increases in the testosterone-cortisol ratio and creatine kinase and an unexpected decrease in cortisol (attributed to anxiousness and an initially high cortisol concentration) have also been observed after the pre-season (fall) camp[11] and similar cortisol concentrations have been observed between starters and non-starter throughout an ACF season[11]. However, no current research has examined markers of internal strain (defined as the stress response)[12] across the phases of an ACF season relative to the different positional groups.

Methods to assess internal strain frequently across a season must offer convenient sampling and allow for timely results to inform decision making[13]. The FORT/ FORD point of care (POC) measurement of capillary blood biomarkers is a relatively invasive test that provides rapid results (within 15 minutes) that are valid and reliable within- and between-day, (displaying a coefficient of variation of 3.9/ 3.7%[14] and 4.55%/ 4.78%[15], respectively) and allows efficient monitoring of biomarkers in a team sport setting[16]. The Free Oxygen Radical test (FORT) is an indirect measure of reactive intermediary by-products of *in vivo* lipid, protein, and nucleic acid oxidation (plasma hydroperoxides) that is known to respond to increases in exercise intensity[15, 17]. The Free Oxygen Radical Defence test (FORD) is an indirect measure of anti-oxidant capacity (plasma anti-oxidant capacity) highlighting an athlete's ability to combat exercise induced increases in reactive nitrogen oxygen species [13]. These measures assessed individually allow for the bidirectional change of each measure to be considered[17] with the ratio of the FORT and FORD tests providing an index of oxidative stress (OSI)[18]. Which has been defined as a disturbance in the prooxidant to antioxidant balance in favor of the former[15]. FORT and FORD measures have been shown to acutely respond to submaximal and maximal running in elite distance runners[17] and measures of alterations in redox homeostasis are elevated post soccer match up to 48 hours[19]. Further, redox biomarkers markers have also shown associations with training load in soccer[20, 21], with FORT and FORD also associated with CMJ variables and subjective measures of muscle soreness during an ACF season[16]. Therefore, the aim of this investigation was to assess objective measures of strain and subjective muscle soreness and it is hypothesised that differences will be observed during the off-season conditioning, fall camp and in-season of ACF within and between the '*Bigs*', '*Combos*' and '*Skills*' positional groups.

Methods

Participants

Twenty-three male student-athlete ACF players (age 20.1 ± 1.4 years; body mass 108 ± 20 kg; height 187 ± 8 cm) participating in the same Division 1A collegiate football team were assessed over 10-weeks. Experimental assessments were performed during off-season conditioning (3-weeks), fall camp (4-weeks) and in-season (3-weeks). The data were analysed in three specific groups; '*Bigs*' (n=9, OL and DL players; [mean ± SD (130.06 ± 14.08 kg, 193.76 ± 4.74 cm)], '*Combos*' (n=9, TE, QB, LB and RB players; [mean ± SD (96.80 ± 11.91 kg, 187.74 ± 8.59 cm)]) and '*Skills*' (n=7, WR and DB players [mean ± SD (89.16 ± 2.10 kg, 183.91 ± 4.56 cm)]). Ethical approval was gained from the University of Wollongong ethics committee and the University of Oregon's research compliance services. Written consent was obtained from each player prior to commencing this investigation.

Design

Upon arrival at the training facility each day, all players completed a subjective wellness questionnaire. In addition, all players performed a CMJ and provided a fingertip blood sample on one day each week (Mon-Fri, randomly allocated) for the 10-week duration of this investigation. Testing occurred between 6:00AM and 7:00AM each morning due to scheduling and to account for potential circadian rhythm effects seen in FORT[14].

Physical Training

The three-weeks off-season conditioning phase (4-8 hours/week) comprised of six resistance training sessions per week, two of which included general conditioning work, repeated sprinting and running. The four-week fall camp phase (20 hours/week) included six football practices and two resistance training sessions per week. During the three-weeks of in-season competition, each football practice session included position-specific drills with, '*Bigs*' undertaking more wrestling and blocking style drills; '*Combos*' engaged in both wrestling/blocking and football specific short accelerations/ deceleration efforts; and '*Skills*' working on specific running patterns to either receive the ball or defend the receiver from getting the ball. In addition, practices in the fall camp phase started with 1 × non-contact and 2 × partial contact game style practice sessions prior to full contact (as per NCAA regulations). In-season game weeks included five football practice sessions (2 with contact) 2 × walk through and 1 × practice/ recovery, sessions totalling approximately 12 hours/week.

Blood Samples

Participants arrived at the practice facility in a fasted state, with the exception of consuming up to 500 mL of water ad-libitum. Participants were seated, the fingertip cleansed with alcohol and left to dry. The participant was then lanced at a depth of 1.6mm, with the first drop of blood wiped from the skin with a cotton bud to avoid contamination. 300µL of capillary blood was drawn into a heparinized capillary tube, capped, immediately refrigerated at 4^{o}C and analysed within 30 minutes. 50µL and 20µL of capillary blood were transferred into separate capillary tubes for FORT and FORD analysis, respectively. The appropriate reagents were added, inverted several times to mix, centrifuged at 5000 $r\cdot min^{-1}$ (2000g) for 1 min, and analysed at 37^{o}C with an absorbance wavelength of 505nm using a Callegari CR3000 (Callegari SpA, Catellani Group, Parma, Italy) according to the manufacturer's instructions (see Lewis et al., 2016a for a detailed description).

Countermovement Jump

Immediately after blood samples were taken, three CMJ were performed on commercially available force platforms, and analysed using ForceDecks software (NMP Technologies, London, UK). Participants were instructed to stand on a dual force platform (AMTI BP-600-900) with one foot on each platform, place hands on hips and jump as high as possible. A single jump (best recorded flight time) was chosen for analysis with; i) flight time calculated as the duration of time the athlete was off the force plate[22], ii) reactive strength index modified (RSImod), as a reliable measure of an athlete's time spent on the ground generating force compared to the time spent in the air[23] and iii) concentric impulse (Ns), calculated from the area under the force-time curve[24] during the concentric phase.

Subjective Wellness Questionnaires

Each morning, prior to training (6.00-7.00am) all players completed a customised subjective wellness questionnaire assessing perceived sleep quality, overall muscle soreness and fatigue using a 5-point Likert scale, where lower values indicated a negative and higher values a positive response[25]. Only subjective muscle soreness was included in the analysis due to previous associations with FORT/ FORD and countermovement jump measures[16].

Training and Competition Loads

Training and competition loads were monitored using 23 global positioning system (GPS) and accelerometry technology (S5, Catapult Sports, Melbourne, Australia), recording at 10 Hz and 100 Hz, respectively. Units were allocated to the group. Due to the low representation of each position group within the investigation and the sample across each phase having ~25% of missing data due to being indoors, unit failure or missed practice, these data were not used for statistical analysis but are presented to display positional averages and variance. The units were turned on and placed outside 10 minutes prior to each practice and game to gain sufficient satellite signal before being placed between the scapula of each athlete in either a custom garment, jersey, or custom fitted pads. Each individual was assigned the same unit in each session to avoid inter-unit variability[26]. Following each session, data were trimmed and downloaded using proprietary software (Openfield, Catapult Sports, Melbourne, Australia). Maximal velocity thresholds were set from the maximal velocity reached in a speed session that required two maximal 40-yard sprints measured using the GPS device, which has been shown to have high accuracy for the quantification of maximal velocity[27]. Metrics presented include total distance and distance in velocity bands (%) relative to each individual's maximum velocity, velocity band 1 = 0 – 30%, velocity band 2 = 30 – 40%, velocity band 3 = 40 – 50%, velocity band 4 = 50 – 60%, velocity band 5 = 60 – 70%, velocity band 6 = 70 – 80%, velocity band 7 = 80 – 90%, velocity band 8 = 90 – 100+% of max velocity.

Statistical analysis

Separate linear mixed models (lme4 package in R; V 1.0.136.) were used to assess the association between each marker of strain and the phase of the season (which was treated as a factor variable) as repeated outcomes. FORT, FORD, OSI, Flight time, RSImod, and muscle soreness were set as the dependent variable, and the season phase as the independent variable with an interaction effect used to assess the impact of position group on between-phase differences. Athlete identity was included as a random effect in each of the models to allow for both between- and within-player variation. Significance (P<0.05) was determined by the linear mixed model and results are reported as the estimate and 95% confidence intervals. Residual plots from these models were checked for normality and constant variance.

Results

In the off-season, FORT (P=<.001 and <.001), FORD (P=<.001 and <.001) and OSI (P=<.001 and <.001) were higher for the '*Bigs*' compared to fall camp and in-season, whilst FORT (P=<.001 and <.001), OSI (P=.02 and <.001), respectively, were lower for the '*Combos*' compared to the fall camp and in-season phases (Figure 1, A, B, C).

Flight Time (P=<.001 and <.001) and RSImod (P=<.001 and <.001) for '*Bigs*' were higher during the off-season when compared to fall camp and in-season (Figure 2, A, B). Muscle soreness was higher (P=<.001 and <.001) for the '*Bigs*' during off-season when compared to fall camp and in-season, and during the in-season compared to fall camp (P=<.001).

Several significant differences between positions were observed. FORT was higher for '*Bigs*' when compared to '*Combos*' during off-season (P=<.001), fall camp (P=.02) and in-season (P=.01) (Figure 1, A). FORD was higher for the '*Skills*' group when compared to '*Bigs*' during off-season (P=.02) and to '*Combos*' (P=.01) during the in-season (Figure 1, B). OSI was higher for '*Bigs*' compared to '*Combos*' (P=<.001) and '*Skills*' (P=.01) during off-season and when compared to '*Combos*' (P=<.001) during the in-season (Figure 1, C). Fight Time was higher for '*Skills*' during fall camp compared to '*Bigs*' (P=.04) and '*Combos*' (P=.01) and compared to '*Combos*' (P=.03) during the in-season (Figure 2, A). RSI modified was higher for '*Skills*' during off-season compared to '*Bigs*', (P=.02) and '*Combos*' (P=.03) during fall camp, and to '*Combos*' (P=.03) during the in-season (Figure 2, C).

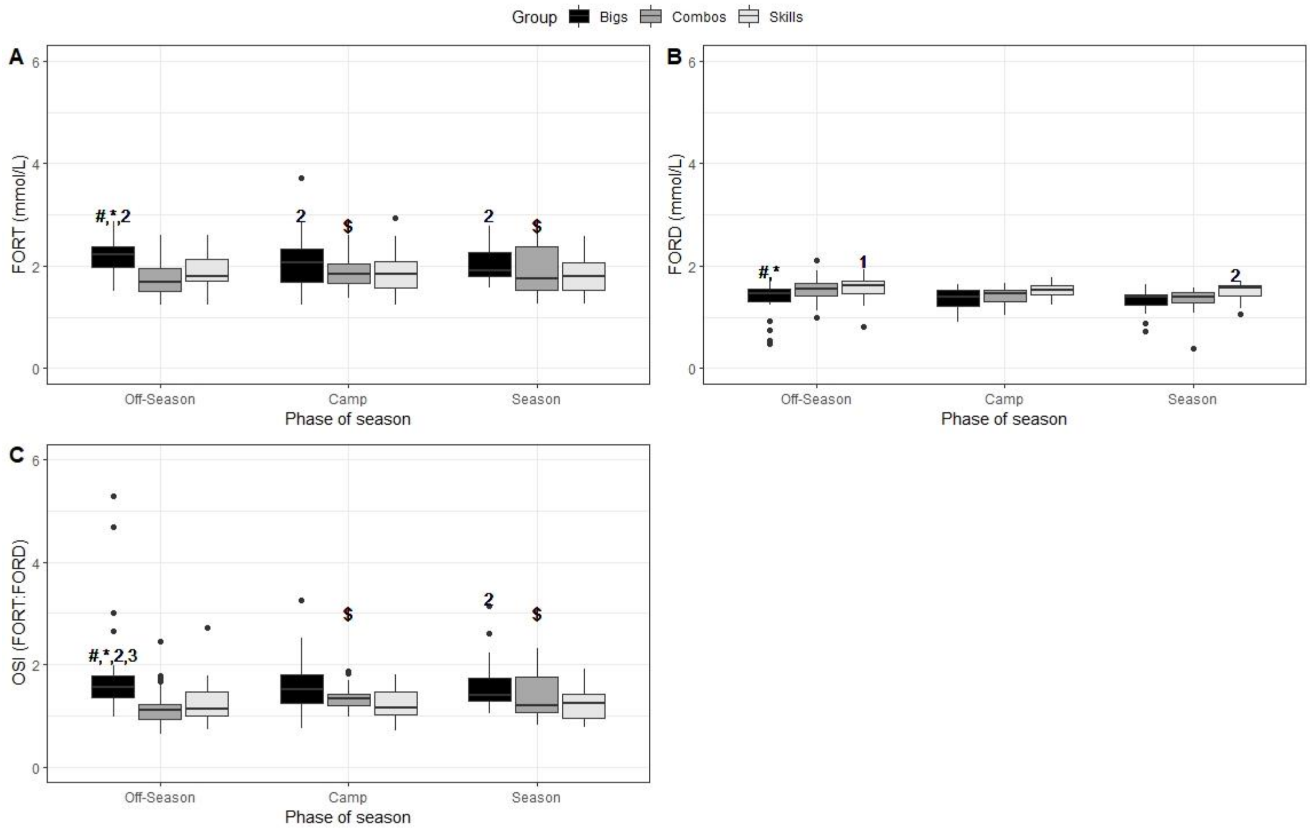

Figure 1: Average FORT (A), FORD (B) & OSI (C) concentrations in '*Bigs*', '*Combos*' & '*Skills*' during the off-season, fall camp, and in-season phases. Significantly higher ($p<0.05$) compared to: $= off-season; # = fall camp; * = in-season; 1 = '*Bigs*', 2 = '*Combos*'; 3 = '*Skills*'. Dots that lie outside the box plots represent outliers.

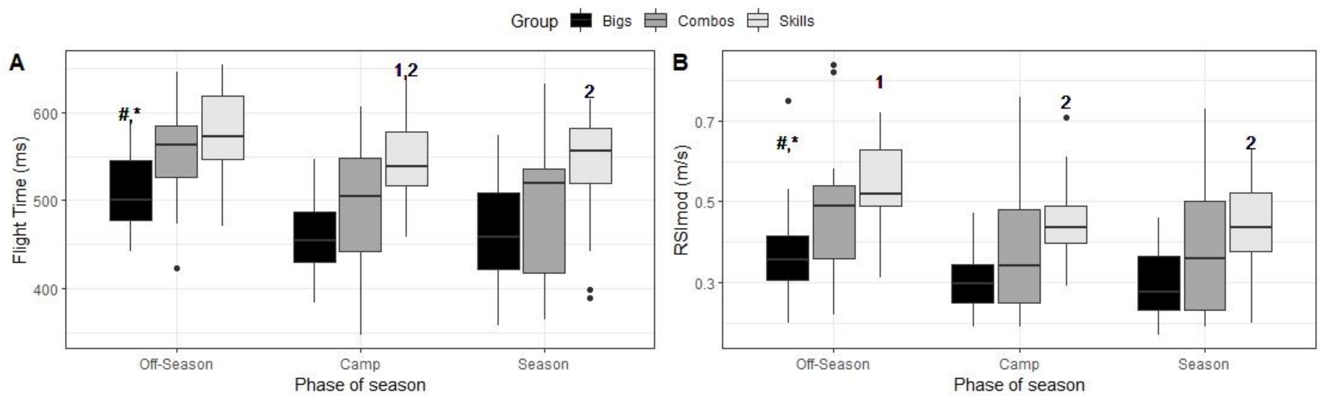

Figure 2: Average Flight Time (A) & RSImod (B) in '*Bigs*', '*Combos*' & '*Skills*' during the off-season, fall camp and in-season phases. Significantly higher ($p<0.05$) compared to: $= off-season; # = fall camp; * = in-season; 1 = '*Bigs*', 2 = '*Combos*'; 3 = '*Skills*'. Dots that lie outside the box plots represent outliers.

Table 1: Differences found in subjective wellness questionnaire muscle soreness between each phase, collected using a 5-point Likert scale.

	Phase 1 (Off-season)	Phase 2 (Camp)	Phase 3 (Season)
Bigs	3.17 (2.78, 3.57) #, *	2.92 (2.57, 3.26)	3.09 (2.74, 3.43) #
Combos	3.09 (2.69, 3.48)	2.98 (2.68, 3.29)	3.00 (2.69, 3.3)
Skills	3.11 (2.47, 3.74)	2.82 (2.49, 3.15)	3.01 (2.69, 3.34)

= significantly greater than fall camp; * = significantly greater than in-season.

Table 2: Descriptive measures of external training load across an ACF season. Distances within velocity bands are presented as mean values (percentage of total distance covered) with 95% confidence intervals [CI].

	Off-season			***Fall camp***			***In-season***		
	Bigs	***Combos***	***Skills***	***Bigs***	***Combos***	***Skills***	***Bigs***	***Combo***	***Skill***
Total Distance (m)	2230 [±253]	2431 [±292]	2632 [±275]	3485 [±158]	4353 [±169]	4885 [±307]	2992 [±276]	3549 [±366]	3951 [±467]
Band 1 Distance (m)	889 [±145] (40%)	987 [±168] (41%)	1072 [±188] (41%)	2479 [±108] (71%)	3073 [±123] (71%)	3161 [±181] (65%)	1852 [±219] (62%)	2208 [±279] (62%)	2239 [±299] (57%)
Band 2 Distance (m)	213 [±42] (10%)	230 [±53] (9%)	224 [±45] (9%)	538 [±32] (15%)	581 [±28] (13%)	645 [±58] (13%)	416 [±56] (14%)	410 [±61] (12%)	452 [±78] (11%)
Band 3 Distance (m)	236 [±43] (11%)	226 [±47] (9%)	230 [±42] (9%)	275 [±29] (8%)	274 [±17] (6%)	418 [±36] (9%)	245 [±39] (8%)	208 [±34] (6%)	296 [±51] (7%)
Band 4 Distance (m)	287 [±58] (13%)	284 [±60] (12%)	253 [±41] (10%)	116 [±18] (3%)	189 [±19] (4%)	298 [±26] (6%)	133 [±27] (4%)	158 [±33] (4%)	231 [±48] (6%)
Band 5 Distance (m)	328 [±76] (15%)	389 [±98] (16%)	457 [±113] (17%)	51 [±11] (1%)	134 [±16] (3%)	202 [±21] (4%)	56 [±14] (2%)	127 [±29] (4%)	183 [±40] (5%)
Band 6 Distance (m)	192 [±62] (9%)	227 [±68] (9%)	281 [±52] (11%)	19 [±6] (1%)	74 [±11] (2%)	105 [±16] (2%)	22 [±8] (1%)	70 [±19] (2%)	100 [±25] (3%)
Band 7 Distance (m)	76 [±27] (3%)	57 [±20] (2%)	82 [±23] (3%)	5 [±2] (0%)	23 [±6] (1%)	48 [±10] (1%)	5 [±3] (0%)	28 [±11] (1%)	44 [±14] (1%)
Band 8 Distance (m)	8 [±4] (0%)	31 [±18] (1%)	32 [±17] (1%)	0 [±0] (0%)	4 [±2] (0%)	8 [±3] (0%)	0 [±0] (0%)	7 [±7] (0%)	12 [±10] (0%)

Velocity Band 1 = 0 – 30%, Velocity Band 2 = 30 – 40%, Velocity Band 3 = 40 – 50%, Velocity Band 4 = 50 – 60%, Velocity Band 5 = 60 – 70%, Velocity Band 6 = 70 – 80%, Velocity Band 7 = 80 – 90%, Velocity Band 8 = 90 – 100+% of max velocity.

Discussion

In this investigation, objective measures of strain and subjective muscle soreness differed between ACF off-season, fall camp, and in-season phases within the same positional group, and between positional groups when compared during the same phase. Compared to fall camp and in-season, the off-season resulted in the greatest FORT, FORD and OSI concentrations for the '*Bigs*', whilst the '*Combos*' displayed lower FORT and OSI. No significant differences were observed, suggesting greater stability in FORT, FORD and OSI concentrations in all phases for '*Skills*'. Subsequently, when comparing between positions, during the off-season the FORT, FORD and OSI in the '*Bigs*' was reflective of greater strain when compared to '*Combos*' and the OSI of '*Bigs*' was also greater than that of the '*Skills*' group. Additionally, during off-season self-reported soreness was highest but CMJ performance (flight time and RSImod) was also greatest amongst the '*Bigs*' when compared to fall camp and in-season phases.

The FORT/ FORD tests assess alterations in redox homeostasis with the ratio of FORT/FORD providing an index of oxidative stress[17]. Herein, the increase in FORD observed within the '*Bigs*' during the off-season conditioning phase in efforts to combat increasing levels of FORT were not great enough to balance OSI. A higher OSI during the off-season is perhaps unexpected as the frequency of athletic involvement during off-season conditioning is lowest during this phase, with a two-fold increase in total hours on field observed during fall camp and in-season phases. These differences are evident in Table 2 by lower typical total distance. However, on inspection, the '*Bigs*' completed 27% of their total distance during the off-season in high relative velocity zones (>5) compared to just 2% and 3%, respectively, in zones >5 during the fall camp and in-season. These zones likely include all sprint-related activities[27]. The distance covered in higher relative velocity bands may thus be the cause of the increased strain for a group that has greater overall mass and larger portions of fat mass[28]. In contrast, increases in FORT and OSI were observed in the '*Combos*' during fall camp and in-season phases when the relative distances (%) covered were comparable to the fall camp phase. The increased contact demands, which are anaerobic in nature during fall camp and in-season may explain the increased FORT and OSI[29].

Alongside the objective evidence for increased physiological strain during the off-season amongst the '*Bigs*', subjective muscle soreness was also greater for this group when compared to the fall camp and in-season. It was thus surprising to see the best CMJ performance (flight time and RSI modified) amongst the '*Bigs*' during the off-season, at the same time as the greatest objective markers of fatigue and subjective soreness were present. Further, whilst not always significant, when assessing the direction of change across all groups, decreases in CMJ performance were present from off-season to fall camp which is in direct contrast to previously reported associations between CMJ performance and changes in FORT and FORD[16]. The observed decrements in neuromuscular performance may be due to accumulated fatigue following high contact volumes and running loads during fall camp. Previous investigations in both Australian rules football and rugby league have shown the highest levels of performance in CMJ jump during the off-season leading into the season, where that performance drops throughout most weeks, leading to overall decreased performance after the completion of the season[30, 31]. Further, across a congested 21-day period containing four rugby league games and 9 training session, CMJ performance has been shown to decline[32]. Therefore, it may be hypothesized that the compounding nature of practices and games as well as decreased rest periods during fall camp and in-season may have a negative effect on neuromuscular function. However, despite the associations between subjective muscle soreness and FORT, FORD and OSI previously observed in ACF[16], in contrast to the '*Bigs*', increases in soreness were not observed in the '*Combo*s' group alongside increases OSI and FORT. This may suggest that the subjective markers of muscle soreness may be less sensitive when compared to a more objective measure of internal strain.

In addition to the observed differences within groups between season phases, distinguishable differences were also observed between positional groups in the same season phase. During off-season conditioning the '*Bigs*' had significantly higher FORT concentrations when compared to '*Combos*', and significantly lower FORD concentrations when compared to '*Skills*' resulting in greater OSI for the '*Bigs*' when compared to both '*Combos*' and '*Skills*'. This observation may suggest that off-season conditioning is relatively harder for the '*Bigs*', with the '*Skills*' group potentially having a greater capacity for recovery with increased FORD concentrations throughout this phase of the season. Interestingly, when observing the relative speed bands during off-season, all three position specific groups covered a similar percentage of their respective total distance in each velocity band. The relative distance covered in velocity bands 4 to 8 across each group during the off-season was roughly 40% of the total distance. These velocity bands equate to the higher intensities of maximal aerobic speed as well as encapsulating initial and maximal sprint speeds across all positions in ACF[27]. For the '*Bigs*', off-season relative distances covered were 6 to 8 × greater when compared to fall camp and in-season, but only 2.8 to 4 × greater for '*Combos*' and '*Skills*' groups, respectively. This level of high-intensity running volume during off-season conditioning experienced by the '*Bigs*' group may explain the difference in internal strain during the off-season, as this positional group is typically involved in wresting and blocking based movements in small spaces and is not often required to run at higher intensities[4]. Indeed, the relative stress associated with high velocity running activities is proposed earlier in this discussion as a cause of the increase FORT amongst '*Bigs*' whose playing demands are not reflected by this type of running and are thus perhaps less accustomed to this type of activity.

Correspondingly, the higher FORD concentrations, may reflect the higher aerobic fitness and improved capacity to recover from anaerobic and aerobic conditioning activity[32]. Indeed, increased concentrations of FORD in contrast to baseline values have also been shown in endurance runners in response to maximal exercise[18]. It could be speculated that the excessive amounts of fat, saturated fat, dietary cholesterol, sodium and potassium consumed in the OL and DL position groups to maintain or gain the weight that is thought to be required for the positional demands[33], compounded with low fibre and unsaturated fats[34] may also have decreased the ability of the '*Bigs*' to combat increasing FORT concentrations during the off-season. FORD was yet also higher in '*Skills*' compared to '*Combos*' during the in-season, which may suggest off-season and fall camp training was more specific to the physiological demands of the '*Skills*' group, resulting in improved exercise induced adaptation[17]. During the fall camp phase, however, no significant differences were observed between the position specific groups across FORT, FORD and OSI. This may be due to each position group training for the same amount of time in a position specific manner for the demands of their position.

Limitations/ future research

Within this investigation several limitations should be considered when interpreting the results. First, results presented include only the last 3-weeks of a 6-week training block (off-season) and the first 3-weeks of a 12-game regular season. As such, the data may not truly reflect changes across a season. However, in alternate sports (soccer), increases in reactive oxygen species were also observed at the end of pre-season with a decline in season[20]. Herein, the compounding nature of a 12-week ACF season may increase or decrease strain depending on training periodisation and game play intensities. Secondly, the monitoring tools analysed alongside FORT/FORD should be considered and whilst, the validity and reliability of CMJ are documented in field-based sports[22], to the authors knowledge no investigation has confirmed the applicability of a CMJ as a valid and reliable assessment of fatigue in ACF. Herein, over an extended period, decrements in jump performance as a result of non-physiological variables can also not be discounted. However, mental fatigue and motivation have previously not been shown to effect CMJ performance has been over acute (60–90-minute) or chronic (6 week) periods[35, 36,37]. Furthermore, regardless of the popularity[38], and a preference for in-house custom-built subjective wellness questionnaires in elite sport settings[8, 25, 39], it must be noted that these questionnaires are not formally validated. Indeed, considering weak associations[16], alternate wellness questions were not included in this analysis. However, the consistent associations between soreness and the objective measures in this investigation and previously by McKay et al (2021) further support the use of subjective muscle soreness as a monitoring tool. Finally, the relatively small sample size should be considered, and practitioners should recognise that this investigation was conducted within a single team subjected to the same training and match demands. Further research is thus required to strengthen these findings in alternate settings and sports.

Practical implications

- When assessing team response from training, positional groups should be analysed separately due to the large differences in phenotypes in ACF.
- The implementation of individual adaptive ranges that account for the time of the season, position and individual historical data may allow for the identification of maladaptation on an individual level.
- The physiological strain differs during the specific season phases of ACF must be considered when analysing and interpreting data.
- The internal strain response may be dependent on the training, relative to position specific demands of the activity and should consider relative speed thresholds as a method of understanding the relative internal physical demand of exercise conditioning.
- Increases in FORT/ FORD may be more sensitive to increased levels of internal strain when compared to CMJ performance and increases in FORT/ FORD accompanied by decreases in CMJ performance may be considered as detrimental fatigue.

Conclusion

This is the first investigation, to the authors knowledge, to assess the internal strain and subjective muscle soreness of an ACF team relative to playing positions with differing phenotypes and physical demands. For the first time, we have shown that these groups have different responses to training in the off-season when a lack of specificity for the positional demands of the game are not considered resulting in greater training related strain amongst '*Bigs*', and relatively lower strain for '*Combos*'. Concurrently, the between position differences observed within the same training phase further highlights the need for future research to consider the unique positional demands of ACF when designing training relative to game related stress.

References

1. Bosch TA, et al., Body composition and bone mineral density of division 1 collegiate football players, a consortium of college athlete research (C-CAR) study. *J Strength Cond Res.* 2019; 33:1339.
2. Wellman AD, et al., Quantification of competitive game demands of NCAA division I college football players using global positioning systems. *The Journal of Strength & Conditioning Research.* 2016; 30:11-19.
3. Wellman AD, et al., Movement demands and perceived wellness associated with preseason training camp in NCAA Division I college football players. *The Journal of Strength & Conditioning Research.* 2017; 31:2704-2718.
4. Wellman AD, et al., Quantification of accelerometer derived impacts associated with competitive games in NCAA division I college football players. *J Strength Cond Res.* 2016.
5. Gabbett TJ, Use of relative speed zones increases the high-speed running performed in team sport match play. *The Journal of Strength & Conditioning Research.* 2015; 29:3353-3359.
6. Fullagar HH, McCunn R, and Murray A, Updated Review of the Applied Physiology of American College Football: Physical Demands, Strength and Conditioning, Nutrition, and Injury Characteristics of America's Favorite Game. *Int J Sports Physiol Perform.* 2017; 12:1396-1403.
7. Wellman AD, et al., Comparison of preseason and in-season practice and game loads in National Collegiate Athletic Association Division I football players. *The Journal of Strength & Conditioning Research.* 2019; 33:1020-1027.
8. Sampson JA, et al., Subjective wellness, acute: chronic workloads, and injury risk in college football. *The Journal of Strength & Conditioning Research.* 2019; 33:3367-3373.
9. Govus AD, et al., Relationship between pre-training subjective wellness measures, player load and rating of perceived exertion training load in american college football. *Int J Sports Physiol Perform.* 20171-19.
10. Hoffman JR, et al., Performance, biochemical, and endocrine changes during a competitive football game. *Med Sci Sports Exerc.* 2002; 34:1845-1853.
11. Hoffman JR, et al., Biochemical and hormonal responses during an intercollegiate football season. *Med Sci Sports Exerc.* 2005; 37:1237.
12. Olusoga P, et al., Stress in elite sports coaching: Identifying stressors. *J Appl Sport Psychol.* 2009; 21:442-459.
13. Lindsay A and Costello JT, Realising the potential of urine and saliva as diagnostic tools in sport and exercise medicine. *Sports Med.* 2017; 47:11-31.
14. Lewis NA, et al., Critical difference and biological variation in biomarkers of oxidative stress and nutritional status in athletes. *PLoS One.* 2016; 11:e0149927.
15. Quinn KM, et al., Reliability of a point-of-care device to determine oxidative stress in whole blood before and after acute exercise: A practical approach for the applied sports sciences. *J Sports Sci.* 2021; 39:673-682.
16. McKay BA, et al., The Association Between Alterations in Redox Homeostasis, Cortisol, and Commonly Used Objective and Subjective Markers of Fatigue in American Collegiate Football. *Int J Sports Physiol Perform.* 2021; 1:1-7.

17. Lewis NA, et al., Effects of exercise on alterations in redox homeostasis in elite male and female endurance athletes using a clinical point-of-care test. *Appl Physiol Nutr Metab.* 2016; 41:1026-1032.
18. Lewis NA, et al., Alterations in redox homeostasis in the elite endurance athlete. *Sports Med.* 2015; 45:379-409.
19. Silva JR, et al., Neuromuscular function, hormonal and redox status and muscle damage of professional soccer players after a high-level competitive match. *Eur J Appl Physiol.* 2013; 113:2193-2201.
20. Becatti M, et al., Redox status alterations during the competitive season in élite soccer players: focus on peripheral leukocyte-derived ROS. *Intern Emerg Med.* 2017; 12:777-788.
21. Le Moal E, et al., Redox status of professional soccer players is influenced by training load throughout a season. *Int J Sports Med.* 2016; 37:680-686.
22. Cormack SJ, et al., Reliability of measures obtained during single and repeated countermovement jumps. *Int J Sports Physiol Perform.* 2008; 3:131-144.
23. Ebben WP and Petushek EJ, Using the reactive strength index modified to evaluate plyometric performance. *J Strength Con Res.* 2010; 24:1983-1987.
24. Kirby TJ, et al., Relative net vertical impulse determines jumping performance. *J Appl Biomech.* 2011; 27:207-214.
25. Fullagar HH, et al., The time course of perceptual recovery markers after match play in Division IA college American football. *Int J Sports Physiol Perform.* 2017; 12:1264-1266.
26. Buchheit M, et al., Monitoring accelerations with GPS in football: time to slow down? *Int J Sports Physiol Perform.* 2014; 9:442-445.
27. Barr M, et al., Validity and reliability of 15 Hz global positioning system units for assessing the activity profiles of university football players. *The Journal of Strength & Conditioning Research.* 2019; 33:1371-1379.
28. Morgan DW, Martin PE, and Krahenbuhl GS, Factors affecting running economy. *Sports Med.* 1989; 7:310-330.
29. Dopsaj V, et al., Hematological, oxidative stress, and immune status profiling in elite combat sport athletes. *The Journal of Strength & Conditioning Research.* 2013; 27:3506-3514.
30. Cormack SJ, et al., Neuromuscular and endocrine responses of elite players during an Australian rules football season. *Int J Sports Physiol Perform.* 2008; 3:439-453.
31. Redman KJ, et al., Effects of the Off-Season on Muscular Power in Professional Rugby League. *Int J Sports Physiol Perform.* 2022; 1:1-6.
32. Twist C, et al., Player responses to match and training demands during an intensified fixture schedule in professional rugby league: a case study. *Int J Sports Physiol Perform.* 2017; 12:1093-1099.
33. Abbey EL, Wright CJ, and Kirkpatrick CM, Nutrition practices and knowledge among NCAA Division III football players. *J Int Soc Sports Nutr.* 2017; 14:1-9.
34. Slattery K, Bentley D, and Coutts AJ, The role of oxidative, inflammatory and neuroendocrinological systems during exercise stress in athletes: implications of antioxidant supplementation on physiological adaptation during intensified physical training. *Sports Med.* 2015; 45:453-471.
35. Fortes LS, et al., Effect of mental fatigue on mean propulsive velocity, countermovement jump, and 100-m and 200-m dash performance in male college sprinters. *Applied Neuropsychology: Adult.* 20211-10.
36. Martin K, et al., Mental fatigue does not affect maximal anaerobic exercise performance. *Eur J Appl Physiol.* 2015; 115:715-725.
37. Crewther B, et al., Temporal associations between individual changes in hormones, training motivation and physical performance in elite and non-elite trained men. *Biol Sport.* 2016; 33:215-221.

38. Taylor K, et al., Fatigue monitoring in high performance sport: a survey of current trends. *J Aust Strength Cond.* 2012; 20:12-23.
39. Gallo TF, et al., Pre-training perceived wellness impacts training output in Australian football players. *J Sports Sci.* 2016; 34:1445-1451.